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UNDERSTANDING EPISODIC MEMORY IN ANIMALS AND HUMANS: A METHODOLOGICAL APPROACH

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AUTHOR’S DECLARATION

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For my family

Memory is the diary that we all carry about with us.

-Oscar Wilde-

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ABSTRACT

This thesis sought to explore two different methodological approaches to episodic memory, namely episodic memory as demonstrated in humans and episodic-like memory as demonstrated in animals.

The results of Chapter 2 were successful in demonstrating episodic-like memory in the rat using recollection alone, despite the fact that performance in this study was significantly poorer compared to the original (Eacott, Easton, & Zinkivskay, 2005). Subsequent experiments within this chapter highlighted potential methodological issues (e.g. interference of odour cues, stability of performance over lengthy testing periods) that impact on such spontaneous tasks.

Chapter 3 investigated the effect of bilateral lesions to the hippocampus on episodic-like memory. The results of Chapter 3 were not in agreement with previous findings as none of the three groups (Sham Group/Partial Hippocampal Group/Hippocampal Group) showed evidence of episodic-like memory. In depth analyses of the three groups lead the author to the conclusion that this was not due to an ineffective task but due to extraneous factors impacting upon the performance of the animals. Analyses of D2 scores and raw exploration times in both phases of the experiment also highlighted the importance of D2 scores in determining object familiarity.

Chapter 4 further investigated the effect of bilateral lesions to the hippocampus on episodic-like memory in animals using an Open Field arena. The addition of landmarks to the testing room resulted in the Sham group successfully

demonstrating episodic-like memory whilst the Hippocampal lesion group remained at chance levels. As there was no significant difference between the two groups it was not possible to conclude that this was as a result of the lesions to the hippocampus. The control task showed neither group demonstrating memory for the more simple ‘what-where’ task, therefore it was concluded that a problem with the methodology still remained. Subsequent experiments within this chapter investigated cleaning methodology, the stability of performance over time, and the effect of task change on performance. The clear variability in the data over lengthy testing periods emphasised the sensitivity of such tasks.

Chapter 5 aimed to investigate whether applying comparable ‘What-Where-When’ and ‘What-Where-Which’ tasks to human investigations of episodic memory would result in similar patterns of data with regard to recollection and familiarity. Analysis of the results revealed the use of other strategies to solve the episodic ‘What-Where-When’ questions. Subsequent experiments within this chapter aimed to confirm the use of strength of memory trace as a strategy for solving these episodic questions. Results from the final experiment suggested that other strategies were also being employed in addition to strength of memory trace. Conclusions were drawn regarding the individual components of episodic memory and their susceptibility to interference from other strategies.

Overall conclusions focused on the definition of episodic memory and the potential implications of alternative strategies impacting on such tasks.

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1 INTRODUCTION

1.1 General Introduction

The purpose of this thesis is to explore two different methodological approaches to episodic memory, namely episodic memory as demonstrated in humans, and episodic-like memory as demonstrated in animals.

In order to investigate both approaches it is necessary to understand firstly, what constitutes episodic memory in humans and secondly, to attend to the ongoing debate as to whether animals can show behavioural manifestations of the different features of episodic memory. Whilst doing so, what will become clear is what Squire (2004) touched upon, that it is not only the task to be learned that is important, but also the strategy that is implemented during that task. The path of most animal research is a logical one, with rationale taken from human studies and adapted for the purpose of further manipulations, to animal studies. This path was no different regarding the study of episodic memory.

What this thesis intends to do is bring this path full circle. As there is a question over whether or not episodic-like memory (Clayton & Dickinson, 1998) in animals is a true reflection of episodic memory in humans, this thesis will investigate episodic-like memory in animals and then develop a comparable task in humans to determine if this reflects episodic memory in humans.

1.2 The Concept of Human Episodic Memory

The concept of episodic memory grew out of semantic memory with which it shares many features. However, episodic memory also possesses features that are unique and that go beyond the semantic system. Episodic memory was initially defined with regard to its distinction from semantic memory (Tulving, 1972) (i.e. remembering personally experienced events versus general facts). However, problems with this early definition of episodic memory stemmed from a lack of relevant evidence. In addition, Tulving (1983) admitted that the traditional, Ebbinghaus-inspired, study/test laboratory experiments of verbal learning and memory could not fully encompass episodic memory due to two important features of episodic memory being omitted.

One such feature involved the content of what the participants in the experiments had to learn. The traditional experiments had concentrated on the simple question of ‘what’. In other words, “what do you remember of...?” Yet episodic memory concerns more than just ‘what’. It concerns the happenings at particular places at particular times, put more clearly, it is about the ‘what’, the ‘where’ and the ‘when’ of an episode (Clayton & Dickinson, 1998). The importance of this will become apparent later on when discussing episodic-like memory in animals.

The other missing feature was what Tulving (1983) originally referred to as ‘recollective experience’, or a conscious awareness of something that has happened in the past. In traditional experiments (to be discussed in detail further on) the reasoning was that if a participant recognises an item in a recognition test they are therefore remembering it from that list i.e. they have a conscious recollection of the item occurring in that list. However, subsequent research showed that this was not necessarily the case (Jacoby, 1991; Roediger & McDermott, 1993; Toth, 2000). Recognition of an item from a study list could occur both with and without awareness. Furthermore, when participants were aware of an item’s previous occurrence in the experiments study list, the awareness could take two forms, either ‘autonoetic’ or ‘noetic’. Autonoetic consciousness has been defined by Wheeler, Stuss, and Tulving (1997, p. 335) as “the capacity that allows adult humans to mentally represent and to become aware of their protracted existence across time”. Such awareness involves a focus of attention on personal experiences. This type of awareness can be contrasted with a noetic form, involving awareness of something objectively known. Wheeler and colleagues emphasised that the distinction is one of experience because one may be noetically aware of one’s body position, for example, or even personally experiences events if they are unaccompanied by an experience of re-experiencing or reliving the past.

Thus, in the context of the traditional recognition experiments, a participant could either remember the episode of an item appearing on the study list (autonoetic), or know that it occurred without remembering (noetic). Tulving (1989) subsequently concluded that a correlation between behaviour and conscious experience need not necessarily exist, and so the traditional research was not focused purely on episodic memory (Tulving, 2002b).

Therefore, by today’s distinction (Tulving & Markowitsch, 1998), “the essence of episodic memory lies in the conjunction of three concepts – self, autonoetic awareness, and subjectively sensed time” (Tulving, 2002b, p. 5). These three concepts proposed as prerequisites for episodic memory are thought to be interrelated and indivisible from one another.

1.3 “Why Do We Remember the Past and Not the Future?”

As defined previously, autonoetic awareness refers to the awareness that humans have of remembering a personally experienced event. This phenomenological experience is different not only from the awareness of the immediate present, but also different from a feeling of mere familiarity. Consequently, a requirement of episodic memory is ‘conscious recollection’, discriminating between past events that are not based on familiarity e.g. differences between strengths of memory traces.

Tulving and Markowitsch (1998) also suggested that episodic memory requires the ability to subjectively sense time. This differs from semantic memory by being oriented to the past, but more specifically, the personal past. Semantic memory does not require mental time travel, for example, it is not necessary to relive one’s actual birth to know when one’s birthday is. Yet Crowder (1986) emphasised that the subjective experience of reliving a past episode should be considered the “controlling definition of episodic memory” (p. 566). In order to mentally travel back in one’s own mind to relive a past event Tulving (2002) posits that this requires a certain form of self-consciousness known as *chronosthesia.* This enables individuals to think about the subjective time in which they live or have lived in the personal past. Although autonoesis and chronosthesia both imply an awareness of self in time, there exists different points of emphasis within the two concepts. In autonoesis emphasis is placed on the awareness of *self* existing in subjective time. However, chronosthesia places emphasis on the awareness of *subjective time* in relation to the self. Therefore, chronosthesia could be considered the temporal aspect of autonoesis.

It has been suggested that an evolutionary advantage of the episodic memory system may be that episodic recollections support the integrity of the self by allowing one to reflect on personal experiences (Wheeler, 2000) by utilising the subjective self-conscious experiences of autonoesis and chronosthesia mentioned previously. Alternatively however, the evolutionary advantage may lie not with necessarily remembering past events, but with supporting the planning of future ones (Dudai & Carruthers, 2005a; Schacter & Addis, 2007) and predicting future possibilities (Schacter, Addis, & Buckner, 2007). This explains why episodic memories are often more inaccurate than semantic counterparts (Schacter, Addis, & Buckner, 2008) and more susceptible to errors and biases (Schacter & Addis, 2007).

It has also been argued that the ability to plan for the future based on past experience was the primary selection pressure for the evolution of the brain structures that are implicated in human mental time travel into both the past and the future. According to this theory animals do not possess episodic memory nor do they have the ability to plan for the future (Suddendorf & Corballis, 2007b). Developmental psychologists suggest that in an episodic context mental time travel does not develop in children until the age of four at which time such abilities come on stream (McCormack & Hoerl, 1999; Perner, 2001; Suddendorf & Corballis, 1997, 2007b; Tulving, 2005; Wheeler, Stuss, & Tulving, 1997). Despite the evidence suggesting that animals and children are capable of interval timing (lasting seconds or minutes) (Friedman, 1993; Gallistel, 1990), they are thought to be incapable of ‘temporal perspective taking’ (i.e. chronosthesia) which extends time both into the distant past and the far future. So although young children may be able to learn the sequence of ordered events, the lack of a unified temporal framework means they are unable to represent events that have occurred at unique temporal locations in their past (McCormack & Hoerl, 1999).

There are also links between how young children acquire episodic memory and episodic future thinking (Atance & O’Neill, 2005; Busby & Suddendorf, 2005) and a parallel decline in mental time travel detail for both the past and the future with advanced age (Addis, Wong & Schacter, 2008). Yet the existence of these links does not mean that there are no differences (for a review see Suddendorf, 2010). Such a topic has led to some interesting suggestions regarding how to examine episodic memory behaviourally in nonhuman animals, for example Suddendorf and Busby (2005) suggest applying a methodology that focuses on future-oriented actions. However, before examining the issue in nonhuman animals it is necessary first to briefly discuss the components of episodic memory and establish how episodic memory in humans can be demonstrated considering the definitions imposed upon it.

1.4 Components of Episodic Memory: Distinguishing between recollection and familiarity

Most people have come across a situation in which we have met someone and have the feeling that they are familiar but are unable to remember information such as their name or where we have seen them before. Experiences such as these suggest that recognition memory can be either based on some sense of familiarity or on the recollection of detailed information about a past episode. In fact the notion that episodic recognition memory consists of distinct components is an ancient one. For example, Aristotle (trans.1931) distinguished between what he referred to as *reminiscence,* the ability to recall the temporal order of events in unique experiences from a more simple, matching of current sensations to impressions of previous experiences, akin to today’s notion of *familiarity.*

From the 1970s onwards cognitive psychologists formalised this view by developing dual-process models (e.g. Atkinson & Juola, 1974; Jacoby, 1983a, 1983b; Jacoby & Dallas 1981; Mandler, 1980; O'Reilly & Norman, 2002; Tulving, 1985). Such models of recognition memory suggest that recognition occurs through two separate memory processes which are clearly distinct: familiarity and recall (variously termed elaboration and integration (Mandler, 1980) or perceptual and conceptual (Jacoby, 1983a)). Familiarity is considered relatively automatic and more quantitative, reflecting signal strength. Recollection however, is a slower process as it requires the recovery of memories that relate to the spatial, temporal and inter-item context of an episode and so is more qualitative in nature (Mandler, 1980). Furthermore, it has also been hypothesised that these two forms of retrieval are different with respect to their underlying retrieval dynamics and neural substrates (for reviews, see Aggleton & Brown, 2006; Diana, Yonelinas, & Ranganath, 2007; Yonelinas et al., 2002). The central aims of these models however, differ in important ways. Some models focus on the functional nature of recollection (e.g. Atkinson & Juola, 1974), some models make claims regarding the neural substrates and mechanisms of the two processes (e.g. O'Reilly & Norman, 2002), while others take the view that familiarity and implicit forms of memory such as priming are two expressions of the same process (e.g. Mandler, 1980).

Other early theorists argued that recognition memory reflected only a single familiarity process. The role of recollection in recognition memory, if indeed there was one, was not thought to be of significance. With regard to recognition it was thought that the signal-detection theory (Egan, 1958) suitably represented single process models. The theory holds that studied items are on average more familiar than new items, however, as the old and new item familiarity distributions overlap a response criterion is required in order to accept only the items above that level of familiarity as having been studied. One advantage of this is that there is only a single memory component to be considered therefore the accuracy of recognition memory can be represented via a single parameter (i.e. d' – the distance between the distribution of the old and new items/the ability of the participant to discriminate between old and new items).

In recent times, advocates of the signal-detection theory have often argued against the dual-process model of recognition memory by proposing that recognition judgements are best construed as being based on a singular memory-strength or confidence variable rather than two separate qualitatively different memory processes (e.g. Donaldson, 1996; Dougal & Rotello, 2007; Dunn, 2004, 2008; Hirshman & Henzler, 1998; Shimamura & Wickens, 2009; Slotnick & Dodson, 2005; Xu & Bellezza, 2001). Yet, even the interpretation of memory strength as a familiarity variable is now also being debated with some theorists preferring to characterise memory strength as *evidence* of the amount of mnemonic information retrieved, in other words, strength of memory and content are essentially the same concept as strength is interpreted as the amount of content retrieved (e.g. Anderson & Bower, 1972; Dunn, 2008).

However the memory strength variable is characterised, signal-detection theorists maintain that recognition memory judgements are based on one process not two. Wixted (2007) suggested that this need not necessarily mean that the signal-detection theory cannot be compatible with dual-process models as long as one considers recollection and familiarity as continuous processes that are then aggregated to determine the memory strength of a test item. A continuous process would have degrees of variance in response to a test item (i.e. yielding varying degrees of confidence and accuracy) whereas in contrast, a categorical process would either occur or not occur (i.e. yield high confidence and high accuracy when seen to occur). Although there is a general consensus that familiarity is a continuous process it is not agreed as to whether this is true for recollection. Some accounts purport recollection to be a categorical process with respect to confidence and accuracy. For example, according to the Dual Process Signal Detection Model (DPSD) (Yonelinas, 1994) recollection succeeds for some items (therefore the recognition judgement is based purely on recollection) and fails for some items (therefore the recognition decision is based purely on familiarity). A recognition judgement that leads to a successful recollection is characterised by high confidence and high accuracy, whereas when recollection fails, the confidence and accuracy of the recognition judgement is dependent on the strength of the familiarity signal (with higher familiarity being associated with higher confidence and accuracy). Parks and Yonelinas (2007, 2009) however, put forward the suggestion that the DPSD model makes no assumptions as to whether recollection is indeed a categorical process, rather it allows for the possibility that recollection is a continuous process. According to the model, there exists a threshold level of memory strength below which recollection is unsuccessful. Above the threshold, recollection is thought to be continuous in nature i.e. recollection can be content rich or content poor.

Such disagreements between the two theories continue to be debated, and, as touched upon above, are particularly apparent when attempting to measure recollection and familiarity.

1.5 How to Measure Human Episodic Memory

It has been established that there exists two different types of awareness, autonoetic and noetic awareness (for definition see section 1.2). According to Tulving's (1983) definition, autonoetic awareness is a reflection of episodic memory and noetic awareness is a reflection of semantic memory. In addition, both of these distinct but overlapping memory systems contribute to recognition memory (Tulving, 1983, 1985).

1.5.1 Traditional Recognition Tests and Episodic Memory

In a traditional recognition test, participants study word or picture lists, and following a delay are presented with a list of studied items that are intermingled with novel items. The aim of such a test is for the participant to decide if a given item was part of the original study list. In early versions of such tests it was presumed that the measured behaviour was true reflection of cognition. If a participant recognises an item in a recognition test, this therefore means that they remember the item from the list, thus they have a conscious recollection of the presence of the item in the study list. However, this is not necessarily the case. Research investigating implicit memory (Roediger & McDermott, 1995; Schacter, 1987), or what is referred to as nonconscious memory (Jacoby, 1991; Toth, 2000), has shown that it could also reflect a lack of such awareness. If autonoetic awareness reflects a remembering or recollection of an item on a study list, then ‘noetic’ awareness reflects the possibility that participants know that an item appeared on a study list without actually remembering that it did (Gardiner, 1988; Gardiner & Richardson-Klavehn, 2000; Knowlton & Squire, 1995; Rajaram, 1993; Tulving, 1985). Therefore, a behaviour could reflect two differing forms of awareness and as such, behaviour and conscious experience is not as clearly correlated as first thought and thus, the traditional research was not actually concerned with episodic memory (Tulving, 2002b). These studies also serve to highlight the point made by Squire (2004), that it is not only the task to be learnt that is important, but also the strategy used to solve the task.

There have been various methods that have been developed to examine the relative contribution of recollection and familiarity to recognition memory, e.g. the ‘remember/know’ procedure briefly introduced above (Tulving, 1985), the ‘process dissociation’ procedure (Jacoby, 1991) and the ‘receiver operating characteristic’ procedure (Yonelinas, 1994). Each procedure shall be discussed in turn, however particular concentration will be placed upon the remember/know procedure due to the fact that a substantial amount of research has adopted this procedure particularly when attempting to determine the functional differences within the medial temporal lobe (e.g. Knowlton & Squire, 1995; Manns, Hopkins, Reed, Kitchener, & Squire, 2003). In addition, Wixted & Mickes (2010) point out that the remember/know procedure is being ever more widely used, with a record number of studies published in 2009.

1.5.2 Using Remember/Know to measure Recollection and Familiarity

With regard to the traditional verbal learning and memory experiments as reviewed by Tulving (2002b), a major problem in tests that measure recognition memory in humans is distinguishing between autonoetic awareness and noetic awareness. However, Tulving (1985) showed that participants could understand the distinction between the two types of awareness and crucially report it through the use of remember and know responses. He proposed that participants were able to indicate which state of awareness pertained to a particular memory by stating '*remember*' if it was retrieved from the episodic memory system or *'know* if it was retrieved from the semantic memory system.

To elaborate, he asked participants to study a list of words. These words were presented again in a recognition test but this time they were interspersed with unstudied words. For each tested word participants were required to make a 'Yes' or 'No' decision as to whether the word had appeared in the list of previously studied words. If the answer was 'Yes' then they were also required to respond either 'Remember' or 'Know'. In this context a 'remember' response indicated that they could consciously recollect something they experienced at the time that they studied that word. A 'know' response indicated that they could not recollect such information, but they recognised the word using other criteria. A substantial amount of research has adopted this simple, yet effective procedure. Because participants are instructed to respond ‘remember’ whenever they recollect a test item, the probability of a ‘remember’ response can be used as an index of recollection. The probability that an item is ‘familiar’ however, is equal to the conditional probability that it received a ‘know’ response given it was not recollected (Yonelinas & Jacoby, 1995).

The concepts of remember and know and the states of awareness that they are purported to capture lend support (relevant but limited due to differences in the central aims) to dual-process theories of recognition memory (see section 1.4). With regard to the remember/know paradigm, the dual-process model suggests that the process of recollection results in a remember experience/response, whereas the familiarity process results in a know experience/response (Kelley & Jacoby, 1998; Yonelinas, 2001b). The idea that these remember and know judgements are a reflection of recollection and familiarity respectively has been strongly opposed by modern single-process signal detection theorists who maintain that remember and know judgments are in fact a reflection of different degrees of memory strength or confidence rather than qualitatively different memory processes (e.g. Donaldson, 1996; Dougal & Rotello, 2007; Dunn, 2004, 2008; Hirshman & Henzler, 1998; Slotnick & Dodson, 2005; Shimamura & Wickens, 2009; Xu & Bellezza, 2001). Therefore, it is not the case that know responses reflect strong, familiarity-based memories that are devoid of recollection. Rather, compared to remember judgements, know responses are actually a reflection of weaker memories that are associated with lesser degrees of confidence and lesser degrees of recollection (Wais, Mickes, & Wixted, 2008).

1.5.3 The Process Dissociation Procedure

Jacoby (1991; 1994) developed a series of techniques with the aim of separating the recollection and familiarity components of recognition memory. In this paradigm, participants study a list of items in two differing contexts, following which are two recognition tests. In what is referred to as the inclusion test, participants are required to identify an item as old if they have previously encountered the item, irrespective of the context in which it was presented. In the exclusion test, participants are asked to identify an item as old only if it was presented in one of the two study contexts. Therefore, although correct responses in the inclusion test may be based on both recollection and familiarity processes, those correct responses in the exclusion test must be based on recollective processes alone. Assuming that these two components of recognition memory are independent, it is then possible to calculate quantitative estimates of both recollection and familiarity (Hay & Jacoby, 1996; Jacoby, Debner, & Hay, 2001; Jacoby, Toth, & Yonelinas, 1993; Joordens & Merolke, 1993; Curran & Hintzman, 1995).

1.5.4 Receiver Operating Characteristics (ROC)

Another compelling method for distinguishing between recollection and familiarity is the analysis of receiver operating characteristics (Yonelinas, 2001a; for a review see Yonelinas, & Parks, 2007). During a typical item recognition experiment participants are asked to study a list of words, faces, or other stimuli. They are then tested with a list that includes both the old items (the items on the study list) and an equal number of new items. The task for the participant is to distinguish each item as either ‘old’ or ‘new’. The resulting ROC analysis plots *hits* (correct identification of old items) against *false alarms* (incorrect identifications of new items as if they were old) across a variations in response criterion (i.e. the propensity to make a positive recognition response). Data points are then curve fitted to by a model with two parameters (Y intercept and d’) using a least-squares method (see Yonelinas, Kroll, Dobbins, Lazzara, & Knight, 1998, for details).

ROC analysis originates from the application of signal detection theory to recognition memory. Therefore, assuming that recognition judgements are based on an assessment of a continuous variable such as familiarity, and assuming that the variances of the familiarity distributions are of new and old items are equal, ROC curves will be symmetrical. However, in normal human participants, the ROC function is typically characterised by two features: the curve is asymmetrical, involving an above-zero Y-intercept, and the shape of the function is curvilinear, upwardly deflected from the line of chance. According to the DPSD model this deflection exists because the ROC curve is a culmination of two different curves, i.e. a continuous curvilinear function reflecting the contribution of familiarity to recognition memory, and a linear function reflecting of the contribution of recollection to recognition memory (Yonelinas, 1994, 2001a). The ‘all-or-none’ nature of recollection results in a ROC curve that is linear, therefore incorporating a threshold level as opposed to being continuous. It is the marrying of this linear component with the otherwise symmetric familiarity ROC curve that results in the asymmetric ROC curves that are synonymous with human recognition memory judgements. Support for this interpretation is evident in the estimates of the linear (recollective) and symmetric (familiarity) components of ROC curves as they are seen to vary alongside different experimental manipulations in a manner similar to estimates resulting from the remember/know procedure (Yonelinas, 2002).

1.6 Functional Dissociations Between Recollection and Familiarity

Previous cognitive and neuropsychological research suggests that recollection and familiarity are functionally distinct processes and through the application of different experimental manipulations different effects on recollection and familiarity can be observed (for reviews see Diana, Reder, Arndt, & Park, 2006; Gardiner, Ramponi, & Richardson-Klavehn, 2002; Rotello, Macmillan, & Reeder, 2004; Yonelinas, 2002). For example during study, manipulations to levels of processing (Gregg & Gardiner, 1994; Rajaram, 1993) and divisions of attention (Gardiner & Parkin, 1990; Yonelinas, 2001a) have a greater effect on recollection compared to familiarity. This is also true in certain subject populations, for example older adults (Healy, Light, & Chung, 2005; Norman & Schacter, 1997; Parkin & Walter, 1992)

Interest in identifying the neural correlates of these two memory processes has steadily increased with implications for current models of recognition memory.

1.7 The Neuroanatomy of Human Episodic Memory

Much research has concentrated on whether recollection which is episodic in nature and familiarity which is semantic in nature, are mediated by the same or different brain structures. The medial temporal lobe (MTL) has long been implicated in these declarative memory processes since patients with large MTL lesions have impairments in both semantic and episodic memory (Scoville & Milner, 1957; Squire, Stark, & Clark, 2004). However, controversy surrounds the division of labour between distinct MTL subregions. For example, there is a continuing debate as to whether the hippocampus and the perirhinal and parahippocampal cortices play different roles in recollection and familiarity (Aggleton & Brown, 1999; Squire, Stark, & Clark, 2004; Tulving & Markowitsch, 1998). One theory is that the hippocampus is a critical component of an extended neural network that supports episodic memory in humans (Aggleton & Brown, 1999; Eichenbaum, 2000; Eichenbaum, Dudchenko, Wood, Shapiro, & Tanila, 1999; Mishkin, Suzuki, Gadian, & Vargha-Khadem, 1997; Moriss & Frey, 1997; O'Keefe & Nadel, 1978; Tulving & Markowitsch, 1998).

Aggleton and Brown (1999) proposed a model of the neural circuitry involved in episodic memory in which they claim that the neural basis of recall and familiarity differ. According to this model recall relies on a circuit that includes the hippocampus (hippocampal fields CA1-4, the denate gyrus and the subicular complex), fornix, mamillary bodies, anterior thalamus and possibly the cingulum bundle (see figure 1.1).

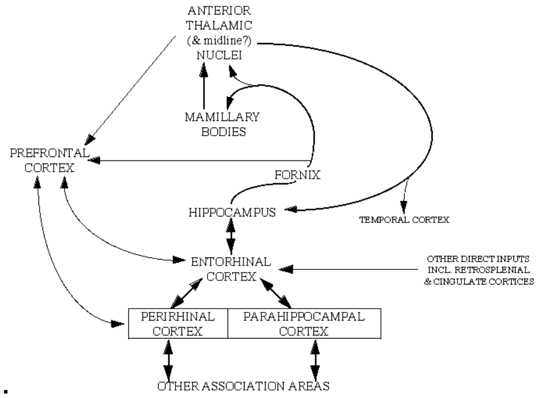


Figure 1.1: Schematic diagram of the principle pathways that allow the encoding of episodic information and underlie recollective aspects of recognition. The relative thickness of the lines indicates the putative importance of the various connections (taken from Aggleton & Brown (1999)).

Particularly, there is the notion that the link from the mamillary bodies and anterior thalamic nuclei, via the fornix, is critical for normal episodic memory (Gaffan, 1992). Furthermore, and as originally proposed by Delay and Brion (1969), the core deficits observed in anterograde amnesia (i.e. a failure to acquire or retain episodic information that occurred after the onset of the brain injury (Tulving, 1983)) result from damage to this axis. Aggleton and Brown (1999) emphasise the importance of the efferents from the hippocampus via the fornix to the diencephalon. In this case the hippocampus refers to the hippocampal fields CA1-4, the denate gyrus, and the subicular complex. The mamillary bodies and the medial thalamus are both medial components of the diencephalon, of which the thalamus, hypothalamus, epithalamus, and subthalamus are components. Such efferents are considered necessary for efficient encoding and therefore effective recall of new episodic memory. Moreover, the presence of projections back from the diencephalon to the temporal cortex and hippocampus also support episodic memory. This extended hippocampal-diencephalic system is crucial for efficient encoding and the subsequent recall of information that is episodic in nature. Damage to the component structures can result in anterograde amnesia and damage to different parts can also result in similar memory impairments.

Aggleton and Brown (1999) also claim that this hippocampal-diencephalic system may not be vital for efficient recognition as recognition is composed of two independent processes (Mandler, 1980) and only one of these processes is dependent on the hippocampus. Item recognition occurring via recollection of the stimulus is hippocampally dependent, whereas recognition occurring via familiarity of a stimulus is not hippocampally dependent. Familiarity according to this model, reflects an independent process that is reliant on a distinct system that involves the perirhinal cortex of the temporal lobe and the medial dorsal nucleus of the thalamus (Brown & Aggleton, 2001; Fortin, Wright, & Eichenbaum, 2004; Mayes, Holdstock, Isaac, Hunkin, & Roberts, 2002, Yonelinas et al, 2002) (see Figure 1.2).

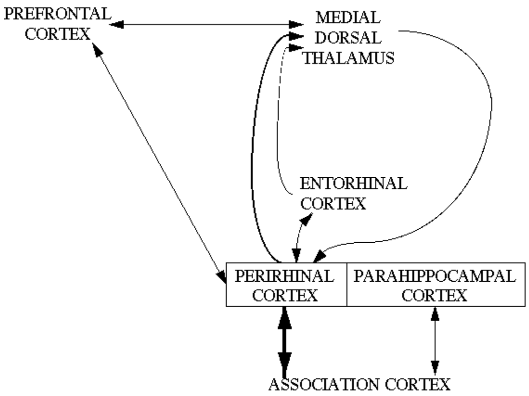


Figure 1.2: Schematic diagram of the principle pathways underlying the detection of item familiarity. The relative thickness of the lines indicates the putative importance of the various connections (taken from Aggleton & Brown (1999)).

As mentioned previously, functional dissociations between recollection and familiarity can be observed in amnesic patients. In most cases of amnesia, there is bilateral involvement of the extended hipopcampal-diencephalic system (i.e. the hippocampus, fornix, mamillary bodies, anterior thalamus, and possibly the cingulum bundle) which leads to severe deficits in both recall and recognition. Studies of human amnesics have implicated the medial temporal lobes and the medial diencephalon in anterograde amnesia (e.g. Stefanacci, Buffalo, Schmolke, & Squire, 2000). Problems arise however, when attempting to identify the critical structures. It is a widely held view that temporal lobe amnesia is a result of damage to the hippocampus, yet whether such damage is sufficient to induce amnesia is debatable. If bilateral damage is necessary, then evidence from amnesic studies where there is discrete unilateral hippocampal damage in one hemisphere alongside more extensive temporal lobe damage in the other hemisphere, would implicate the hippocampus (Penfield & Mathieson, 1974; Woods, Schoene, & Kneisley, 1982). Other evidence comes from amnesics who have confirmed bilateral pathology confined to the hippocampus and adjacent parahippocampal gyrus or uncus (DeJong, Itabashi, & Olson, 1969; Glees & Griffiths, 1952). The high proportion of cases where there is bilateral pathology and spared recognition in addition to implicating the hippocampus (Aggleton et al., 2005; Baddeley, Vargha-Khadem, & Mishkin, 2001; Barbeau et al., 2005; Bastin et al., 2004; Holdstock, Mayes, Gong, Roberts, & Kapur, 2005; Holdstock et al., 2002), also implicates the fornix (Aggleton et al., 2000) and mamillary bodies (Dusoir, Kapur, Byrnes, Mckinstry, & Hoare, 1990). This suggests that damage within this extended hippocampal system impairs recall but partially spares recognition, thus, damage exterior to this system selectively contributes to the recognition deficit.

Such investigations provide further support for the dual-process models of recognition memory if the spared recognition reflects a selective preservation of familiarity based recognition. Using a variety of techniques such as the remember/know procedure and the ROC procedure it has been shown that amnesics with recognition sparing in fact show a selective sparing of familiarity (Aggleton et al., 2005; Barbeau et al., 2005; Bastin et al., 2004; Eldridge, Knowlton, Furmanski, Bookheimer, & Engel, 2000; Eldridge, Engel, Zeineh, Bookheimer, & Knowlton, 2005; Holdstock et al., 2002; Holdstock et al., 2005; Yonelinas et al., 2002).

However, cases where amnesia is a result of hypoxia (lack of oxygen to the brain) do not always support this view. Selective hippocampal shrinkage due to hypoxia has often revealed clear and equivalent deficits in both recall and recognition (Manns, Hopkins, Reed, Kitchener, & Squire, 2003; Wixted & Squire, 2004), yet the degree of the shrinkage is no greater than in cases where there is spared recognition. The leads some researchers to suggest that the hippocampus is important for both recollection and familiarity and the extent, therefore, to which they are dissociable has also been questioned (Jenson, Kirwan, Hopkins, Wixted, & Squire, 2010; Manns, et al., 2003; Squire et al., 2004; Squire et al, 2007; Wais, Wixted, Hopkins, & Squire, 2006; Wixted, 2007; Wixted & Squire, 2004). This lack of consistency continues the debate, particularly because other hypoxic cohorts do show a degree of spared recognition (Quamme, Yonelinas, Widaman, Kroll, & Sauvé, 2004; Yonelinas et al., 2002).

One issue that stems from such studies is that not only does there exist much individual variability within this aetiology, but also there is the probability that diffuse damage is contributing to the deficits in memory (Allen, Tranel, Bruss, & Damasio, 2006). This has led researchers to attempt to model anterograde amnesia in animals and investigate the effects of precise lesions in animals. A prerequisite of this however, is the development of tasks that probe the same forms of memory that are found to be impaired in amnesics, namely episodic memory. Although animal studies would clearly allow for a much broader range of investigative techniques that have higher anatomical, pharmacological, physiological, genetic and molecular precision, the question arises as to whether it is possible to study episodic memory in animals.

1.8 The Concept of Episodic-like Memory in Animals

The concept of episodic memory has changed somewhat since it was introduced nearly 40 years ago, from a general idea of *consciousness* that both the episodic and semantic memory systems both shared (Tulving, 1972) to one that is more system specific.

With such a human-centric view of episodic memory it would initially appear that developing animal models of it would be impossible, particularly considering there are no agreed behavioural markers of consciousness in non-verbal animals. Some even argue that this reflects a stark discontinuity in the evolution of cognitive abilities (Suddendorf & Corballis, 1997, 2008; Tulving & Markowitsch, 1998). However, Clayton and Dickinson (1998) attempted to resolve this issue by concentrating on Tulving’s (1972) original definition which focuses on the content of episodic memory i.e. *what* happened, *when* it happened, and *where* it happened. They propose that “the merit of this definition is that the simultaneous retrieval and integration of information about these three features of a single, unique experience may be demonstrated behaviourally in animals” (Griffiths, Dickinson, & Clayton, 1999, p. 76). They termed this ability *episodic-like memory* (Clayton & Dickinson, 1998) in order to distinguish between the behavioural and phenomenological criteria for episodic memory, given that the latter (e.g. autonoetic and chronosthetic consciousness), which usually accompanies conscious recollection in humans, cannot be assessed in non-human animals. Although more recently this definition of episodic-like memory has been refined (Clayton, Bussey, & Dickinson, 2003) before discussing how and why, it is necessary to focus on the classic experiment of Clayton and Dickinson (1998) which has led to over a decade’s worth of research into episodic-like memory in non-human animals.

Clayton and Dickinson (1998) exploited the natural behaviour of Western scrub-jays (*Aphelocoma californica*). In the wild these birds scatter-hoard perishable insects that degrade over time in addition to seeds that remain palatable for almost indefinite periods. Therefore it would be advantageous for the scrub-jay to remember not only where it cached, but also whether the cached food is perishable and, if it is perishable, how long ago the cache was made. Such a what-where-when memory for the caching episode would allow the scrub-jay to recover the perishable food before it becomes unpalatable. In the wild, this what-where-when memory would derive additional benefits, for example, the continuous risk of caches being pilfered means that the older the cache the higher the probability that the cache is already empty. This then impacts on optimal retrieval times and discounting of cache locations that have been found empty at recovery after only a short time interval has passed since caching. Having the capability to integrate information concerning when the cache had occurred and what had been cached is also important for those species that cache different types of food that decay at different rates, ensuring that items are recovered before they decay (for further discussion see Grodinski & Clayton, 2010).

In controlled laboratory experiments, hand-reared scrub-jays were given a series of trials in which they were allowed to cache the preferred wax moth larvae (‘wax worms’) as well as the less preferred peanuts in sand-filled ice cube trays. By attaching Lego blocks to these ice cube trays they were not only spatially distinct but also trial-unique. This allowed the scrub-jay at recovery to use the structure as a cue to retrieve a memory of the caching episode. Caching in this experiment always occurred in the morning. To investigate the ‘when’ aspect of episodic-like memory there were short (4 hour delay) and long trials (124 hour delay). In the short trials the trays were returned to the bird’s cage in the afternoon of the same day in order for fresh caches to be recovered. In the long trials the trays were not returned to the bird’s cage until the afternoon of the fifth day, during which time the wax worms had perished. During the initial trials the scrub-jays searched for the wax worms rather than the peanuts, reflecting their food preference. However, within four trials of both long and short delays, they searched at recovery for the wax worms in the short trials but changed to searching for the peanuts in the long trials. Clayton and Dickinson reason that the test trials demonstrate that such a change in the pattern of searching is dependent upon memory for the caching episode at recovery rather than on any cues stemming from the caches themselves. In addition, prior to the test trials, all the caches were removed from the trays, however the scrub-jays were still continuing to preferentially search the wax worm sites after the short delay but the peanut site after the long delay. This was taken as evidence that the scrub-jays were relying on memory and not on unintended cues present at test.

Since this initial demonstration, numerous other studies have also shown that scrub-jays have a detailed representation of what, where, and when food was cached. For example, it has been shown that scrub-jays can remember the specific contents of their caches rather than just relative preferences (Clayton & Dickinson, 1999a), they can use the detailed what-where-when information to search for a preferred food type (their food preferences were altered through specific satiety) (Clayton & Dickinson, 1999b) and remember the relative time of caching as well as what type of food was cached in each cache site (Clayton and Dickinson, 1999c). Subsequent experiments also show that scrub-jays can remember which perishable foods they have hidden where and how long ago, irrespective of whether the food had decayed or ripened (Clayton, Yu, & Dickinson, 2001; de Kort, Dickinson, & Clayton, 2005).

As mentioned previously, there has been a recent refinement of the definition of episodic-like memory. It has been argued that although memory for the what-where-when of a single episode is necessary for episodic-like memory, it is not sufficient (Clayton, Bussey, & Dickinson, 2003). Suddendorf and Busby (2003) suggest that such what-where-when memory *may* be episodic or may equally involve cognitive processes that have no consideration of the past. Clayton, Bussey, and Dickinson (2003) point out that what-where-when memory represents the *content* of the behavioural criteria, yet *structure* and *flexibility* are equally important. The integration of the individual components will allow for discrimination between similar episodes that occurred at different times and that can be used flexibly depending on the available semantic information.

1.8.1 Structure

The integrated structure means that the components of an event are bound together in memory. Consequently, probing of an episodic memory for any one feature of the episode will result in automatic retrieval of the other features. Without this binding, or integrated structure, an animal would be unable to discriminate between different episodes that share common features. Clayton and colleagues (2001) highlighted this issue by showing that scrub-jays are able to discriminate between episodes in which the same food was cached but in different locations and at different times. In the wild the relevance and importance of such an integrated structure becomes apparent. The continuous risk of caches being pilfered implies that the older the cache the more likely it is to have been pilfered. This may then affect optimal retrieval times and also increase the discounting of cache locations that have been found empty at recovery, depending upon the time that has elapsed since caching (Grodinski & Clayton, 2010).

1.8.2 Flexibility

It is also important for those species that cache different types of food that decay at different rates to be able to integrate new information about the decay rate of different food types that is received after caching. In order to do so it is necessary to have a flexible declarative memory system. Clayton, Bussey, and Dickinson (2003) argue that declarative memories are reliant on the flexible utilisation of memorised information, and can be updated when new information is acquired. Clayton, Yu, & Dickinson (2003) clearly demonstrate such flexibility. In their study scrub-jays were allowed to cache perishable and non-perishable food types, however, during the interval between caching and recovery they were given the opportunity to learn that the perishable food type degraded faster than previously experienced. If the birds are using a flexible declarative memory system, knowledge regarding the rate of perishability of the particular food type will be updated. Consequently search behaviour at recovery will be altered appropriately, despite the fact that episodic information concerning the initial caching event was encoded before the acquisition of the new knowledge regarding decay rates. The results of this study show that the scrub-jays did in fact do this. As the scrub-jays continued to search for the perishable food if it had been cached recently, the possibility that they had just developed an aversion to searching for food that may perish was ruled out.

The types of rules that are learnt also reflect this flexibility. In addition to learning that a food is perishable, the scrub-jays are also able to learn that following a short interval food is inedible, however later on it will ’ripen’ (de Kort et al., 2005).

1.8.3 Other Avian Models of Episodic-Like Memory

Like the Western scrub-jay, magpies (*Pica pica*) are opportunistic food-hoarders whose food preferences often include those food types that degrade over time (Birkhead, 1991). Zinkivskay, Nazir, and Smulders (2009) showed that magpies demonstrate memory for what type of food they have hidden, and where and when they have hidden it. Their experimental design differed however from Clayton and Dickinson (1998), as none of the trials relied on one food type being preferred over another. In this case the type of food was made interesting only by its colour. Zinkivskay and colleagues also stated that the original study of Clayton and Dickinson (1998) limited the number of possible locations in which the scrub-jays could search for food upon return. The magpies however, were allowed to hoard as many food items (out of those available) as possible therefore creating a continuous spatial environment in which items could be found. Furthermore, unlike in the studies carried out by Clayton and colleagues (see Salwiczek, Watanabe, & Clayton, 2010), Zinkivskay et al. incorporated control trials in which the food items were removed prior to test to eliminate any possible visual and olfactory cues.

Feeney, Roberts, and Sherry (2009) propose that episodic-like memory as observed in the scrub-jays and magpies may be a more general ability that extends itself to other species that cache food, particularly if selection pressures require the ability to remember what was cached, where, and when. In their study, although black-capped chickadees (*Poecile atricapillus*) demonstrated memory for what food type was cached and where, they were unable to alter their search behaviour according to the retention interval. Feeney and colleagues suggest that in contrast to the scrub-jays, the chickadees did not hide the food themselves but instead found the food items that the researchers had hidden. It is possible then, that an integrated representation of what-where-when memory can only occur if the food is cached by the birds themselves as opposed to being hidden, if the two rely on different cognitive processes. Furthermore, the authors question the ecological validity of the paradigm considering that the wooden board used to hide the food items was placed on the ground, akin to the ice-cube trays for the scrub-jays, however the natural behaviour of chickadees is to store their food in shrubs and trees. Consequently, the authors adapted the experimental design to be more species-appropriate. By replacing the wooden board with four artificial trees with branches that contained holes with unique landmarks, the chickadees were now able to demonstrate memory for what-where-when. However, Salwiczek and colleagues (2010) suggest that further investigation into the ‘when’ component is needed in addition to examining the structure and flexibility of the chickadees memory for what, where, and when.

It has been argued that the avian models of episodic-like memory as described above are limited for several reasons. Firstly, Clayton and colleagues (Clayton & Dickinson, 1998; 1999a; 1999b, 1999c; Clayton, Yu, & Dickinson, 2001; 2003) make use of hand-reared scrub-jays and the experimental paradigm they employ relies on their natural food-storing abilities, hence it may not be transferrable to other species (Eacott, Easton, & Zinkivskay, 2006). Salwiczek et al. (2010) however, argue that the performance of the chickadees in the food-finding paradigm suggests that the demonstrations of what-where-when memory found in the scrub-jays and magpies cannot be inextricably linked, or restricted to, food storing birds. Rather it is likely to be a cognitive capacity with more general applications. Furthermore, Zentall et al. (2001) have suggested that demonstrations of episodic-like memory must be done so through the use of an *unexpected question*. The test should be unexpected as episodic information should be encoded automatically, thus, a trail-unique learning paradigm should be applied. As the above studies have an element of training, memory for a unique episode is not being measured, rather the tasks are being solved through the acquisition of semantic knowledge about when to recover the particular food types as opposed to recalling episodically which foods have been cached and where. The scrub-jays for example, had to learn that worms went bad after a certain interval (Clayton & Dickinson, 1998), and the magpies had to learn which colour food was edible after a certain retention interval (Zinkivskay et al., 2009). Clayton and Russell (2009) suggest that such criticisms stem from a misunderstanding of the theoretical interpretations of the role of semantic and episodic-like memory in the control of caching. Clayton and colleagues (2003) propose that during such training when the birds learn about the properties of the food, they must flexibly integrate, for example, a semantic-like rule concerning how long each food type remains fresh with a specific episodic-like memory of which caches they had hidden and where in a given tray on a specific day, as each caching event is in fact unique.

Using the trial-unique learning paradigm, Zentall and colleagues (2001) tested pigeons (*Columba livia*) ability to report the location they had recently pecked, without prior experience of having to do so. Although the results of the experiment suggest that they were able to do just that, Singer and Zentall (2007) suggest that discrimination of proprioceptive cues present when the unexpected question occurs could serve as an alternative explanation to the use of episodic-like memory to answer the unexpected question. In their follow-up study they attempted to correct for this by using a different type of differential sample response i.e. location, in addition to reducing the likelihood that beak position was being used as a cue at the time of test (however, see Zentall, Singer, & Stagner, 2008) and found that they were able to accurately answer the unexpected question of where they had pecked.

Zentall and colleagues (2008) conclude that although their study and previous studies (Singer & Zental, 2007; Zental et al., 2001) may not be considered as rigorous demonstrations of episodic-like memory, nevertheless they demonstrate memories that are unlikely to be accounted for by semantic or rule-based processes. Crystal (2010) does point out however, that as episodic memory is generally regarded as a long-term memory it is interesting that the above studies by Zentall and colleagues have only made use of short delays between encoding and test (0-2 sec).

Skov-Rackette, Miller, & Shettleworth (2006) also tested pigeons on the unexpected question paradigm. Importantly, this is the only study that explicitly tests the structural criterion of episodic memory in another animal species aside from scrub-jays. Pigeons were found to perform well when trained to respond to either a what, where, or when question, even though the test component was unknown at the time of encoding. This would suggest simultaneous encoding of the three elements. Performance however was not correlated when two successive tests of one stimulus were presented. This suggests that what, where, and when memories in pigeons are not integrated but rather encoded independently.

1.8.4 Other Animal Models of Episodic-Like Memory

In addition to the previously discussed avian models of episodic memory, there has been a significant amount of research attempting to establish models of episodic-like memory in other non-human animals. Inspired by Clayton and Dickinson's (1998) study, Hampton, Hampstead, and Murray (2005) adapted the food-caching paradigm of the scrub-jays to investigate whether rhesus monkeys (*Macaca mulatta)* could demonstrate memory for the what, where, and when of a foraging event. However, although the monkeys quickly learned to first search for their preferred food, and to avoid empty foraging locations, they were unable to learn that the preferred food was available after the short, but not the long delay. The monkeys were therefore able to remember the *what* and *where* components of a trial unique event, but failed to remember the *when* component. Hampton and colleagues (2005) argue that their study is not the only study that fails to demonstrate the *when* component of episodic-like memory (e.g. Bird, Roberts, Abroms, Kit, & Krupi, 2003) and therefore perhaps the episodic-like memory demonstrated in scrub jays is a result of specific selection pressures faced by food-storing birds. However, Salwiczek et al. (2008) consider the foraging paradigm to be unsuitable for testing episodic-like memory in rhesus monkeys as their natural behaviour does not require them to cache perishable and non-perishable foods, nor does their survival depend on them burying food for consumption at a later date. Furthermore, as they are primarily herbivorous, it is not necessary to keep track of decay rates (Hampton et al., 2005).

As Hampton et al (2005) mention, there are other studies that fail to demonstrate the when component of episodic-like memory. Bird et al. (2003) tested laboratory rats (*Rattus norvegicus)* for their ability to remember which foods had been cached, where, and how long ago. Although the rats were shown to have reliable memory for the type and location of food, they were unable to demonstrate memory for *when* they had cached the food. Again, Salwiczek et al (2010) argue that most species of rat do not cache food in the wild to the same extent that jays and other food-caching corvids do, nor is their survival, or the survival of primates, reliant on their caches. Hampton and colleagues suggest that evidence for episodic-like memory in other species may emerge once appropriate paradigms have been developed.

However, Babb and Crystal (2005) utilised the food scavenging behaviour of rats in order to demonstrate that rats also have a detailed representation what, where, and when specific events occur. Using an 8-arm radial maze rats were trained to remember where they had previously encountered food that they could then recover after either a short or a long delay (30 minutes or 4 hours respectively). Initially the rats learned that out of the four accessible arms of the maze, only one contained the preferred food type (chocolate pellets). They then learned that when all eight arms of the maze were accessible that the four previously inaccessible arms contained the less-preferred food type (regular pellets). In addition, if the rats were returned to the maze following the long delay the chocolate pellets were replenished, however, this was not the case following the short delay. The results showed that the rats did learn to avoid the previously baited arms and to re-visit the chocolate arm after only the long delay, so demonstrating that rats could use the length of the delay as a cue by which to determine to their choice of arm to search. Furthermore, when the preference for the chocolate pellets was eliminated (using Lithium Chloride (LiCl)) there was found to be a notable reduction in the number of visits to the chocolate arm when compared to the previous testing phase using the long delay. Babb and Crystal argue that the rats could not have reduced their number of visits to the chocolate arms without discriminating between memory for what, where, and when.

Hampton et al. (2005) argue that because the chocolate pellets were available in the afternoon testing sessions but not the morning testing sessions, time of day could serve as a cue in solving the task i.e. in determining whether or not to search or avoid the chocolate baited arm. Follow up studies (Babb & Crystal, 2006a, 2006b; Naaqshbandi, Feeney, McKenzie, & Roberts, 2006) address this issue by controlling for time of day and determine that this cannot be used to discriminate what, where, and when. However, as study phases and testing phases occurred on successive days, the rats could have discriminated between alternate days (i.e. did the study occur yesterday or today) (Crystal, 2009). This issue will be discussed in more detail in the following section.

1.9 What is When?

It becomes clear from such studies on non-human animals, that the ‘when’ component presents a challenge to researchers as ‘when’ has a variety of guises. ‘When’ could refer to a regular time slot (e.g. morning or afternoon), a time relative to another point (e.g. yesterday or the first/second time) or a precise point in time (e.g. when I broke my arm). As episodic memory concerns those memories for specific past events, not all the above guises fall under the heading of episodic. Considering 'when' as a regular time slot certainly would not be considered episodic. Considering 'when' relative to another time point also poses a problem. For instance, if an animal can only show memory for whether a specific event was more or less recent (e.g. first or second exposure), but cannot show memory for the precise occasion when that event occurred, there is a possibility that strength of memory is being utilised to retrieve the information. Therefore, a true and complete episodic what-where-when memory is not being demonstrated (Eacott & Easton, 2009). Certainly, Friedman (1993) suggests that humans use such processes in order to judge the time of an episode. This again raises the important issue that strategy as well as task needs to be considered (Squire, 2004).

Such an argument has been raised with the study of Kart-Teke, De Souza Silva, Huston, and Dere (2006). They adopted a paradigm for their study based on the spontaneous recognition paradigm (Ennaceur & Delacour, 1988) which utilises a rat's innate preference for exploring novel aspects of their given environment. Rats were first allowed to explore an open field environment in which there were four copies of an object in certain locations. In the second exposure phase (after an hour delay) there were now four copies of a second object in different locations. In the final test phase, two copies of each of the objects were presented. One of each of these objects was in a location that had been previously seen, yet the other copy of each object had moved to a different location within the open field. The rats preferentially explored the item that had been seen least recently and that had changed location, in that respect it was the most novel aspect of their environment.

Kart-Teke, et al. (2006) conclude that this demonstrates memory for ‘what’ (i.e. the object seen), ‘where’ (i.e. if the object had moved location), and ‘when’ (i.e. if it was encountered in the first or second exposure phase) that is considered episodic-like memory in animals. However, as just discussed, the preferential exploration of the least recently seen object may simply reflect a reduced strength memory trace for that object (Easton & Eacott, 2008).

Easton and Eacott (2008) suggest that strength of memory trace could also be a potential explanation for the memory seen in scrub-jays (Clayton & Dickinson, 1998). However, Clayton, Griffiths, Emery, and Dickinson (2001) refute this hypothesis stating that such an account assumes that the discriminability of memory traces does not vary with their strength. In a study using a specific satiety devaluation procedure Clayton and Dickinson (1999a) reported that the discriminability of the ‘what-where’ memories for devalued and non-devalued food was comparably good after one week as after only a few hours. Clayton and colleagues argue that if strength of memory trace was impacting upon searching behaviour then there would be an observed reduction in the overall level of searching with respect to the retention interval, however this was not found to be the case.

Strength of memory trace is not the only discriminating factor that poses problems for researchers attempting to demonstrate memory for the what, where, and when of an episode. As highlighted by Hampton and colleagues (2005) (see section 1.8.4) the issue of what is ‘when’ in some episodic-like tasks is debatable. They argue that in the study by Babb and Crystal (2005), time of day (morning or afternoon) could be inadvertently offering a reliable discriminative stimulus for solving the task. Although subsequent studies have shown that time of day cannot be used to discriminate between memory for what, where, and when, it has been shown that rats, for example, can discriminate between alternate days (Crystal, 2009). Roberts and colleagues (2008) suggest that such tasks are not purely episodic in nature as ‘when’ in these cases may only be referring to a relative memory of ‘how long ago’. Animals may be remembering how long ago an event occurred by keeping track of how much time has elapsed since caching or encountering a particular food item in a particular location and are using elapsed time as an indicator for revisiting or avoiding a location (Roberts, 2002). In fact, in their recent study, Roberts et al. (2008) showed that rats could remember the when of an episodic-like memory trace in terms of the relative time elapsed (i.e. how long ago) but not with regard to an absolute time of day at which the event occurred, consequently the authors conclude that episodic-like memory in rats is distinctly different to human episodic memory. Conflicting data is presented by Zhou and Crystal (2009) who suggest that memory for what, where, and when in their study could not be solved by judging the relative familiarity of the study items or timing an interval between study and test. According to de Kort, Dickinson, and Clayton (2005) such a criticism cannot be levelled at Clayton and Dickinson’s (1998) work with scrub-jays as they point out that the recoveries after both the short and long delay always occurred at the same time of day (4 hours after caching on the same day as caching or 5 days after caching), therefore, neither circadian rhythms, nor the state of hunger at the time of recovery could act as a discriminative stimulus that would influence the scrub-jays searching behaviour.

Crystal (2010) proposes that the ability to use what, where, and when based on time of day may actually be quite widespread. For example, a study by Ferkin, Combs, delBarco-Trillo, Pierce, & Franklin (2008) showed that male meadow voles (*Microtus* pennsylvanicus) can remember where and when they encountered a female and in what stage of postpartum estrus she was in. However, the use of a 24 hour delay leads some to question whether or not circadian interval timing as opposed to episodic recall is being measured (Cheke & Clayton, 2010).

Although the above study by Ferkin et al. (2008) and the study by Kart-Teke et al. (2006) detailed earlier have no learnt element to them, they are reliant on the recognition of the stimulus and its location. Yet, as already established, human episodic memory is associated with recall mechanisms, not familiarity based ones. Therefore it cannot be claimed that these tasks are relying on episodic recall mechanisms. Studies by Babb and Crystal (2005, 2006a, 2006b) have also been criticised as although their studies claim to rely on recall processes only, their experimental paradigm involves an extensive number of training trials that could result in rule based learning (Cheke & Clayton 2010; Clayton and Russell, 2008). Although the same could be said for Clayton and Dickinson’s (1998) study with scrub jays, the number of training trials differ considerably. In addition, the studies of Babb and Crystal have recently been criticised for failing to control for familiarity (Cheke & Clayton, 2010), yet similar claims against Clayton and colleagues have not been upheld (see Clayton & Dickinson, 1999a). From the studies discussed here, it seems that Clayton and colleagues (1998; 1999a; 1999b; 1999c; 2001; 2003) have indeed shown that non-human animals can demonstrate episodic-like memory that is not based on familiarity, and that does not utilise cues such as time of day, circadian rhythms, or state of hunger.

1.10 What is Which?

Considering the issues that surround what constitutes the ‘when’ component of episodic-like memory, it is perhaps more appropriate to view it as memory for what happened on a specific occasion, as opposed to what happened at a particular time as identified by for example, temporal order (first or second) or elapsed time (a long or short delay). This concept of ‘occasion’ not only specifies a particular point in time but also allows for that point in time to be additionally identified by non-temporal contextual identifiers (e.g. when I gave a talk in London).

Such contextual identifiers have proven very useful in discriminating episodes. Gaffan (1994) demonstrated in monkeys that when simple object discrimination learning occurred when objects were in a fixed location against a discrimination-unique visuo-spatial background or scene, learning of these discriminations increased at a marked rate to the point where it approached one-trial learning. Gaffan suggests that discrimination via such a ‘scene’ is analogous to episodic memory in that the event being remembered has a particular location with respect to particular background. It is that unique background that serves to identify the memory of that event as unique, thus defining the occasion. Such learning it has been claimed, should not be regarded as an alternative form of scene learning, but as a form of episodic-like memory (Eacott & Easton, 2009; Eacott & Norman, 2004).

Therefore, Eacott and Norman (2004) made use of this broader what-where-which definition of episodic-like memory, where ‘which’ serves as the occasion setter that defines an event as unique. Their task placed reliance upon rats innate preference for novel items (Ennaceur & Delacour, 1988). An open field apparatus was used in which the floor and wall coverings (context), objects, and the locations of the objects were manipulated by the experimenter. In the first of two exposure phases the rats were presented with two objects in a particular context in the open field. In the second exposure phase the same two objects were presented but in opposite locations and using a different context. The test phase presented the rat with one of the previous experienced contexts but now with two copies of one of the previously experienced objects. Consequently, one of these objects was in a location not previously associated with that context for that object. Due to the rat’s innate preference for novelty, exploration of this novel object-location-context (what-where-which) combination was significantly higher than for the familiar combination. As discussed above, previous demonstrations of episodic-like memory in the rats have been criticised for not only being dependent on ‘how long ago’ but also for the amount of training required. Eacott and Norman’s task only required habituation to the apparatus and could theoretically be adapted for use with other species. Eacott and Norman (2004) also demonstrated that this task is sensitive to lesions of the fornix. Considering all these factors, this task proves a useful tool in investigating episodic-like memory in not only rats but other common laboratory animals (e.g. Kouwenberg, Walsh, Morgan, & Martin, 2009).

Despite the usefulness of this task, it received the same criticisms that other recognition tasks received (e.g. Ferkin et al 2008; Kart-Teke et al., 2006) with regard to the fact that both familiarity and recall mechanisms can be employed. Arguments from Eacott and Gaffan (2005) as to why the demonstrated what-where-which memory was reliant on recall mechanisms shall be discussed later in reference to underlying neural substrates.

In an attempt to fend off such criticism Eacott, Easton, and Zinkivskay (2005) modified the Eacott and Norman (2004) task to show that rats could remember an event as defined by the absolute definition of what-where-which using only recollection. In this novelty-based task an E-maze apparatus was used which allowed for an ‘objects visible’ pre-training stage, and an ‘objects hidden’ test stage. During the objects visible stage the rats were exposed to a first context in the E-maze in which there were two different objects to explore. These were in certain spatial locations and were visible to the rat from the start arm of the E-maze. When returned to the E-maze for the second exposure phase in a different context, the objects were placed in a different configuration. Between exposure to the second context and the test phase the rats were held in a holding cage in which was a copy of one of the objects presented in the E-maze that the rats were free to explore. They were then returned to the E-maze for the test phase which used one of the previously encountered contexts. As expected, rats typically explored the object that was not present in the holding cage with them, giving more credence to the theory that they possess an innate preference for novelty (Ennaceur & Delacour, 1988). The experimental phase of this task was referred to as the ‘objects hidden’ stage.

The process was akin to the ‘objects visible’ stage, however, in this case the objects were ‘hidden’ out of sight of the animal in the arms of the E-maze. Eacott, Easton and Zinkivskay reason clearly that in the objects visible stage, because the objects are in fact visible when the rat emerges from the start arm, the choice of the non-habituated object could be solely based on familiarity. Yet, in this objects ‘hidden’ stage, because the objects were not visible to the rat when emerging from the start arm, the rat needed to ‘recollect’ the prior experience in the particular context in order to successfully find the non-habituated novel object. This aspect of the task cannot be solved using familiarity mechanisms alone.

The task successfully demonstrated the what-where-which memory as rats selected the non-habituated object during the experimental stage of the task. As Eacott and Norman (2004) previously suggest, this what-where-which triad can be considered to be episodic-like in animals. Importantly, this task shows the flexibility of episodic memory as it is known to be in humans and as deemed crucial by Clayton, Bussey and Dickinson (2003). Preference for the non-habituated object occurs after exposure to the original event, and depending on which object is used during habituation, either object could be the preferred choice. Unlike other tasks investigating episodic-like memory in animals (e.g. Ferkin et al., 2008; Kart-Teke et al., 2006), this task can only be solved using recollection of past experiences. The objects hidden stage of the task does not allow for the interference of familiarity cues. Furthermore, the task fits the criterion of an integrated structure as it can only be solved by combining the knowledge of knowing what object needs to be searched for, which context is present, and where the object is located. This task is unique in the fact that it does not rely on reward, it does not require substantial pre-training, and it can also be adapted to different species of common laboratory animals. But more importantly, it was the first, and only task to date, that demonstrates recall of what-where-which memory in rats in an unlearned task.

1.11 How Can Animals Studies Contribute to Understanding the Neural Basis of Episodic Memory?

Although some aspects of the paradigms used in the animal studies investigating memory for what-where-when/which are still questioned, their contribution to the understanding of the neural substrates of episodic memory are without doubt invaluable. Despite the debate as to whether episodic memory depends on a dissociable neural system (Aggleton & Brown, 1999), there is much support for the hippocampus playing a critical role (Aggleton & Brown, 1999; Eichenbaum, 2000; Eichenbaum et al., 1999; Mishkin et al., 1997; Moriss & Frey, 1997; O'Keefe & Nadel, 1978; Tulving & Markowitsch, 1998).

Although the study by Eacott and Norman (2004) was criticised due to the possible interference of familiarity processes, Eacott and Gaffan (2005) argued that the pattern of performance of the same animals in variations of the task support the claim that what-where-which measures the recall component of recognition memory. In their study, those rats with lesions specifically in the hippocampal system were impaired on the what-where-which task, yet dual component tasks such as what-where and what-which were not impaired. This apparent dissociation was not due to the level of difficulty as rats with lesions exterior to the hippocampal system (postrhinal cortex) were found to be relatively unimpaired in the what-where-which tasks but impaired in the dual component what-which task. This double dissociation of impaired recollection within the hippocampal system and impaired familiarity exterior to this system reflects the two components of recognition memory and to an extent lends support to the dual-process models of recognition memory (Atkinson & Juola, 1974; Jacoby, 1983a, 1983b; Jacoby & Dallas, 1981; Mandler, 1980; O'Reilly & Norman, 2002; Tulving, 1985). Gaffan's (1994) investigations into scene memory in monkeys showed that those monkeys with fornix lesions were severely impaired when each discrimination was associated with a particular spatial location on a unique background scene. When a discrimination was only associated with a location or a scene then the effects of the fornix lesions were less apparent. In addition to this, there is further evidence that such what-where-which memory as demonstrated in the open field (Eacott & Norman, 2004) and in the E-maze (Easton, Zinkivskay, & Eacott, 2009) is dependent on the fornix.

The application of ROC analyses (see General Introduction, Section 1.6.4.) to investigations of memory in non-human animals has several implications. Firstly, experiments that employ the use of a recognition paradigm (e.g. Kart-Teke et al., 2006; Dere, Huston, & De Souza Silva) cannot provide conclusive evidence for recollection (as opposed to familiarity). Secondly, if non-human animals also exhibit these two distinct response types, mediated by equivalent brain areas to those in humans, then this implies that they are experiencing something akin to recollection.

Studies employing ROC curves have attempted to dissociate recollection and familiarity (Fortin et al., 2004; Sauvage et al., 2008) but have not escaped without criticism (Wixted & Squire, 2008). Easton, Zinkivskay, and Eacott (2009) reason that although statistical analyses of ROC curves provides evidence for both mechanisms, there is a need for direct behavioural evidence for the dissociation in the rat. In their study they demonstrated that although lesions to the fornix impair the recall for what-where-which memory, recognition was unimpaired. Using the what-where-which task in the E-maze (Eacott et al., 2005) Easton et al., (2009) found that rats with lesions to the fornix did not turn to the relatively novel, hidden object, yet those rats with sham lesions did make the appropriate turn. This result indicates that those rats with lesions to the fornix are unable to recollect episodic-like memory. However, recognition of objects by the same animals on the same trials was unimpaired (with respect to the sham-lesioned animals) by the same lesions. In addition, as recall and familiarity are components of recognition (Yonelinas, 2001a) and recall is impaired in this task (based on first turn behaviour), the observed normal recognition performance must be due to intact familiarity. This study therefore gives credence to the two separate neural circuitry systems put forward by Aggleton & Brown (1999) which also suggests that the fornix has a role in recollection processes but not familiarity processes. This is the first task to demonstrate behaviourally a dissociation between the neural systems involved in the recall and familiarity circuits in animals.

A previous study by Eacott & Norman (2004) would appear to contradict this data. In their study they tested fornix lesioned rats in the open field using the what-where-which task (a task which allows for an objects visible stage only) and reported that the fornix lesioned rats demonstrated impaired performance of this task. However, Easton et al., (2009) explain that it is the difference in the nature of the two tasks that result in this possible confusion. In the Eacott & Norman (2004) task the test phase involves two copies of the same object. Object preference was determined if the rat remembered information regarding what object they saw, where they saw it and in what context it was in. In this respect the rats would require episodic-like memory as defined previously (Eacott et al., 2005). In Easton et al's. (2009) task, as the E-maze is used the method differs. During the objects visible stage two different objects are presented to the rat, although both have been seen before, only one of these objects has been habituated to. In this case, during the objects visible task only an object preference is needed. The objects visible stage of the Easton et al., (2009) task does not require episodic-like memory and as such lesions to the fornix bear no effect, yet in the Eacott & Norman (2009) task performance is impaired as episodic-like memory is a necessity.

However, Easton et al. (2009) do not disregard the possibility that the impairment observed may actually be an impairment of only a single component of episodic memory such as memory for the object, spatial location or even context. Although object memory was seen to be intact in this task, spatial nor contextual memory was specifically taken into account, both of which to some degree rely on the hippocampal system (Broadbent, Squire, & Clark, 2004; Smith & Mizumori, 2006).

Previous studies using the open field observed that rats with lesions to the fornix (Eacott & Norman, 2004; Norman & Eacott, 2005) or with lesions to the hippocampus (Langston & Wood, 2006) show significant memory in tasks manipulating combinations of components such as object and place or object and context, yet are impaired at what-where-which memories. This implies that the fornix impairment seen in Eacott & Norman (2004) was an impairment in the triad of what-where-which memory. It also suggests that Easton et al., (2009) did not observe an impairment in spatial or contextual memory alone. It still however, does not allow for any conclusions to be drawn as to whether there is a failure in the recall of any of the individual components of episodic-like memory. This matter is not easily resolved considering recall in itself is dependent on the hippocampal system (Aggleton & Brown, 1999; Fortin, Wright, & Eichenbaum, 2004; Yonelinas, 2001a) therefore if in a spatial memory task there is a failure of recall, how would this be differentiated? Not only this, but as recall is a core factor in episodic memory (Clayton & Dickinson, 1998; Tulving, 1983), any task requiring recall would also be subservient to the systems and neural circuitry that episodic memory is reliant upon.

The value of such tasks in animals is clear. Research has continued to focus on other neuroanatomical structures in an attempt to further understand the complex neural networks associated with episodic memory. The greater understanding that researchers have regarding such forms of memory is directly relevant to furthering our understanding of memory impairments in ageing and related diseases.

1.12 Conclusions

Just as the definition of episodic memory in humans has undergone revisions (Tulving, 1972; Tulving & Markowitsch, 1998) so has the definition of episodic-like memory (Clayton & Dickinson, 1998; Clayton, Bussey, & Dickinson, 2003). Using these definitions there is now good evidence that animals have the capacity for episodic-like memory. It has been suggested that the requirements for episodic memory in animals are harder to achieve than those requirements concerning human episodic memory (Eacott & Easton, 2009) which may in part explain why the methodology of such studies has often been called into question (Babb & Crystal, 2005; 2006a; Clayton & Dickinson, 1998; Eacott & Norman, 2004; Ferkin et al., 2008; Hampton et al., 2005; Kart-Teke et al., 2006). Considering the aforementioned, the broad aim of this thesis was to further investigate episodic memory, both in humans and animals with respect to issues of methodology.

The starting point for such an investigation lay with a task that has been shown to demonstrate episodic-like memory based on recall (Eacott et al., 2005), that can also be used to dissociate the recall and familiarity processes (Easton et al., 2009). Chapter 2 aimed to replicate the study (Eacott et al., 2005) in order to be able to investigate the effects of precise lesions of the hippocampus in Chapter 3. The reviewed studies have contributed significantly to understanding the underlying neural substrates of episodic memory. Much of the research has lent support to the notion that there are dissociable neural networks for episodic memory (Aggleton & Brown, 1999) of which the hippocampus plays a crucial role (Aggleton & Brown, 1999, 2005; Atkinson & Juola, 1974; Baddeley et al., 2001; Barbeau et al., 2005; Bastin et al., 2004; Eacott & Gaffan, 2005; Eacott & Norman, 2004; Easton et al., 2009; Eichenbaum, 2000; Eichenbaum et al., 1999; Ergorul & Eichenbaum, 2004; Fortin et al., 2004; Holdstock et al., 2005; Holdstock et al., 2002; Jacoby, 1983a, 1983b; Jacoby & Dallas, 1981; Langston & Wood, 2006; Mandler, 1980; Mishkin et al., 1997; Moriss & Frey, 1997; Norman & Eacott, 2005; O'Keefe & Nadel, 1978;

O'Reilly & Norman, 2002; Tulving, 1985; Tulving & Markowitsch, 1998). Yet to date, the effects of precise lesions to the hippocampus have not been investigated using such a task can demonstrate this dissociation.

The direction of Chapter 4 was influenced in part by the results of the previous chapters. The issue that the requirements of episodic memory in animals dictate that it is harder to demonstrate was indeed reflected by the previous chapters. And so in keeping with the broad aim of investigating methodologies associated with episodic memory, Chapter 4 attempted to carry out the same task using another previously successful methodology (Langston & Wood, 2006). Whilst doing so, other methodological issues came to light and were also investigated further.

Finally, Chapter 5 attempted to address demands that episodic-like memory in animals is not comparable with episodic memory in humans due to the fact that episodic memory in humans is associated with a feeling of travelling back in time (Conway & Pleydell-Pearce, 2000) and autonoetic awareness (Tulving, 2002b). Yet it has been pointed out that memories that appear to be episodic in nature are not always associated with a strong feeling of travelling back in times even in humans (Crawley & Eacott, 2006). Also, there are human tasks that are accepted as demonstrating episodic memory despite such ‘mental time travel’ not always being assessed. This lends support to those who suggest that the criteria required for episodic-like memory in animals to be accepted as such is much more stringent than with human episodic memory. The specific aim of Chapter 5 therefore, was to address the issue of whether what is regarded as episodic-like memory in animals can be transferred and demonstrated as episodic memory in humans as “perhaps tasks modelled on the episodic-like memory tasks given to animals but performed by human participants might reveal if such tasks are really subjectively experienced as like episodic" (Eacott & Easton, 2009).

2 EPISODIC MEMORY AND THE E-MAZE

2.1 Introduction

Since Clayton and Dickinson's (1998) initial demonstration of episodic-like memory in Scrub jays, numerous other studies have also shown that scrub-jays have a detailed representation of what, where, and when food was cached (Clayton & Dickinson, 1999a; 1999b; 1999c). As Clayton & Dickinson's scrub-jays were at that point the only non-human animals in which these "What", "Where", and "When" aspects of episodic-like memory had been demonstrated, Eacott & Norman (2004) designed a behavioural task that was transferrable to other species of common laboratory animals such as the rat. In their task, Eacott & Norman define episodic-like memory as "What", "Where" and "Which" with "Which" replacing "When" as the occasion setter that discriminates between one experience and another similar experience. It was possible however, that the episodic-like memory demonstrated was not a result of recollection processes alone as the task could potentially be solved through the familiarity of the objects experienced. As episodic memory is said to rely on recollection of past experience, Eacott, Easton, & Zinkivskay (2005) created a task demonstrating just that (for further details of the task see General Introduction, Section 1.10), whilst also satisfying the criteria of structure and flexibility deemed essential for episodic-like memory (Clayton, Bussey, & Dickinson, 2003).

Due to the success of Eacott et al.'s (2005) task, a replication was considered a justified starting point for the studies before attempting any modifications such as lesion studies. The aim of such a replication would be to increase the level of performance and eliminate any variability in the data. Such variability in the data, as observed in Eacott et al.'s study may require further manipulations to the methodology. It may also be necessary to carry out further days of this task. Eacott, Easton and Zinkivskay successfully demonstrated the what-where-which memory after a relatively short period of sixteen days. For lesion studies to be carried out it is necessary to have a task that that shows performance stable over numerous testing trials. This however leads on to further problems. It is possible that such long periods of testing may be detrimental to the overall performance of the task as the task itself may gradually become less novel. If this were to occur, manipulations regarding the overall novelty of the task would have to be addressed.

2.2 Experiment 2a

The first experiment aimed to replicate the results of Eacott et al. (2005) and so introduced no differences in methodology from the original study. The purpose of this study was to not only demonstrate the what-where-which memory as done so previously, but also to determine a baseline for which any further manipulations can be compared against.

2.2.1 Methods and materials

2.2.1.1 Subjects

Sixteen experimentally naïve Dark Agouti male rats (Harlan Laboratories, UK) underwent surgery. They were housed in cages of four and were subject to diurnal conditions (12 hour light/12 hour dark cycles). Testing always took place during the light cycle and never started before 7am or finished after 7pm. Access to food and water was ad libitum, levels of which were monitored daily as governed by the Animal (Scientific Procedures Act) (1986) and approved by the Home Office Project licence.

2.2.1.2 Apparatus

2.2.1.2.1 E-Maze

The E-Maze used in this task measured 9.5 x 35.5 x 17 inches. Made from mdf the walls and the floor were coloured grey and covered in perspex. This formed context X. Slots between the walls and floor and the perspex allowed for inserts to be used to change the context. Inserts of black and white patterned wallpaper were used as context Y. The E-maze also had a Perspex roof made up of sections. The lines separating these sections would be used as marker points for distinguishing a choice of left or right. A Perspex trap door separated the start-arm from the rest of the E-maze. The rats were placed in this start arm at the beginning of every trial. It should be noted that the E-maze used in the current study was different to the maze used in the original study of Eacott et al. (2005).

2.2.1.2.2 Objects

Objects consisted of three items (e.g. lego or toys) put together to form a more complex object. To begin with two different objects were used each day and four copies of each object were made. Copies of objects were needed as scheduling made it possible to run two rats simultaneously. A copy of each object was needed for the two habituation cages, a copy of each for the sample phases and a copy of each for the test phase.

2.2.1.2.3 Objects and E-Maze

In the objects visible stage, these objects were placed at either end of the length of the E-maze (see Figure 2.1). When the rat exited the start arm the objects were in view. A choice was recorded when the nose of the rat explored the object. In the objects hidden stage these objects were placed at the end of the outer arms (see Figure 2.2). In this stage when the rats appeared from the start arm it was not possible to see these objects. A choice was recorded when the nose of the rat went over the line indicated by a new section of the perspex lid. Exploration of an object was timed in seconds using a stopwatch. Exploration was when the rat’s nose was exploring the object. If the body of the rat was touching the object but the nose was not this did not constitute exploration. Before the rat was placed in the start arm of the maze non-transparent lids were used to cover the maze so the rats would not be able to see the objects inside. These were then removed once the rat was in the start arm.

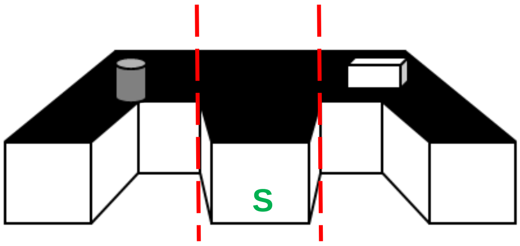


Figure 2.1: Position of Objects in the E-maze during Objects Visible

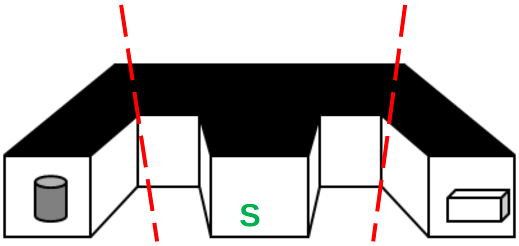


Figure 2.2: Position of objects in the E-maze during Objects Hidden

Figures 2.1 and 2.2 above show the locations of the objects in the E-maze for both the Objects Visible and Objects Hidden stage respectively. The green ‘S’ indicates the start arm where the rat is initially placed. The red dashed lines indicate the specific location where the rats’ noses crossed and thereby signifying a choice.

Figure 2.3: Photograph of a rat in an E-maze exploring objects

Figure 2.3 shows an example of a rat in an E-maze exploring the objects in the Objects Visible position.

2.2.1.2.4 Test Room and Experimenter

The task was always run in the same conditions. Lighting consisted of two 25w bulbs shone off the walls of the room in order to ensure that the E-maze was equally lit in all arms and there were no shadowed areas. During the task the experimenter sat out of sight in complete silence. Rats were monitored via a TV on which the rats' behaviour were being recorded to be analysed later that day.

2.2.1.3 Design

All animals were subject to the same E-maze, object habituation and task habituation. A schedule of object placement, context and test object were counterbalanced across each day and over the test period. The independent variables that were manipulated were therefore object location and context. The dependent variable measure was direction of first turn and also the amount of time spent exploring the object.

2.2.1.4 Data Collection

2.2.1.4.1 First Turns

In Objects Visible a correct choice would be made when the rat's nose touched an object.

In Objects Hidden a correct choice would be made on the direction of the rat's first turn. This was determined on when the rat's nose crossed a line on the transparent perspex roof. These were scored as they happened. If a decision was unclear it would be reviewed on the video recording when the experiment had finished that day.

2.2.1.4.2 Exploration Time and D2 Scores

For both Objects Visible and Objects Hidden exploration time was scored after the experimental day was finished, from video using a stopwatch. The criteria for this exploration were that the rat's nose had to be touching and exploring the object. If the body of the rat was touching the object but not the nose this was not considered exploration. These times were then converted into D2 scores. A D2 score is a discrimination ratio which divides the difference in exploration time (D1) by the total time spent exploring the two objects:

D2 = (exploration of novel object - exploration of habituated object)/ (exploration of novel object + exploration of habituated object).

D2 scores were calculated for each day which could then be averaged over the number of testing days.

Analysis of first turns and exploration time were done each day following the experiment in order to keep track on performance and any possible stress factors.

2.2.1.5 Procedure

2.2.1.5.1 Habituation

In order to not cause unwanted stress to the animals they were habituated to the procedure in stages. For two days the rats were placed in the E-maze (context X) in pairs for 20 minutes. For another two days they were then placed in the E-maze alone (context X) for 20 minutes with objects in the objects visible position. The next two days they were placed in the E-maze for 20 minutes with objects again in the objects visible position but this time using context Y. For one day this time was then reduced to 10 minutes for context X and the next day for context Y. They were then introduced to the habituation cage and experiencing the E-maze more than once a day. One day (context X) they experienced objects visible for 5 minutes, the habituation cage for 5 minutes and then returned to the E-maze for 5 minutes. This was repeated the next day using context Y. The final two days involved habituating the rats to experiencing both contexts in one day. The first sample for example would be 3 minutes in context X, to 3 minutes in the habituation cage, to 3 minutes in context Y, to the habituation cage again and then finally another 3 minutes in either X or Y. In total there was twelve days habituation to this procedure.

2.2.1.5.2 Objects Visible

Twenty days of objects visible trials were carried out. This method involved two sample phases, an habituation phase and a test phase. The rats were individually placed into the start arm of the E-maze. For the first sample phase they spent 2 minutes exploring the E-maze and the objects in one context. They were then transferred to the habituation cage (empty) for as long as it took the experimenter to change contexts (approximately 1 minute 30s). In the second sample phase they then returned to the E-maze for 2 minutes this time experiencing a different context and the objects in opposite locations. The habituation phase lasted 8 minutes in which they were in the holding cage for 8 minutes habituating to an object (determined by the counterbalanced schedule). The final test phase returned the rat to the E-maze for 2 minutes in a particular context with two copies of one of the objects. This schedule made it possible to interleave the testing of two rats. Whilst one rat was habituating to an object for 8 minutes another rat was undergoing the sample phases. After day twelve of objects visible the exploratory behaviour of the animals appeared to suggest that odour may have been building up on the objects and affecting exploration. Such behaviour was an observable increase in the exploration of one object that could not be explained by object interest. It was decided therefore to adopt a regime of cleaning the objects with alcohol wipes after each cage to eliminate any odour build-up.

2.2.1.5.3 Objects Hidden

A preparation day was carried out after finishing objects visible and before starting objects hidden. For this day rats were not habituated to objects they were instead just introduced the new position of the objects.

The same method was followed as that for objects visible apart from the location of the objects obviously differed – in this case the objects were hidden in the outer arms of the E-maze. Sixteen days of objects hidden were then carried out.

2.2.2 Results

All statistical analyses reported are 2 tailed. All figure legends include calculated standard error means (SEM) indicated by error bars. Symbol (*) indicates significance ≤ 0.05. Where multiple t-tests are conducted Bonferroni corrections are made.

2.2.2.1 Objects Visible

2.2.2.1.1 First Turn Data

First Turn data in the Objects Visible stage gives an indication of object preference. Over twenty days of Objects Visible the animals significantly preferred turning towards the RN (Relatively Novel) object (t (15) = 2.952, p = 0.01) with a mean percentage correct score of 56.9.

After day 12 of Objects Visible observations of the exploratory behaviour of the animals indicated that there was the possibility that odour was starting to build up on the objects. Therefore, from day 13 onwards alcohol wipes were used to clean the objects after each cage.

After the twenty days of Objects Visible was complete the data was analysed to determine if any difference could be found and possibly attributed to the cleaning method. Alpha corrected (Bonferroni) one sample t-tests ($p \leq 0.025$) show that during the first twelve days of Objects Visible in which no cleaning of the objects took place, performance was at chance ($t (15) = 1.735$, $p = 0.103$) with an average percentage correct of 56.8. During the last eight days where the objects were cleaned after each cage performance was also still at chance ($t (15) = 1.952$, $p = 0.07$), resulting in an average percentage correct of 57. Despite the mean values being similar to the twenty days as a whole, the lack of a significant result reflects the smaller sample sizes.

Over the twenty days of Objects Visible as a whole a significant object preference was shown for the RN object, it was therefore deemed appropriate to move on to the experimental stage of the task.

2.2.2.2 Objects Hidden

2.2.2.2.1 First Turn Data

Eacott et al.’s (2005) results from First Turn data showed a preference for turning towards the RN object over 16 days with an average percentage correct of 65.2 ($t (15) = 5.583$, $p \leq 0.001$). In the current study over the 16 days of Objects Hidden the animals also showed a significant preference for turning towards the RN object with an average percentage correct of 56.6 ($t (15) = 2.229$, $p = 0.042$). However, the performance of the current study was found to be significantly poorer than the aforementioned task (t (30) = 2.120, p = 0.042) (see figure 2.4).

Figure 2.4: Objects Hidden: First Turn Data (± SEM)

2.2.2.2.2 D2 Scores

Average D2 scores over the 16 days of Objects Hidden show that there was a significant preference for exploring the RN object demonstrating object familiarity (t (15) = 5.888, p ≤ 0.001). However, by looking at the average D2 scores for each animal over the 16 days (see Figure 2.5) the variability between them is highlighted.

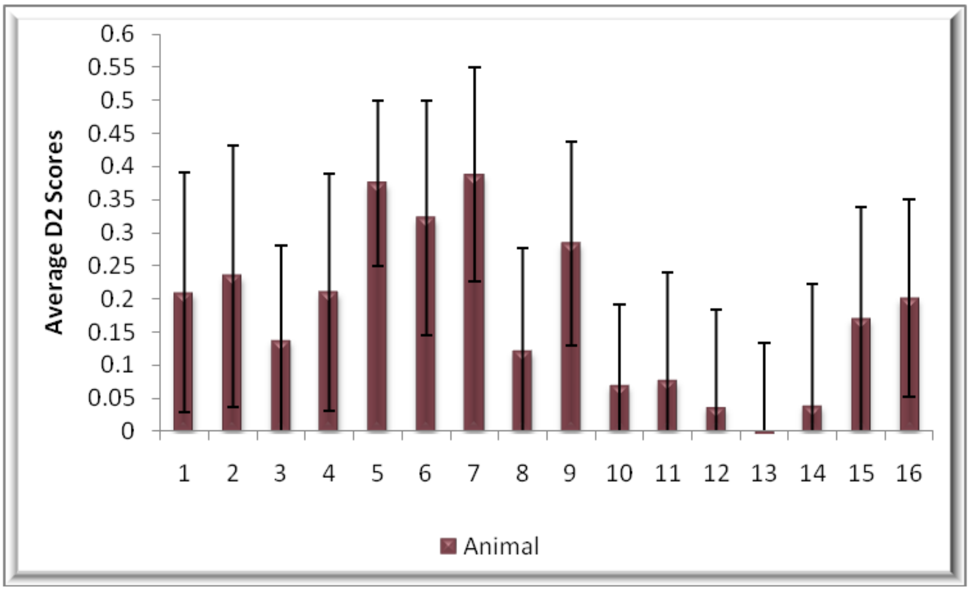


Figure 2.5: Objects Hidden: Average D2 Scores (± SEM) for each animal.

It also serves to show that the last two cages of animals (animals 8-16) appear to be performing significantly more poorly than those in the first two cages (average D2 score first two cages = 0.249; average D2 score second two cages = 0.108: t (14) = 2.807, p = 0.014)

2.2.3 Discussion

Overall, the 20 days of Objects Visible and 16 days of Objects Hidden did prove to be successful and has achieved the objective of replicating Eacott, et al.'s (2005) study. In doing so it demonstrated recollection of the object (what), its location (where) and its context (which) that is considered to be episodic-like memory in animals. However, when comparing performance of first turns in Objects Hidden, performance in the current study was shown to be significantly poorer than that in the original task. This led to the question as to what possible factors could be contributing to this difference. It is true that testing situations differed between the two studies in several respects. The testing room of the current study was adjacent to a corridor which may have been susceptible to disturbance. Whilst the current study was taking place there were several other researchers undertaking studies in adjacent testing rooms which again may contribute an element of noise disturbance. Aside from the testing rooms, the actual E-mazes themselves also differed. In the current study the size of the E-maze was larger and the materials used to differentiate between the contexts were also different. Another factor to consider is that the current study shared objects with other researchers in the area. As this was not the case for Eacott, et al. it must be considered as a potential factor and should be investigated further.

The current study also looked at the variability between animals. By doing so it showed that the performance of the last two cages was significantly poorer than those in the first two cages. It was hypothesised that this could be due to a build up of odour on the objects. When object cleaning was brought in during Objects Visible performance was not found to be significantly above chance for the first twelve days before object cleaning nor the last eight days after cleaning. This result may suggest that the cleaning method was not sufficient to eliminate the odours present. Another contributing factor may also be that this problem extends back to the habituation cages. If odour is built up in the habituation cage it may distract the animals from exploring the object inside. This would then result in the object being less familiar than intended and so being more attractive when encountered in the E-maze as odour would not be a distraction. To investigate this hypothesis further it was necessary to carry out additional days of Objects Hidden with modifications to the method.

2.3 Experiment 2b

The 16 days of Objects Hidden in Experiment 2a was successful in demonstrating episodic-like memory using recollection alone. However, it was clear that not only were there significant differences in the level of performance in Eacott, et al.'s (2005) task and Experiment 2a, but also that in Experiment 2a the last two cages' performance was significantly different to the first two cages. As there are no differences in the methodology between the first two cages and the last two cages it was hypothesised that this could be due to a build up of odour on the objects. This poses a potentially serious problem as any odour on the objects would increase exploration in a manner unrelated to the design of the experiment (i.e. the animals will explore the objects with interesting odours as opposed to objects which are unhabituated) therefore subsequent data will be noisy. Because of this, a cleaning method for the objects was introduced during the Objects Visible stage. The cleaning method did not appear to be detrimental to performance considering no significant difference was found in performance before and after its introduction. However, the performance before and after did remain at chance suggesting that the cleaning method may not have been sufficient to eliminate the odours present. In addition, it is also possible that the issue of odour extends beyond the objects themselves and may actually affect the animals whilst in the habituation cages and in turn still affect their performance. Therefore, another eight days of Objects Hidden were carried out but now with some modifications to the method. If in fact the cleaning method that was introduced in Experiment 2a was not effective enough in eliminating the odours from the objects it seems likely that this materialises only after the first two cages when there will have been a build up of the first eight rat’s odours on the objects. Therefore, by using four objects over two days this would allow for the first two cages to be presented with objects A and B (for example) and the last two cages with objects C and D. The following day the first two cages would see objects C and D and the last two cages would see objects A and B. Adopting this procedure would ensure that only eight animals could potentially odorise the objects, which appears from the data of Experiment 2a to be the limit for odour.

2.3.1 Methods and Materials

The method followed was the same as that for Experiment 2a aside from the modifications. With the possibility that the cleaning method used in the second part of Objects Visible was not sufficient in eliminating the odours on the objects themselves, a modification was devised that instead used four objects over two days. Half the group were presented with two objects one day and the other half with the other two, the next day this was reversed. This particular modification was used in the hope to further limit any odours on the objects. New habituation cages were also introduced after the second cage, cleaning the habituation cages with alcohol wipes after each cage, whilst continuing to clean the objects after each cage. Another eight days of Objects Hidden were carried out with these modifications to the methodology.

2.3.2 Results

2.3.2.1 Objects Hidden

2.3.2.1.1 First Turn Data

Experiment 2b showed the average first turn percentage correct dropping to 53.9%. The rats were not significantly choosing to turn towards the novel object in preference to the habituated object (t (15) = 1.159, p = 0.264).

This drop in performance in terms of First Turn data from Experiment 2a to Experiment 2b was not of significance (t (15) = 0.583, p = 0.569) (see Figure 2.6).

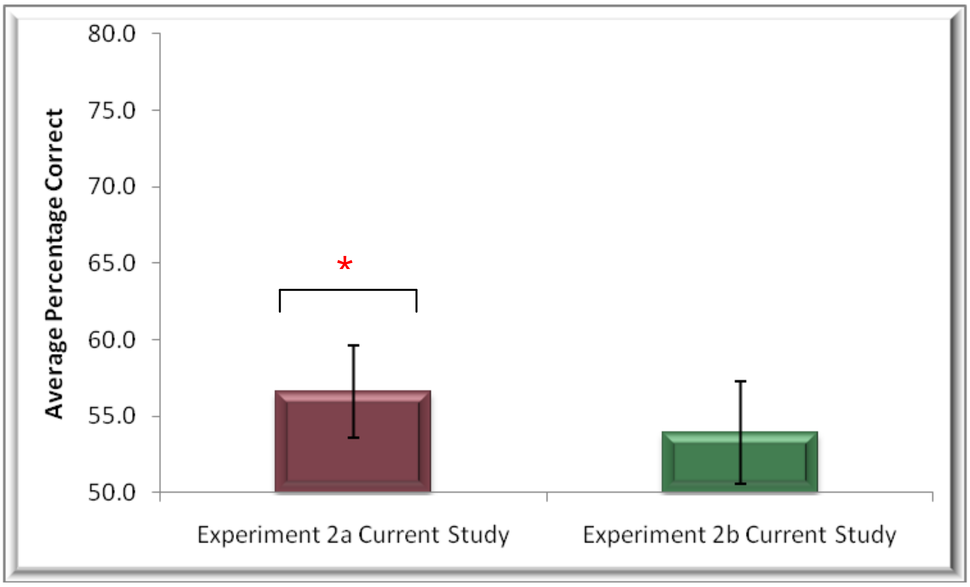


Figure 2.6: Objects Hidden: First Turn Data (± SEM) Experiment 2a and 2b

2.3.2.1.2 D2 Scores

Exploration times supported the first turn data by showing no significant preference for the novel object with a mean D2 score of 0.053 (t (15) = 1.120, p = 0.28).

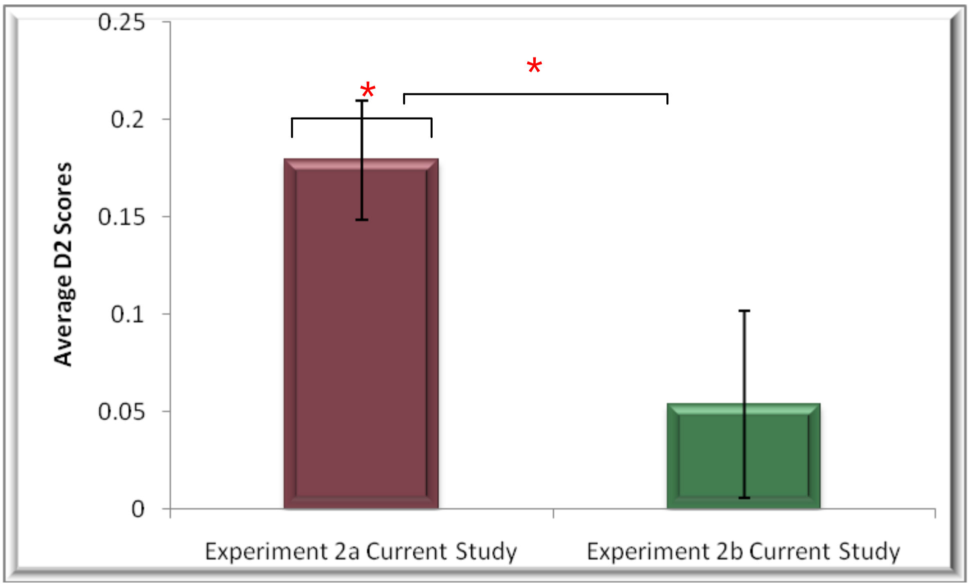


Figure 2.7: Objects Hidden: Average D2 Scores (± SEM) Experiment 2a and 2b

However, although there was seen to be no significant drop in First Turn data from Experiment 2a to 2b, there was found to be a significant drop regarding D2 scores (t (15) = 2.383, p = 0.031) (see Figure 2.7).

2.3.3 Discussion

It is clear from the results that the change in methodology from using two objects in one day to using four objects over two days has not been effective. In fact, when analysing D2 scores it is apparent that exploration of the RN object has dropped significantly. As it is D2 scores i.e. object interest that influences First Turn data i.e. object preference, it appears that object interest in this case has diminished prior to object preference, which would explain the fact that there was no significant object preference in this experiment compared to Experiment 2a.

The methodology of Experiment 2b differed to that of Experiment 2a in that four objects were used over two days and a new cleaning method regarding the habituation cages was introduced. As performance was seen to drop significantly it is not clear as to whether it is the change in the use of objects or the change in the cleaning method that is having this effect. As there was seen to be no significant drop in performance in Experiment 2a before the cleaning method was introduced and after, the significant drop in performance observed the current study was thought to be a result of the change in the use of objects. The new cleaning method was introduced to improve the performance of the last two cages. However, these results are blurred by the apparent drop in performance. In order for these results to become clearer it is necessary to alter the methodology once more.

2.4 Experiment 2c

Experiment 2b showed that despite the change in methodology performance dropped even further. Although there was no significant difference between First Turn data from Experiment 2a to 2b there was a significant difference in D2 scores. The two changes in methodology were regarding object use and cleaning method. The decision to keep this new cleaning regime was based on the fact that after the introduction of the cleaning method in the Objects Visible phase of Experiment 2a there was no significant difference in performance, therefore although not improving performance significantly it was also not detrimental to it. In addition, during Objects

Hidden, performance of the last two cages differed from that of the first two cages. However, any possible improvement in performance in Experiment 2b may have been masked by the change in use of the objects. As mentioned previously, carrying out many days of testing is a necessity when conducting behavioural experiments in the E-maze, particularly when also investigating modifications to the methodology. It would not be surprising therefore if at some point performance dropped that was not only due to factors such as odour, but also the fact that the task itself was becoming less novel. One potential way of boosting performance when this occurs would be to introduce a ‘genuinely novel’ object, an object not previously seen during the sample phases. With this added novelty, object interest and consequently object preference should be enhanced.

With the above in mind, a further thirty days of Objects Hidden were carried out to test the object modification outlined above, and also to determine if this would result in performance stabilising over time.

2.4.1 Methods and Materials

The method used was the same as that for 2a with regard to the schedule. With regard to cleaning method it was decided to continue with the method used in Experiment 2b as any possible improvement due to this cleaning method may not have become apparent due to the change in the use of objects.

Modifications to the method involve reverting back to using two objects over one day, however, there was also the introduction of a ‘genuinely novel’ (GN) object at test (this required two copies of an extra object to be made).This would be an object that the rats were not previously habituated to. Previously the rats were experiencing an object, either habituated or non-habituated. This non-habituated object was not completely novel as they had seen it before in the two sample phases. The aspect that was novel was its location in a specific context. This GN object was new in all these aspects and should therefore prove more interesting to the rats. The non-habituated object and the GN object were paired at test. This GN object was not cleaned as it was only used for the test phase.

With these modifications another 30 days of Objects Hidden were carried out. This high number of days was carried out to investigate whether performance could be sustained over long periods of time.

2.4.2 Results

2.4.2.1 Objects Hidden

2.4.2.1.1 First Turn Data

The modifications to the methodology resulted in a significant preference for turning towards the now GN object over thirty days (t (15) = 3.044, p = 0.008) with an average percentage correct of 59.1.

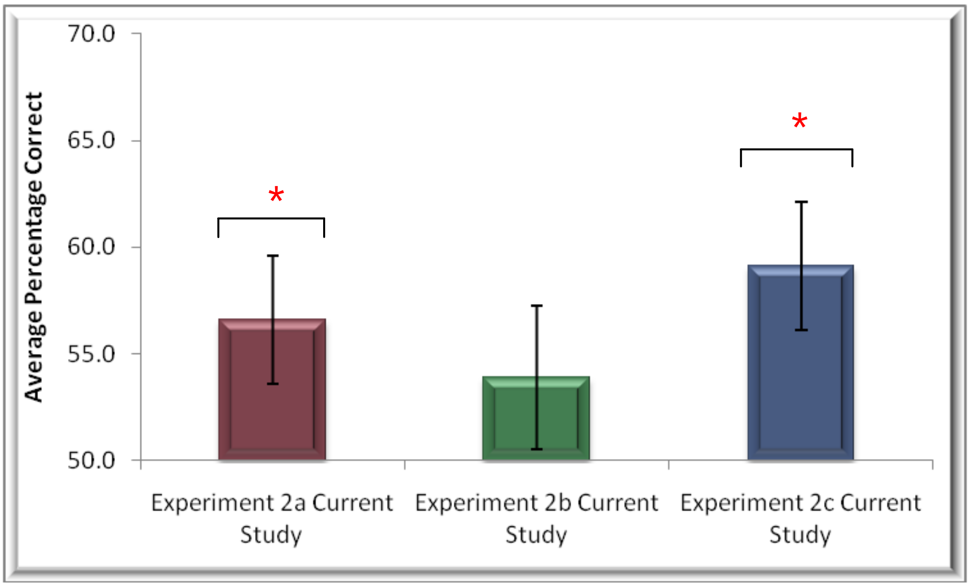


Figure 2.8: Objects Hidden: First Turn Data (± SEM) Experiment 2a, 2b and 2c

However, there was found to be no significant effect of group (experiment) on performance (F (2, 30) = 0.825, p = 0.448) (see Figure 2.8)

When considering performance over time, for analyses purposes the thirty days were split into days 1 to 15 and days 16 to 30 to investigate whether performance was significantly different in the first half of the testing period compared to the second half. Alpha corrected (Bonferroni) one sample t-tests ($p \leq 0.025$) show that during the first half of the testing period (days 1 to 15) performance was significantly above chance levels with an average percentage correct of 57.9 (t (15) = 2.515, p = 0.024). During the second half of the testing period (days 16 to 30) there was also a significant preference for turning toward the GN object with an average percentage correct of 58.8 (t (15) = 3.120, p = 0.007). There was found to be no significant difference in the performance between the first half and the second half of these thirty days (t (15) = -0.357, p = 0.726), indicating that performance was stable.

2.4.2.1.2 D2 Scores

The introduction of the GN object resulted in a significant preference for exploring the GN object (t (15) = 39.148, p ≤ 0.001).

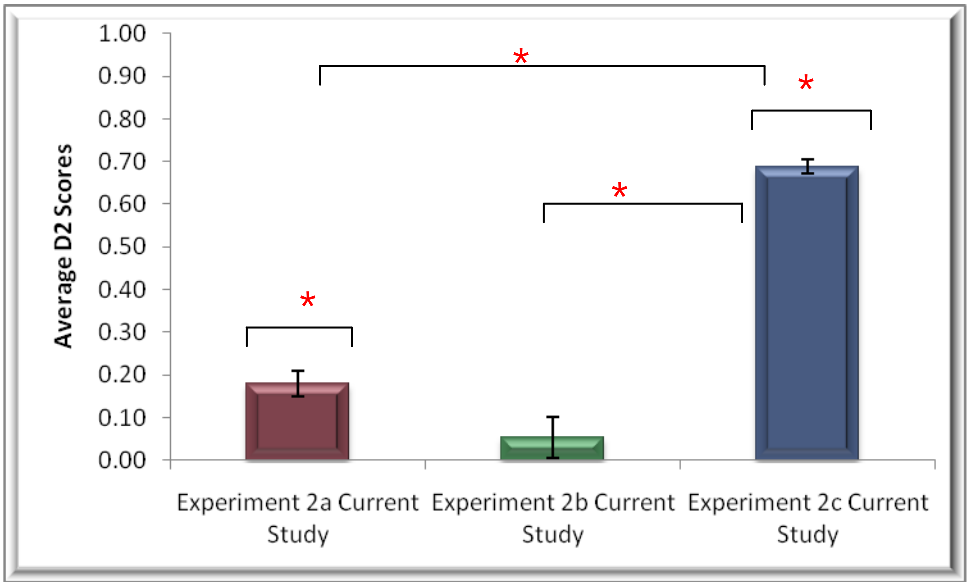


Figure 2.9: Objects Hidden: Average D2 Scores (± SEM) Experiment 2a, 2b and 2c

The GN object also resulted in an effect of group (experiment) on performance (F (2, 45) = 90.841, p ≤ 0.001). Alpha corrected (Bonferroni) post hoc analyses (p ≤ 0.016) found there to be a significant increase in D2 scores from Experiment 2b to 2c (t (15) = -12.685, p ≤ 0.001) and from Experiment 2a to 2c (t (15) = 13.516, p ≤ 0.001) (see Figure 2.9).

Again, when considering the performance over time, alpha corrected (Bonferroni) one sample t-tests (p ≤ 0.025) showed exploration to significantly favour the GN object during the first 15 days with an average D2 score of 0.604 (t (15) = 27.138, p ≤ 0.001) and also the last 15 days with an average D2 score of 0.734 (t (15) =

36.352, $p \leq 0.001$). Unlike for First Turn data however, there was a significant increase in the exploration of the GN object during the second half of the experiment compared to the first half ($t(15) = -4.619$, $p \leq 0.001$).

2.4.3 Discussion

The addition of the GN object resulted in First Turn data being significantly above chance and so again demonstrating episodic-like memory using recollection alone. However, this was not a significant improvement from Experiment 2a or Experiment 2b. D2 scores were also significantly above chance and this was a significant improvement from both Experiment 2a and 2b.

The current experiment also examined the stability of performance over a relatively long period of time. By splitting the experiment into two blocks of fifteen days performance was shown both in the first half of the experiment and the second half to be above chance levels. There was also found to be no significant difference in First Turn data between the first half and the second half of the experiment.

Although the improvement in First Turn data did not reach significance, there was seen to be a significant improvement in D2 scores. It would be logical to surmise that increased object interest (i.e. D2 scores) would lead to an object preference which would be observed in improved First Turn data. As this was not seen, perhaps then this reflects that object preference does not necessarily mirror the level of interest in the object. First Turn scores did not have to significantly improve for D2 scores to significantly improve. It could be that the first turn is not so important for the animals as they have been habituated to two minutes in the maze and they have learnt that even if they turn towards the habituated object first they will still then have time to explore the GN object. This is also seen in the results that show First Turn data does not significantly differ from the first half of the experiment to the second half, yet exploration of the GN object does, in fact it improves as the experiment continues. However, this could also suggest that stability of First Turn data is necessary for D2 scores to improve.

2.5 Experiment 2d: Probe Day

A probe day was carried out that followed the same procedure as Experiment 2c, however no objects were placed in the habituation cages. This was to determine whether or not the episodic-like memory observed was based on memory or whether it was based on the animals being able to locate the GN object from the start arm using odours or other unintended cues. If these results were seen to be above chance this would suggest that the animals are using unintended cues to locate the GN object instead of using memory. Results from D2 scores should still be significantly above chance as even though the animals have not habituated to an object, the GN object has not been seen before, whereas the other two objects were seen during the sample phases of the task.

2.5.1 Results

2.5.1.1 First Turn Data

As expected First Turn data for the probe day showed no preference for the GN object with an average percentage correct of 56.3 (t (15) = 0.488, p = 0.633) lending reassurance that the performance demonstrated in Experiments 2a to 2c was based on memory and the animals were not locating the GN object using unintended cues.

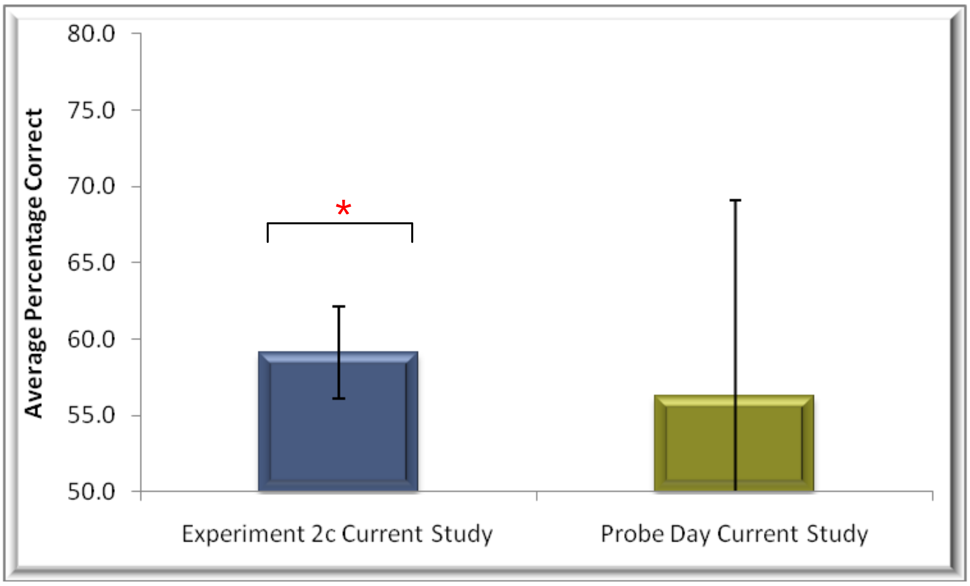


Figure 2.10: Objects Hidden: First Turn Data (± SEM) Experiment 2c and Probe Day

Although Experiment 2c saw First Turn data above chance and the Probe day did not, there was no significant drop in performance (t (15) = -0.211, p = 0.835).

2.5.1.2 D2 Scores

A one sample-t-test confirms as expected, a continued significant preference for exploring the GN object with an average D2 score of 0.751 (t (15) = 17.299, p ≤ 0.001).

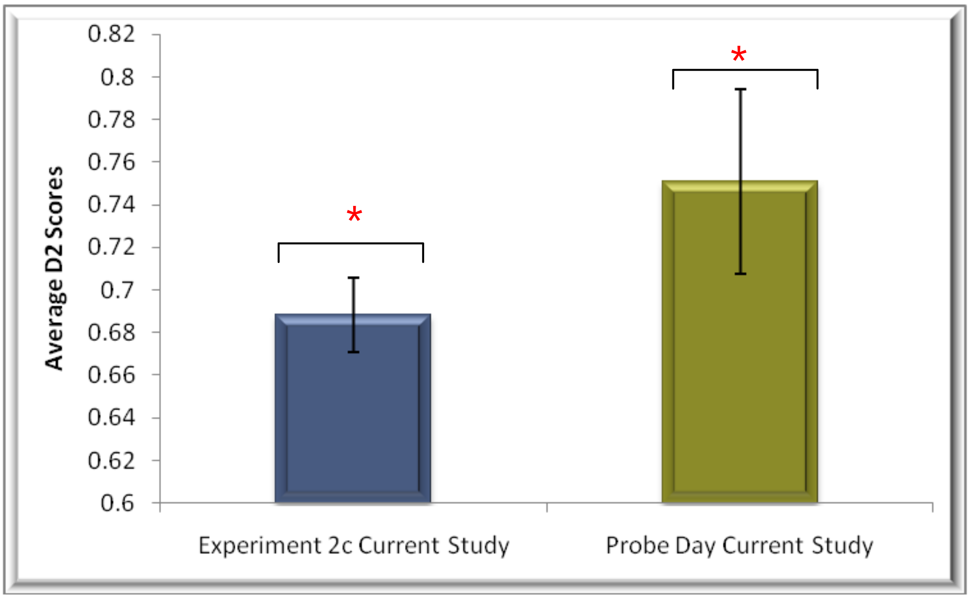


Figure 2.11: Objects Hidden: Average D2 Scores (± SEM) Experiment 2c and Probe Day

There was however, no significant difference in the exploration of the GN object from Experiment 2c to the Probe day (t (15) = -1.343, p = 0.199).

2.5.2 Discussion

Reassuringly, First Turn data from the Probe day was at chance, confirming that the episodic memory demonstrated in Experiment 2c was not a result of being able to locate the GN object by odour or other unintended cues. There was a continued significant preference for exploring the GN object which was also as expected. As explained previously, as the GN object was only seen at test and not in either of the sample phases it still holds its novelty and so according to the rats' innate preference for novelty (Ennaceur & Delacour, 1988) exploration should favour this object.

2.6 Discussion

The current chapter has been successful with regard to the original aim of replicating Eacott, et al.'s (2005) study demonstrating the what-where-which memory triad that can be considered episodic-like in animals. This replication reinforced the claim by Eacott et al. that the task cannot be solved based on familiarity, instead it necessitates the need to recollect a prior experience in order to be successful.

Despite this successful replication, the results were found to be significantly different to the original study (Eacott et al., 2005). The observed difference in First Turns may have been due to differences in the E-maze that was used. The E-maze used in the current chapter used contexts to differentiate between different occasions, however it may be that in the maze used here that these occasion setters were more difficult to differentiate than in the original study. Contexts in the original study were one of two colours (black or grey) and had different textures (plain or mesh), whereas in the current maze the context were either grey or a mixture of black, white and grey with no textures. It is possible that the simple block colours and textures made it easier for the animals to differentiate from one context to another. Testing in the original study was also not hampered by other experiments taking place in neighbouring testing rooms, yet the current study saw neighbouring testing rooms occupied which again may have caused stress induced neophobia.

The results of the current chapter also highlight other methodological issues that require attention before any further manipulations such as lesion studies can be carried out. When conducting lesion studies it is necessary to have a task that not only shows true episodic-like memory, but also to have a task that is consistent over time.

By analysing the data further it is clear that such spontaneous tasks can be vulnerable to extraneous variables that upon detailed analyses clearly influence the results. A method of cleaning the objects was introduced during the Objects Visible stage, and although not having a detrimental effect of the results, performance before and after its introduction remained at chance, suggesting that the cleaning method may not have been sufficient to eliminate the odours present. The observed drop in performance of the last two cages suggested that further manipulations to the methodology were needed to rectify this issue. If odour is having an impact on the animals' exploratory behaviour then what has previously been concluded to be demonstrations of episodic-like memory, may in fact be a misconception. It could be that the animals are locating the non-habituated object via odour pathways or other unintended cues and not through the recollection of any memory. However, the deterioration of the last two cages also suggests that these pathways can become saturated to the point where exploratory behaviour indicates neither an object preference nor navigation via odour.

Experiment 2b addressed this problem by altering the methodology regarding object use and cleaning. Object use was spread out over two days and the cleaning method no longer restricted itself to the object but instead included the habituation cages also. However, this alteration in methodology did not have the desired effect as even though first turn data did not drop significantly, the results were at chance level and so not demonstrating the episodic-like memory seen in Experiment 2a.

There was however, a significant drop in D2 scores that resulted in no preference for exploring the RN object, which explains why First Turn data was at chance. As the manipulations to the methodology were two-fold it was not clear what was causing this result. It was hypothesised that the change in objects from having one set of objects made each day to having two sets over two days and interchanged between the cages was more likely to have caused the results rather than the cleaning method due to the fact performance was not seen to drop following its introduction in the Objects Visible phase of Experiment 2a. The issue of odour was a problem that could only deteriorate further and so the new cleaning regime was adopted as standard for future experiments. It was also hypothesised that as many days of the task had been carried out that it was the task itself that may have lost its novelty factor.

Considering this Experiment 2c saw the introduction of the GN object was with the hope of not only enhancing the novelty of the task but also boosting performance. This particular manipulation to the methodology did have the desired effect. First Turn data showed the animals now demonstrating episodic-like memory using recollection alone, this was also reflected in a significant improvement in D2 scores. In addition to this it was also important to determine whether this performance could be maintained over relatively long periods of testing which would be necessary if future experiments were to involve lesion experiments. Thirty days of Objects Hidden were carried out and to further analyse the performance over time these days were split into two blocks of fifteen days. With regard to First Turn data, performance was found to be above chance levels during both the first and the second half of the experiment, with no significant difference between the first fifteen days and the second fifteen days. D2 scores however significantly improved in the second half. This can be explained by the fact that it is D2 scores that drive First Turn data. In other words, in order for object preference to significantly improve, object interest has to improve first. It also implies that the stability of First Turn data may impact on D2 scores. These results also suggest that the data from Experiment 2b was a culmination of odour saturation on the objects and in the maze and the fact that the task was beginning to lose its novelty aspect. Reassuringly, the probe day confirmed that the episodic-like memory seen in Experiments 2a and 2c were not the result of the rats using odour or other unintended cues to locate the RN/GN object but rather the observed result was a true reflection of their memory.

Regarding the introduction of the GN object, in retrospect although it improved performance as expected, as a permanent change in methodology it is not viable. This is due to the fact that a) it served its purpose in adding novelty to the task and improving performance, and b) that further investigations using this method (e.g. lesion studies) may produce data that cannot be decisively explained. It could be that if a lesion group were impaired on the task that this impairment may lie in the fact that the lesion affects the ability to recognise that there is a GN object and that this is replacing the RN object. However, differentiating this from an impairment in episodic-like memory would be impossible. In addition, there is the fact that First Turn data in Experiment 2c was not significantly improved. Therefore, it would be appropriate to revert back to the RN object and determine if the temporary novelty that the GN object brought to the task was enough to bring performance above chance.

The current chapter has highlighted several important issues that impact on spontaneous tasks such as the one described here. It is clear that data from such tasks needs to be analysed in depth to determine if there are any unusual patterns of data that indicate the influence of extraneous variables such as odour. As explained previously, the influence of such variables can lead to illusory data and inaccurate conclusions. In addition, it is apparent that the aspect of novelty that is so intrinsic to such tasks can also have a detrimental effect on the results. Although it is important to have a task that is stable over time, this stability requires consistent levels of novelty which is not an easy balance to find. However, the flexibility of such tasks allows for manipulations to the methodology that can readdress this balance if necessary.

This chapter has resulted in a task that successfully demonstrates episodic-like memory using recollection alone, and a task that appears to be stable over time. Therefore it was deemed appropriate to further investigate episodic-like memory in the E-maze, in particular to investigate the effect of lesions to the hippocampus.

3 EPISODIC-LIKE MEMORY AND THE HIPPOCAMPUS

3.1 Introduction

Chapter 2 was important in highlighting the significance of the now modified What-Where-Which task created by Eacott, Easton and Zinkivskay (2005). Normally, object memory tasks rely on recognition, that is, the animal has a choice between a visible object that is novel and a familiar object in an open field arena. In an Open Field arena, the fact that the both objects are visible to the animal at the start of the test phase of the task, apparent preference for the novel object may be more related to object familiarity rather than actual object recollection. When investigating episodic memory, tasks that demand free recall have been suggested to be of more value than recognition tasks as the latter can involve correct responses based on familiarity which is not episodic in nature (Kelley & Jacoby, 2000). Unlike previous tasks (Eacott & Norman, 2004; Gaffan, 1994), the task developed by Eacott et al. (2005) successfully demonstrated episodic-like memory in animals through the use of recollection processes only. As the objects were hidden, the task did not allow for familiarity cues and so was not solved using recognition. Differentiating between the tasks that measure episodic-like memory using recall (Clayton and Dickinson, 1998; Eacott & Gaffan, 2005) or recognition (Kart-Teke, De Souza Silva, Huston, & Dere, 2006) is crucial when considering that human recognition memory allows for both familiarity and recall (Yonelinas, 2001).

Although studies have attempted to dissociate recollection and familiarity through the analyses of ROC curves (Fortin et al., 2004; Sauvage et al., 2008), direct behavioural evidence in the rat has been lacking. However, in a recent study Easton et al. (2009) were able to behaviourally separate measures of familiarity and recall and in doing so implicate the fornix in the recall circuit but not the familiarity circuit, therefore lending support to the two separate neural circuitry systems proposed by Aggleton and Brown (1999). The nature of the task according to Easton et al. defends itself against apparent contradictory evidence (Eacott and Norman, 2004).

The current experiment aimed to investigate the effect of bilateral lesions to the hippocampus on episodic-like memory using Eacott et al.'s (2005) what-where-which task in the E-maze. The benefit of such a task is that it allows for the measurement and differentiation of familiarity and recall in the same animals in the same trials. It also then allows for the measurement of the separate components of episodic-like memory to be assessed and the effect of hippocampal lesions on these individual components to be determined. The nature of previous studies such as Langston & Wood (2006) have not allowed for this differentiation between familiarity and recall due to the fact that the task was conducted in the open field. The relevance of these bilateral hippocampal lesions is also related to the studies investigating fornix lesions due to the fact that the fornix contains a variety of pathways that project both to and from the hippocampus.

Cutting the fornix often mimics the effects of hippocampectomies (Aggleton & Brown, 1999), yet does not result in retrograde cell loss in the medial temporal lobe (Diaitz &Powell, 1954), therefore the resultant loss of memory must be due to the disconnection of pathways and not simply the loss of hippocampal cells (Fujii, 2008). It has also been hypothesised that the fornix may be less of an important conduit of hippocampal afferent and efferent projections in the monkey compared to the rat (Zolamorgan, Squire, & Amaral, 1989). Eacott & Gaffan (2005) suggest that the hippocampus, as evidenced by lesions of the fornix, has a distinct function of its own which encompasses information regarding objects, positions and contexts. Considering the results reported by Easton et al., (2009) and the successful replication of Eacott et al. in Chapter 2, the next logical step is to investigate this further by undertaking the same task but with rats that have bilateral lesions to the hippocampus. The effect of these lesions on overall what-where-which memory and the individual components of episodic-like memory can then be observed.

3.2 Experiment 3

3.2.1 Methods and materials

3.2.1.1 Subjects

Twenty experimentally naïve Dark Agouti male rats (Harlan laboratories, UK) underwent surgery. Two animals died in the immediate postoperative period and so 18 were used in the studies described in the current chapter. They were housed in cages of four and were subject to diurnal conditions (12 hour light/12 hour dark cycles). It should be noted that Sham animals and the Hippocampal lesioned animals were housed together in their cages, they were not separated into their respective lesions/sham groups.

Testing always took place during the light cycle and never started before 7am or finished after 7pm. Access to food and water was ad libitum, levels of which were monitored daily as governed by the Animal (Scientific Procedures Act) (1986) and approved by the Home Office Project licence.

3.2.1.2 Surgery

In order for surgery to begin rats had to reach a weight of 180 grams. The surgical procedures were carried out by Dr Anthony McGregor and were carried out over a period of 17 days. The surgical procedure was chosen due to its success in previous studies (Jones, Pearce, Davies, Good, & McGregor, 2007; McGregor, Good, & Pearce, 2004; Pearce, Good, Jones, & McGregor, 2004).

3.2.1.2.1 Hippocampal lesion group (n=8)

The method for anaesthesia was a mixture of isoflurane and oxygen (5% isoflurane for induction and 2% for maintenance). Once under deep anaesthesia each rat was then placed into a stereotaxic frame (Kopf Instruments, Tujunga, CA). The primary incision was made along the midline of the scalp and through use of a dental burr it was then possible to remove the bone overlying the neocortex. Using the stereotaxic frame allowed secure positioning of a 2 µl Hamilton syringe containing ibotenic acid. An electronic microdrive (Model KDS 310, KD Scientific, New Hope, PA) was attached to the plunger of the Hamilton syringe in order to regulate the volume and rate of infusion of the excittoxin. Ibotenic acid (Tocris, Bristol, UK) was dissolved in phosphate-buffered saline (pH 7.4). The resultant solution was of a 63 mM quantity and was infused (0.05 – 0.10 µl) at a rate of 0.03 µl/min at 28 sites (for details of the stereotaxic coordinates of the injection sites refer to Coutureau, Galani, Gosselin, Majchrzak, & Di Scala (1999). After each infusion the Hamilton syringe was left in place for 2 minutes. This allowed the solution to diffuse away from the injection material and into the surrounding tissue.

At the end of the procedure the incisions of the scalp were closed with clips. All rats received a 10ml injection of saline and glucose solution, and 1ml of buprenorphine as an analgesic. The animals were then placed in a recovery box. The temperature of the recovery box was maintained at a constant 40°C for 3-4 hours. From the recovery box the rats were then housed alone for an appropriate period of time (1 to 2 days) until it was deemed that sufficient recovery had taken place and only then were they transferred back to their original home cages. Testing of these animals did not begin until a minimum of 14 post-operative days of recovery had passed. Two animals died during recovery leaving a total of 10 animals for this group.

3.2.1.2.2 Sham Group (n = 8)

The surgical procedure for the Sham group was intended as a control for the effects of the surgical procedures undergone by the Hippocampal lesion group so a similar surgical procedure was adhered to. The skin was incised and the neocortex was exposed. Perforation of the dura was carried out using a Microlance3 25 gauge needle to control for the possibility of mechanical damage to the underlying parietal cortex but critically no injection was administered.

The procedure following surgery for the sham group followed the same protocol as outlined for the hippocampal lesioned group.

3.2.1.3 Perfusion

For histological purposes, at the end of testing, or if necessary after an animal was euthanized, animals were perfused intracardially with a 5% formol-saline solution. The brains were removed, placed in 10% formol-saline for at least 4 hours and then placed into 25% sucrose solution for 24-48 hours before being sectioned. They were sectioned horizontally into 50µm slices and every 5th section was stained with cresyl violet (Nissl stain).

3.2.1.4 Apparatus

Apparatus is the same used and described in Chapter 2.

3.2.1.5 Design

Design is the same used and described in Chapter 2. Counterbalancing in this case also took into account counterbalancing within as well as across the two groups.

3.2.1.6 Data Collection

The same method of data collection was used as that described in Chapter 2.

3.2.1.7 Procedure

3.2.1.7.1 Habituation

Habituation was carried out in stages to minimise the effects of stress on the animals. Habituation for this experiment was different to the habituation procedure followed in Chapter 2 due to the fact that the animals had undergone extended recovery following surgery therefore the habituation procedure was extended. The initial stage of habituation allowed the rats to explore the E-maze in groups of two. Each cage housed four rats and so each cage had two pairs for habituation. Two of the cages however (cages 1 and 5) housed only three rats (due to the loss of rats 3 and 17) and so were simply kept in their cage group.

For two days the rats were placed in the E-Maze in their groups in context X (grey) for 30 minutes with the objects in the objects visible position (refer to chapter 2). Following this they then had four days of context X in groups for 20 minutes, with objects in the visible position. These six days were then repeated using context Y (wallpaper and mesh floor). Day 13 of habituation the rats were again in groups for 20 minutes in context X with objects in the visible position. Day 14 followed the same procedure but in context Y.

Once the rats had been sufficiently habituated to the E-maze and both contexts it was then possible to expose them to the E-maze individually. Four days of alternate contexts were then used. In these four days the rats were exposed to the E-maze individually for 15 minutes with objects in the visible positions.

The habituation cage was then introduced. Day 19 exposed the rats to 10 minutes alone in the E-maze with objects visible and then to 10 minutes alone in the habituation cage (without an object) before being returned to the holding cage. Day 20 followed the same procedure but using context Y. Having introduced the habituation cage it was now necessary to introduce an object in the habituation cage. Day 21 of habituation allowed the individual rats to explore the E-maze in Context X with objects visible for 2 minutes. They were then placed in the habituation cage for 8 minutes, during the first 7 minutes the habituation cage contained no object, it was only for last minute that an object was introduced. This was to try and increase object interest during habituation immediately prior to entering the maze. After these 8 minutes the rat was returned to the E-maze for a final 2 minutes in the same context and then returned to the holding cage. Day 22 of habituation followed the same procedure but used context Y. Up to this point the context of the E-maze was never changed within a day. Therefore day 23 of habituation saw individual rats exploring the E-maze in context X with objects visible for 2 minutes. They were then placed in the habituation cage (empty) whilst the context was changed. They then were placed back in the E-maze, this time in context Y for a further 2 minutes. They were then placed in the habituation cage for 8 minutes (empty except for the final minute when an object was introduced). They were returned to the E-maze for a final 2 minutes in context Y before being returned to the holding cage. Day 24, the final day of habituation, saw the same procedure followed but on this day the context order was XYX.

3.2.1.7.2 Cleaning Procedure and Object Details

The cleaning procedure followed was that used in experiments 2b, 2c and 2d. Objects were cleaned after every cage, habituation cages were cleaned after every cage and these cages were changed after cage 3. The maze was also cleaned at the end of every testing day. With regard to objects, despite the initial success of the ‘genuinely new novel’ object it was deemed inappropriate to use this object as it may mask the true effects of the lesion on any episodic-like memory observed. Therefore, the original method of using a ‘relatively novel’ (RN) object was again adopted.

Sixteen days of Objects Visible were carried out. The procedure for Objects Visible is the same to that detailed in Chapter 2, Experiment 2a but counterbalanced for a different number of animals and for between groups.

3.2.1.7.3 Objects Hidden

After 16 days of Objects Visible, a blank day of Objects Hidden was carried out. This involved the objects being placed in the hidden locations but no exposure to objects in the habituation cages (see Chapter 2 Experiment 2a for details).

Following this blank day, 16 days of Objects Hidden were carried out. Methodology regarding the objects were the same as detailed in Chapter 2, Experiment 2a and cleaning method followed the procedure outlined in Experiment 2b.

3.2.2 Results

3.2.2.1 Histology

Volume of damage was calculated by using images from Paxinos & Watson (1999) magnified to 160%. Once the appropriate lesions were drawn onto these images transparent graph paper (0.5mm x 0.5mm squares) was then used to count the area of lesion damage which could be used to calculate percentage of volume damage. Due to the histological process slides for all the animals were not at identical levels related to Bregma and Interaural, therefore for consistency and comparative purposes measurements were taken at three levels where the hippocampus for all animals appears most dorsal, ventral and midway between the two. Volume of damage to the Subiculum, Parietal Cortex (for the one animal sectioned corronally) and Hippocampal White Matter were also included. Although the Subiculum was not intended to be damaged, the proximity of it to the CA1 field of the Hippocampus means unintended damage is common. Unintended damage to other areas will be discussed as necessary.

Histological analyses indicated that of the 10 animals that survived surgery and completed testing, only 5 had hippocampal lesions which were considered sufficient (≥70% bilaterally) for the purposes of the study. This criteria was adopted from previous studies using the same surgical procedure (Jones et al., 2007) but made more stringent (i.e. ≥70% bilaterally not ≥65% bilaterally) under the guidance of surgeon Dr Anthony McGregor. The criterion was also reinforced by the results of studies investigating hippocampal lesion size on spatial memory (Broadbent, Squire & Clark, 2004), the significance of which is that episodic memory must involve some degree of spatial encoding.

3.2.2.1.1 Partial Hippocampal Group (Partial HPC) (n = 5)

Of those 5 animals that were excluded (but included in separate analyses) lesions ranged from 37% to 69.2% (see Table 3.1 and Figures 3.1 to 3.5). This group is to be referred to as the Partial HPC group. The lesions extended from approximately 3.10mm to -8.42mm posterior to Bregma. Possible reasons for the surgery being partially successful with respect to the aforementioned criteria include the fact that an unpiloted analgesic post-surgery was used which may have interacted with the excitotoxin. In addition, the supplier of the excitotoxin was new to the surgeon as was the surgery set up.

Table 3.1: Percentage of damage for animals considered insufficient to be regarded as a full hippocampal lesion (see also corresponding Figures 3.1 to 3.5).

Animal		Hippocampus			Subiculum			Parietal Cortex			Hippocampal White Matter		
		L %	R %	**M**	L %	R %	**M**	L %	R %	**M**	L %	R %	**M**
PHPC 2*	Bregma -3.60mm/Interaural 5.40mm	91	97	**94**	0	0	**0**	33	93	**63**	0	0	0
	Bregma -4.80mm/Interaural 4.20mm	91	96	**93.5**	0	0	**0**	43	81	**62**	0	0	0
	Bregma -6.04mm/Interaural 2.96mm	10	30	**20**	4	10	**7**	0	0	**0**	0	0	0
	Mean	**64**	**74.3**	**69.2**	**1**	**3**	**2**	**25**	**58**	**41.7**	0	0	0
PHPC 5	Bregma -3.10mm/Interaural 6.90mm	54	59	**56.5**	3	3	**3**	-	-	-	0	30	**15**
	Bregma -5.60mm/Interaural 4.40mm	41	25	**33**	0	0	**0**	-	-	-	0	0	**0**
	Bregma -8.42mm/Interaural 1.58mm	17	26	**21.5**	11.5	16	**13.75**	-	-	-	0	0	**0**
	Mean	**37.3**	**36.7**	**37**	**4.8**	**6.3**	**5.6**	-	-	-	0	**10**	**5**
PHPC 11	Bregma -3.10mm/Interaural 6.90mm	59	65	**62**	13	10	**11.5**	-	-	-	0	12.5	**6.25**
	Bregma -5.60mm/Interaural 4.40mm	34	25	**29.5**	0	0	**0**	-	-	-	0	0	**0**
	Bregma -8.42mm/Interaural 1.58mm	13	26	**19.5**	3	7	**5**	-	-	-	0	0	**0**
	Mean	**35.3**	**38.7**	**37**	**5.3**	**5.7**	**5.5**	-	-	-	-	**4.2**	**2.1**
PHPC 15	Bregma -3.10mm/Interaural 6.90mm	56	63	**59.5**	0	10	**10**	-	-	-	0	0	**0**
	Bregma -5.60mm/Interaural 4.40mm	66	55	**60.5**	0	0	**0**	-	-	-	0	0	**0**
	Bregma -8.42mm/Interaural 1.58mm	9	22	**15.5**	3	10	**0**	-	-	-	0	0	**0**
	Mean	**43.7**	**46.7**	**45.2**	**0**	**6.7**	**3.3**	-	-	-	0	0	**0**
PHPC 19	Bregma -3.10mm/Interaural 6.90mm	70	75	**72.5**	11	6	**8.5**	-	-	-	30	0	**15**
	Bregma -5.60mm/Interaural 4.40mm	66	41	**53.5**	0	0	**0**	-	-	-	0	0	**0**
	Bregma -8.42mm/Interaural 1.58mm	30	17	**23.5**	8.3	5	**0**	-	-	-	0	0	**0**
	Mean	**55.3**	**44.3**	**49.8**	**6.4**	**3.7**	**2.8**	-	-	-	**10**	**0**	**5**

*coronal sections

Table 3.1 shows the 5 animals that were considered to have insufficient bilateral lesions to the hippocampus based on the criteria outlined previously.

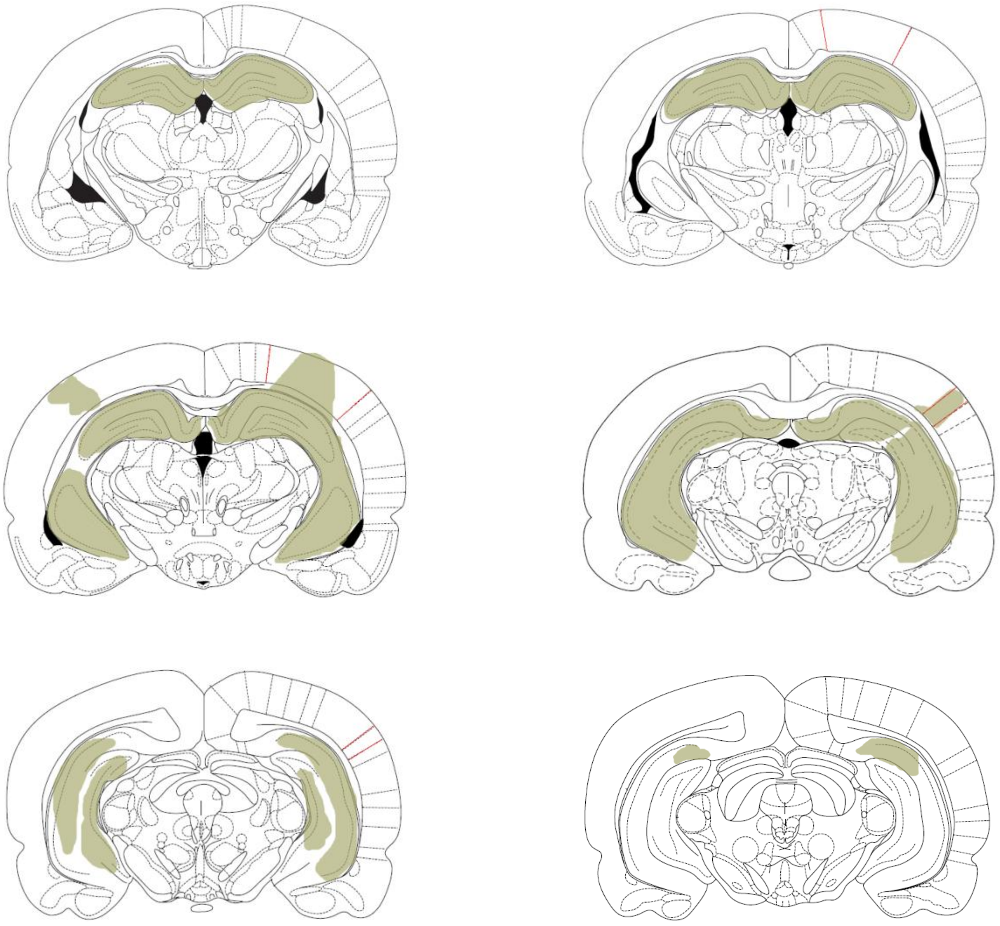


Figure 3.1: Partial HPC Group: Coronal Sections (starting at Bregma 360mm, Interaural 5.40mm and finishing at Bregma -6.04, Interaural 2.96mm) showing an individual animal (PHPC 2). The associative parietal cortex is indicated by red lines. Hippocampal cell loss and/or associative parietal cortex damage is shaded gold. See Table 3.1 for corresponding volume figures. Taken from Paxinos and Watson (2007).

Figure 3.1 shows corronal sections from an animal from the Partial HPC group. In addition to hippocampal cell loss there is also shown to be some associative parietal cortex damage that is not uniformly distributed.

Figure 3.2: Partial HPC Group: Horizontal sections (starting at Bregma -3.10mm Interaural 6.90mm and finishing at Bregma -8.42mm Interaural 1.58mm) showing an individual animal (PHPC 19). Hippocampal cell loss is shaded gold. Thinning of Hippocampal White Matter is highlighted on the figure. See Table 3.1 for corresponding volume figures. Taken from Paxinos and Watson (2007).

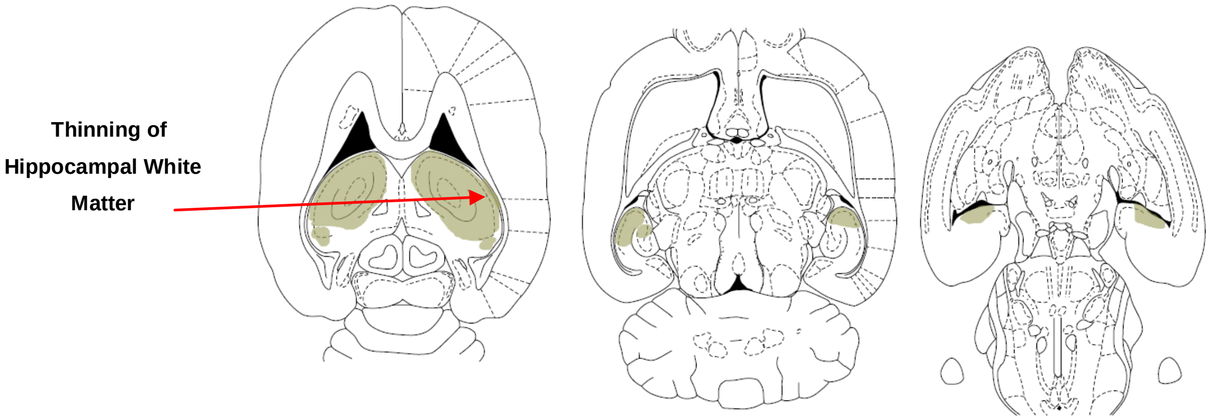


Figure 3.3: Partial HPC Group: Horizontal Sections (starting at Bregma -3.10mm Interaural 6.90mm and finishing at Bregma -8.42mm Interaural 1.58mm) showing an individual animal (PHPC 5). Hippocampal cell loss is shaded gold. Thinning of Hippocampal White Matter is highlighted on the figure. See Table 3.1 for corresponding volume figures. Taken from Paxinos and Watson (2007).

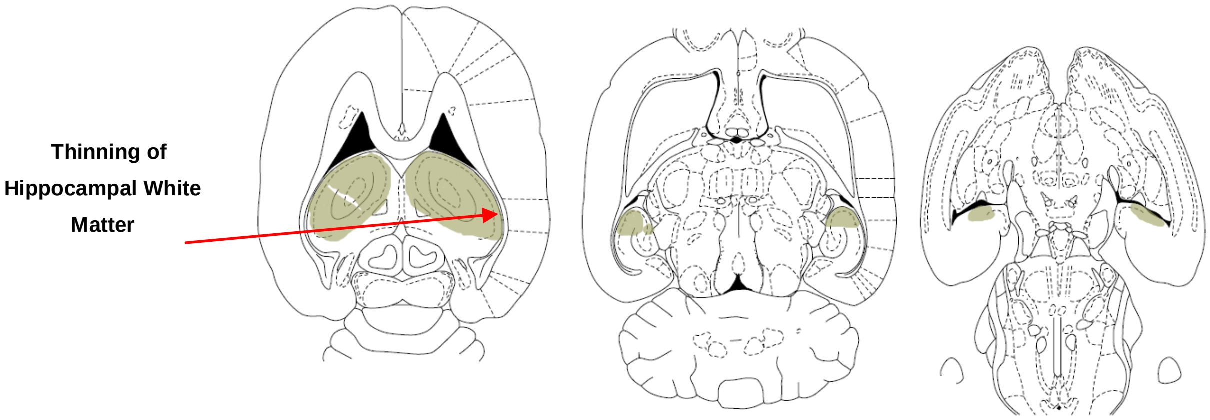


Figure 3.4: Partial HPC Group: Horizontal Sections (starting at Bregma -3.10mm Interaural 6.90mm and finishing at Bregma -8.42mm Interaural 1.58mm) showing an individual animal (PHPC 11). Hippocampal cell loss is shaded gold. Thinning of Hippocampal White Matter is highlighted on the figure. See Table 3.1 for corresponding volume figures. Taken from Paxinos and Watson (2007).

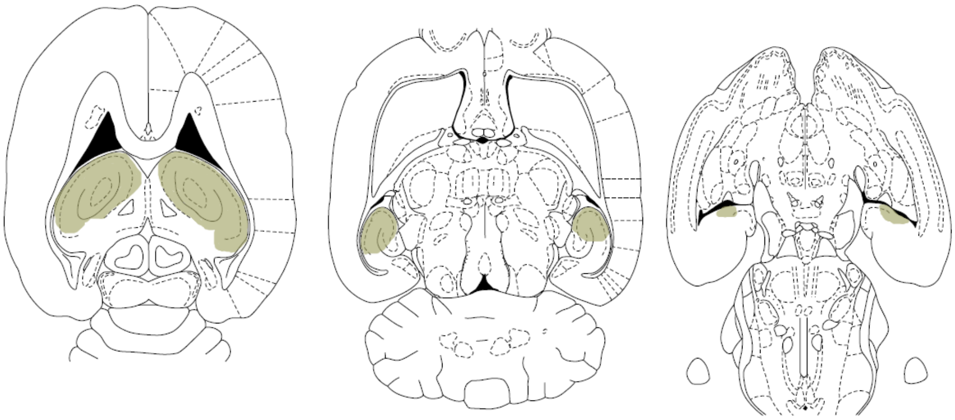


Figure 3.5: Partial HPC Group: Horizontal Sections (starting at Bregma -3.10mm Interaural 6.90mm and finishing at Bregma -8.42mm Interaural 1.58mm) showing an individual animal (PHPC 15). Hippocampal cell loss is shaded gold. See Table 3.1 for corresponding volume figures. Taken from Paxinos and Watson (2007).

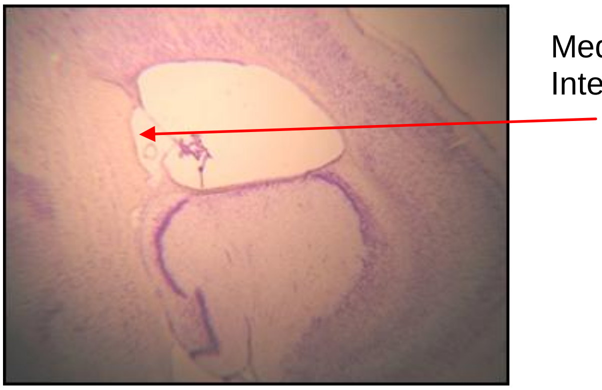
Displacement of structures and gliosis possibly caused by partial hippocampal cell loss was noted in three of the above animals. Displacement was found in the areas of the lateral amygdaloid nucleus (see Figure 3.6), the stria terminalis (see Figure 3.7) and the globus pallidus (see Figure 3.8).

Lateral Amygdaloid
Nucleus Displaced

Figure 3.6: Photograph of Nissl-stained horizontal section showing an expanded right ventricle in an animal from the Partial HPC group. The expanded right ventricle has caused the lateral amygdaloid nucleus to be displaced as highlighted. Unknown if gliosis originates from slight hippocampal damage.

Stria Terminalis Displaced

Figure 3.7: Photograph of Nissl-stained horizontal section showing an expanded right ventricle in an animal from the Partial HPC group. The expanded right ventricle has caused the stria terminalis to be displaced as highlighted. Unknown if gliosis originates from slight hippocampal damage.



Medial Globus Pallidus and
Internal Capsule Displaced

Figure 3.8: Photograph of Nissl-stained horizontal section showing an expanded right ventricle in an animal from the Partial HPC group. The expanded right ventricle has caused the internal capsule and medial globus pallidus to be displaced. Unknown if gliosis originates from slight hippocampal damage.

Figures 3.6 to 3.8 shows evidence of displacement of certain structures due to the expansion of the ventricles. It is more likely that the gliosis near to these areas actually originates from slight hippocampal cell loss rather than actual damage to surrounding structures.

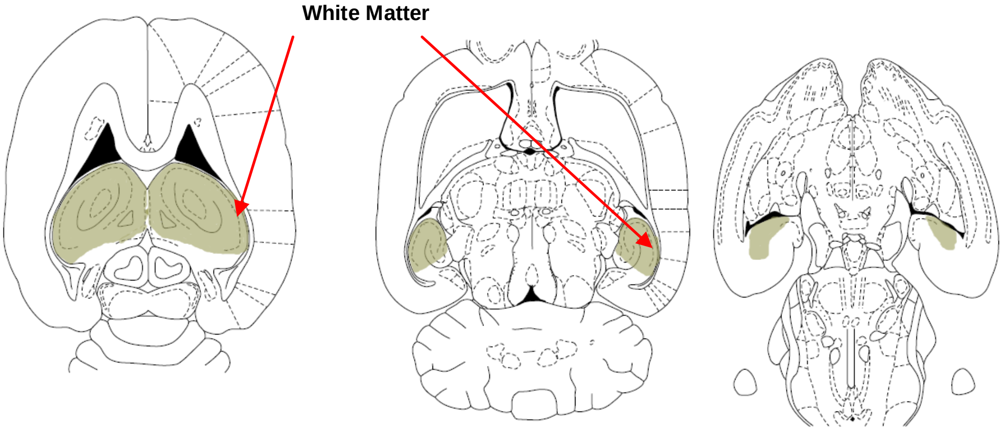
3.2.2.1.2 Hippocampal Lesion Group (HPC) (n = 5)

Those 5 animals that were included, whose lesions were sufficient with regard to the aim of the study, had lesions ranging from 70% to 75.2% (see Table 3.2 and Figures 3.9 to 3.13). This group is to be referred to as the HPC group (n = 5). The lesions extended from 3.10mm to -8.42mm posterior to Bregma.

Table 3.2: Percentage of damage for animals considered sufficient to be regarded as a full hippocampal lesion.

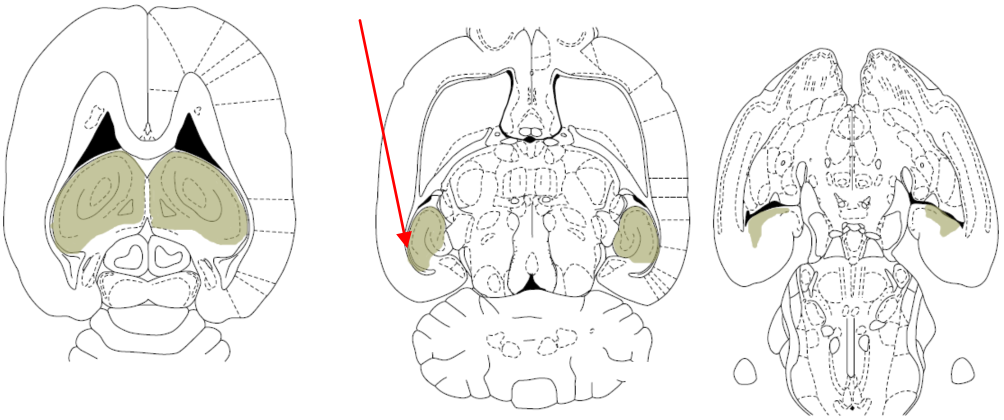
Animal		Hippocampus			Subiculum			Parietal Cortex			Hippocampal White Matter		
		L %	R %	**M**	L %	R %	**M**	L %	R %	**M**	L %	R %	**M**
HPC 6	Bregma -3.10mm/Interaural 6.90mm	96	95	**95.5**	11	9	**10**	-	-	-	0	25	**12.5**
	Bregma -5.60mm/Interaural 4.40mm	84	89	**86.5**	0	0	**0**	-	-	-	0	43	**21.5**
	Bregma -8.42mm/Interaural 1.58mm	30	26	**28**	50	20	**35**	-	-	-	0	0	**0**
	Mean	**70**	**70**	**70**	**20.3**	**9.7**	**15.0**	-	-	-	0	**22.7**	**11.3**
HPC 9	Bregma -3.10mm/Interaural 6.90mm	98	97	**97.5**	17	14	**15.5**	-	-	-	0	0	**0**
	Bregma -5.60mm/Interaural 4.40mm	91	100	**95.5**	40	20	**30**	-	-	-	43	0	**21.5**
	Bregma -8.42mm/Interaural 1.58mm	26	35	**30.5**	23	17	**20**	-	-	-	0	0	**0**
	Mean	**71.7**	**77.3**	**74.5**	**26.7**	**17.0**	**21.8**	-	-	-	**14.3**	**0.0**	**7.2**
HPC 12	Bregma -3.10mm/Interaural 6.90mm	96	98	**97**	89	94	**91.5**	-	-	-	0	0	
	Bregma -5.60mm/Interaural 4.40mm	77	89	**83**	0	0	**0**	-	-	-	0	0	**0**
	Bregma -8.42mm/Interaural 1.58mm	48	43	**45.5**	37	30	**33.5**	-	-	-	0	0	**0**
	Mean	**73.7**	**76.7**	**75.2**	**42.0**	**41.3**	**41.7**	-	-	-	0	0	**0**
HPC 13	Bregma -3.10mm/Interaural 6.90mm	97	93	**95**	74	69	**71.5**	-	-	-	0	0	**0**
	Bregma -5.60mm/Interaural 4.40mm	81	95	**88**	0	0	**0**	-	-	-	17	0	**8.5**
	Bregma -8.42mm/Interaural 1.58mm	35	26	**30.5**	10	7	**8.5**	-	-	-	0	0	**0**
	Mean	**71**	**71.3**	**71.2**	**28**	**25.3**	**26.7**	-	-	-	**5.7**	**0.0**	**2.8**
HPC 18	Bregma -3.10mm/Interaural 6.90mm	98	100	**99**	83	94	**88.5**	-	-	-	0	0	**0**
	Bregma -5.60mm/Interaural 4.40mm	66	95	**80.5**	0	0	**0**	-	-	-	0	0	**0**
	Bregma -8.42mm/Interaural 1.58mm	52	39	**45.5**	13	10	**11.5**	-	-	-	0	0	**0**
	Mean	**72**	**78**	**75**	**32**	**34.7**	**33.3**	-	-	-	0	0	**0**

Figure 3.9: HPC Group: Horizontal sections (starting at Bregma -3.10mm Interaural 6.90mm and finishing at Bregma -8.42mm Interaural 1.58mm) showing an individual animal (HPC 12). Hippocampal cell loss is shaded gold. See Table 3.2 for corresponding volume figures. Taken from Paxinos and Watson (2007).



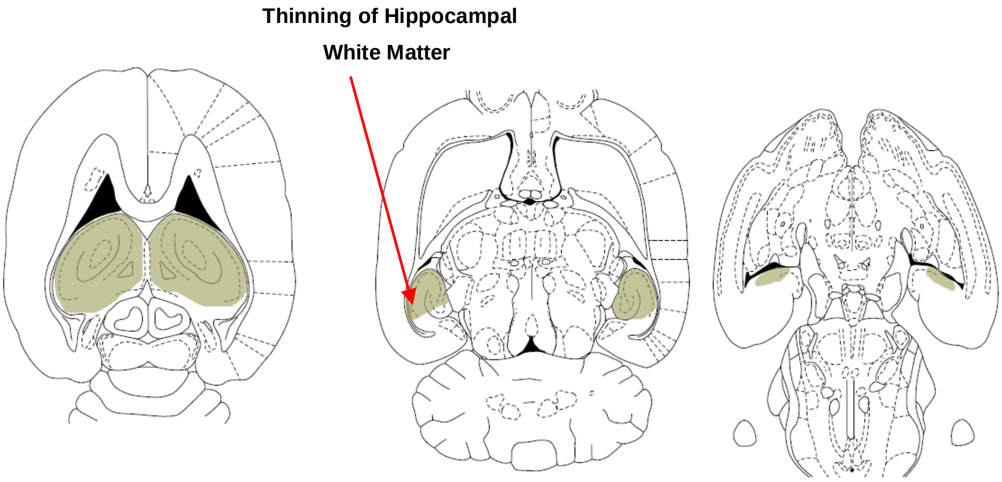
Thinning of Hippocampal White Matter

3.10: HPC Group: Horizontal Sections (starting at Bregma -3.10mm Interaural 6.90mm and finishing at Bregma -8.42mm Interaural 1.58mm) showing an individual animal (HPC 6). Hippocampal cell loss is shaded gold. Thinning of Hippocampal White Matter is highlighted on the figure. See Table 3.2 for corresponding volume figures. Taken from Paxinos and Watson (2007).



Thinning of Hippocampal White Matter

Figure 3.11: HPC Group: Horizontal Sections (starting at Bregma -3.10mm Interaural 6.90mm and finishing at Bregma -8.42mm Interaural 1.58mm) showing an individual animal (HPC 9). Hippocampal cell loss is shaded gold. Thinning of Hippocampal White Matter is highlighted on the figure. See Table 3.2 for corresponding volume figures. Taken from Paxinos and Watson (2007).



Thinning of Hippocampal White Matter

Figure 3.12: HPC Group: Horizontal Sections (starting at Bregma -3.10mm Interaural 6.90mm and finishing at Bregma -8.42mm Interaural 1.58mm) showing an individual animal (HPC 13). Hippocampal cell loss is shaded gold. Thinning of Hippocampal White Matter is highlighted on the figure. See Table 3.2 for corresponding volume figures. Taken from Paxinos and Watson (2007).

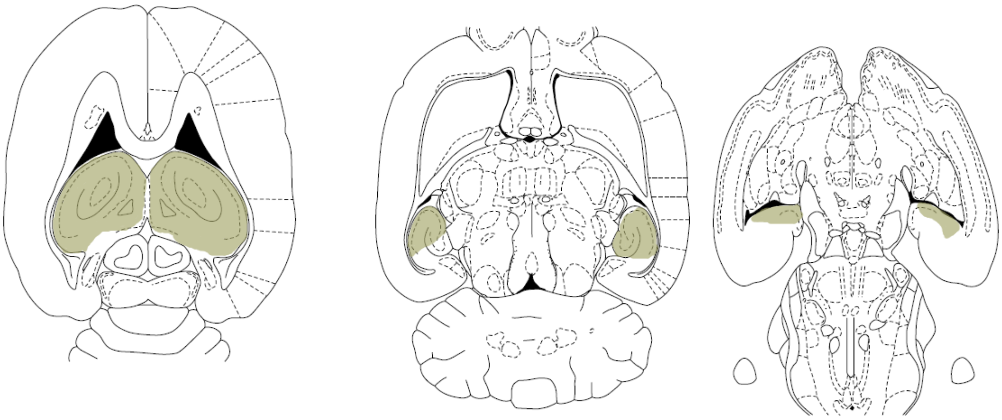


Figure 3.13: HPC Group: Horizontal Sections (starting at Bregma -3.10mm Interaural 6.90mm and finishing at Bregma -8.42mm Interaural 1.58mm) showing an individual animal (HPC 18). Hippocampal cell loss is shaded gold. See Table 3.2 for corresponding volume figures. Taken from Paxinos and Watson (2007).

Displacement of structures and gliosis possibly caused by partial hippocampal cell loss was noted in two of the above animals. Displacement was found in the areas of the Stria Terminalis (see Figure 3.14) and slight damage was noted to the lateral septal nuclei (see Figure 3.15).

Figure 3.14: Photograph of Nissl-stained horizontal section showing an expanded right ventricle in an animal from the HPC group. The expanded right ventricle has caused the stria terminalis to be displaced as highlighted. Unknown if gliosis originates from slight hippocampal damage.

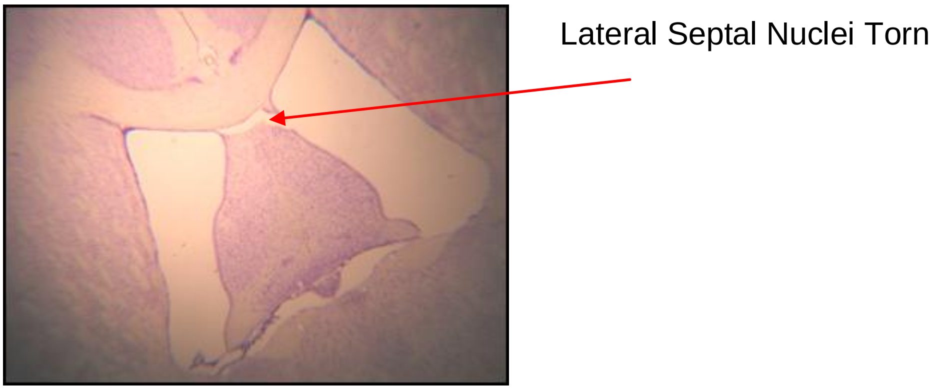


Figure 3.15: Photograph of Nissl-stained horizontal section from an animal from the HPC group showing a tear in the lateral septal nuclei.

Figures 3.14 and 3.15 show evidence of the displacement of the stria terminalis due to the expansion of ventricles and damage to the lateral septal nuclei. It is unclear if the latter is caused by the histological process. Visible gliosis is likely to originate from slight hippocampal cell loss rather than actual damage to surrounding structures. Damage to the lateral septal nuclei did not appear to affect the behaviour of the animal in any notable way.

3.2.2.2 Objects Visible

All statistical analyses reported are 2 tailed. All figure legends include calculated standard error means (SEM) indicated by error bars. Symbol (*) indicates significance ≤ 0.05. Where multiple t-tests are conducted Bonferroni corrections are made. Regarding tests for correlations, outliers were considered such if they were ± 2 SD's away from the mean).

3.2.2.2.1 First Turn Data

First Turn Data in the Objects Visible stage reveals which object the animals explored first, be it the habituated or relatively novel (RN) object. Analyses reveal that over 16 days of Objects Visible neither the Sham group (t (7) = 1.680, p = 0.137), the HPC group (t (4) = -0.720, p = 0.512), nor the Partial HPC group (t (4) = 0.791, p = 0.473) showed a significant preference for turning towards the RN object for their first turn with mean percentage correct scores of 56.3, 44.4 and 54.4 respectively.

3.2.2.2.2 D2 Scores

D2 scores in the Objects Visible stage, indicate if the animals are showing any object preference. Over the 16 days of Objects Visible, the Sham group show a preference for exploring the RN object (t (7) = 2.844, p = 0.025) with a mean D2 score of 0.08. The HPC group (t (4) = -1.149, p = 0.315) and the Partial HPC group (t (4) = 1.966, p = 0.121) showed no such preference with mean D2 scores of -0.11 and 0.07 respectively indicating the variance between the groups.

A one-way ANOVA shows that there is an effect of group on average D2 scores (F (2,15) = 3.757, p = 0.048). An alpha corrected (Bonferroni) independent t-test (p ≤ 0.016) revealed that this difference lies between the performance of the Sham group and the HPC group (t (11) = 2.327, p = 0.013). Analyses of the differences between the other groups did not yield significant results (see Figure 3.16).

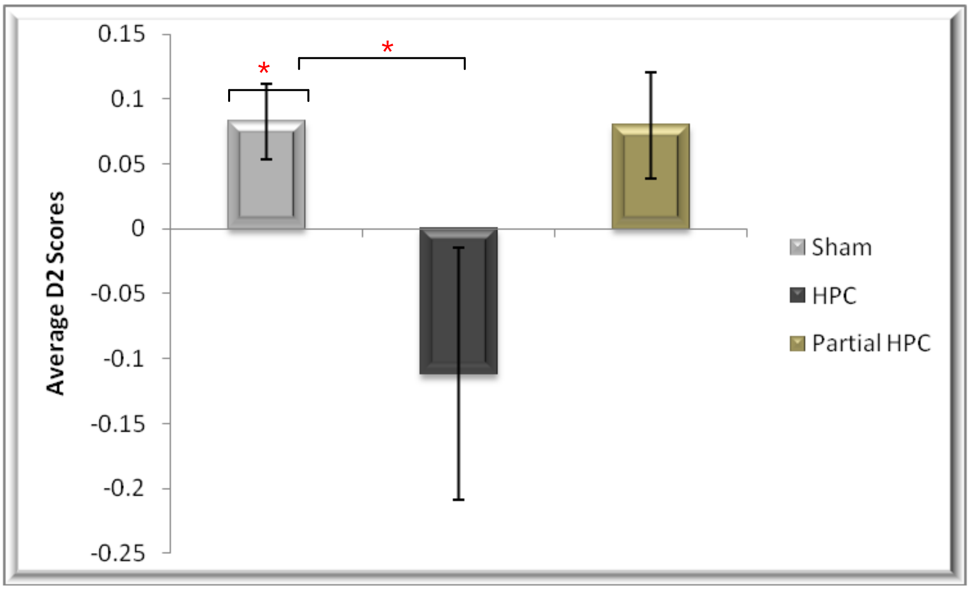


Figure 3.16: Objects Visible: Average D2 Scores (± SEM)

3.2.2.2.3 Relationship between first turn data and D2 scores

The above results appear to show that First Turn data and average D2 scores do not always reflect each other. It would be expected for the Sham group that high D2 scores would be reflected in high levels of performance in First Turn data and vice versa, however, over 16 days the Sham group do in fact show a preference for exploring the RN object, yet their performance on First Turns is at chance. In fact, the Sham group almost approach a significant negative correlation between their average First Turn data over the 16 days and their average D2 scores over the 16 days (n = 8, r = -0.706, p = 0.051). This suggests that despite the fact they showed a preference for exploring the RN object, they did not turn toward the RN object first. They only showed this preference after exploring the original habituated object. No correlation was expected for the HPC group as recall (and so First Turn data) should be impaired. After removing an outlier according to the parameters stated previously, the HPC group showed no correlation between their average First Turn data over the 16 days and their average D2 scores over the 16 days (n = 4, r = -0.789, p = 0.211). Over these 16 days the HPC group did not show an object preference for the RN object, which was reflected in their relatively poor First Turn data. The Partial HPC group also showed no such correlation between their First Turn data and their D2 scores over the 16 days. There was no relationship between the direction of their First Turn and their object preference at exploration (n = 4, r = 0.565, p = 0.320).

As First Turn data is either correct or incorrect a correlation between D2 scores and First Turn data was conducted using average scores over the 16 days. This showed that overall for the three groups there was no relationship between the direction of their First Turn and their object preference at exploration (n = 17, *r* = -0.073, p = 0.780).

3.2.2.2.4 Exploration Times

Despite the aforementioned results, it is possible that First Turn scores can be affected by noise at the time of turning. Any noise at this stage may cause the animal to freeze or react differently to what is considered their normal behaviour. It is also possible that D2 scores can hide the true nature of exploration. Exploration of 1 second of the RN object and no exploration of the habituated object would lead to a perfect positive D2 score, yet it hides the fact that exploration was poor. One way to overcome this is to look at exploration times.

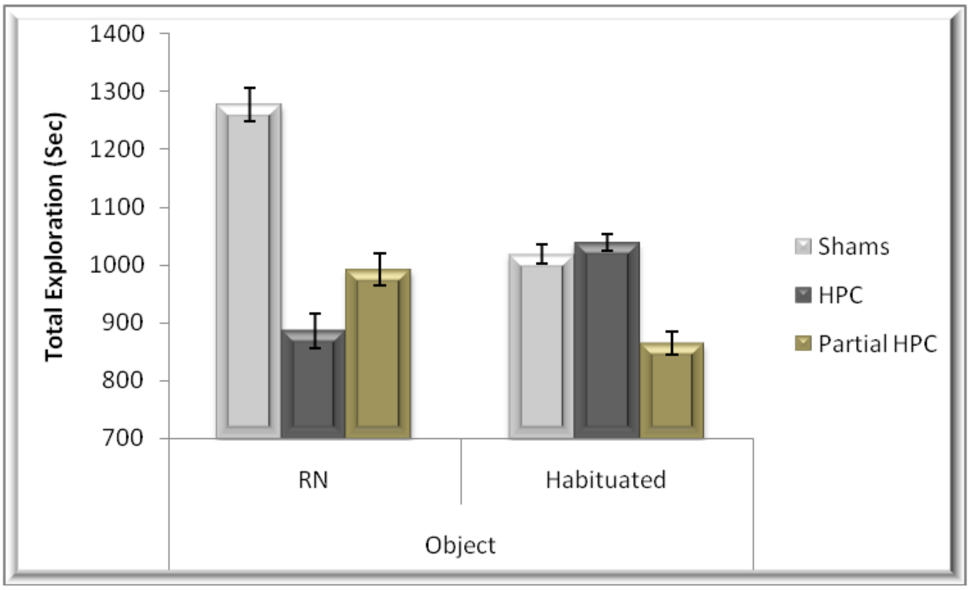


Figure 3.17: Objects Visible: Total Exploration time (± SEM) of each group for the RN and Original object.

Figure 3.17 above shows the differences in explorations times for each group for both the RN object and the Habituated object.

A repeated measures ANOVA (3x2: 3 x group, 2 x object) reveals that there is no effect of object on exploration (F (1,15) = 0.499, p = 0.491), no interaction between object and group (F (2,15) = 2.323, p = 0.491) and no effect of group overall (F (2,15) = 1.669, p = 0.222).

Although these differences between the groups regarding exploration times was not significant, the actual difference highlights the need to analyse exploration times along with D2 scores. It also raises a question for future analyses as to whether exploration is higher in the Objects Visible task compared to the Objects Hidden task. This will lead to further questions regarding habituation times and the length of tasks.

Over the 16 days of Objects Visible only the Sham group showed a preference for exploring the RN object, however, exploration was still high, therefore the task was changed to Objects Hidden. It was theorised that a change in task may increase interest and boost performance.

3.2.2.3 Objects Hidden

3.2.2.3.1 First Turn Data

Over 16 days of Objects Hidden neither the Sham group (t (7) = -0.733, p = 0.487), the HPC group (t (4) = 0.526, p = 0.627), nor the Partial HPC group (t (4) = -1.304, p = 0.262) showed a significant preference for turning towards the RN object for their first turn with mean percentage correct scores of 46.5, 47.5 and 42.5 respectively.

3.2.2.3.2 D2 Scores

D2 scores show that over 16 days of Objects Hidden the Sham group did not show familiarity of the RN object (t (7) = 0.682, p = 0.517) with an overall mean D2 score of 0.05. The HPC group (t (4) = 1.009, p = 0.37) and the Partial HPC group (t (4) = 0.757, p = 0.491) also showed no preference for exploring the RN object, with mean D2 scores of 0.08 and 0.03 respectively.

Unlike in the Objects Visible phase, a one-way ANOVA shows that there is no effect of group on performance (F (2,15) = 0.098, p = 0.907).

3.2.2.3.3 Relationship between First Turn data and D2 scores

A significant positive correlation was found between average First Turn Data and D2 scores over the 16 days for the groups overall (n = 18, r = 0.523, p = 0.026). Corresponding analysis of residuals employing a one-sample Kolmogorov-Smirnov test revealed the data to be normally distributed (n = 18, d = 0.958, p = 0.508). As individual groups however, it was only the Sham group that neared a significant correlation between First Turn and D2 scores (n = 8, r = 0.690, p = 0.058).

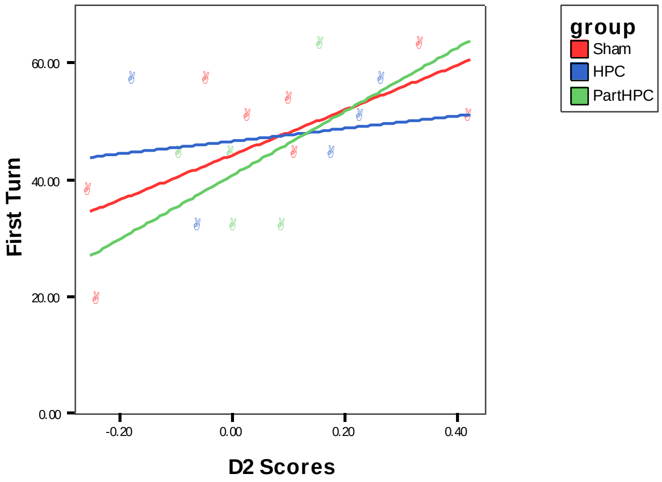


Figure 3.18: Objects Hidden: Significant positive correlation between First Turn and D2 Scores over 16 days for all 3 groups.

Although First Turn data and D2 scores are positively correlated for the three groups as a whole over the 16 days of Objects Hidden (Figure 3.18), this may not necessarily equate to a successful episodic-like task.

3.2.2.3.4 Exploration Times

As mentioned previously, First Turn data and D2 scores can be affected by noise and the mathematical nature of the D2 score can hide the true extent of exploration and therefore familiarity of an object. Analysis of exploration times therefore gives a clearer picture of the animals behaviour.

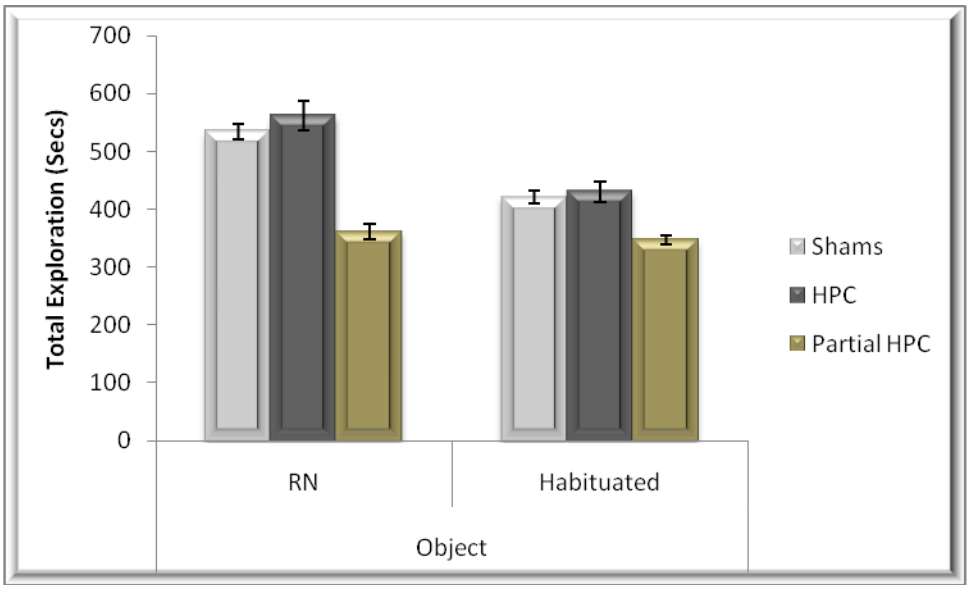


Figure 3.19: Objects Hidden: Total exploration time (± SEM) of each group for the RN and Original object.

Figure 3.19 shows the differences in exploration for the three groups regarding both objects.

A repeated measures ANOVA (3x2: 3 x group, 2 x object) determines that there is no effect of object type on exploration times (F (1,15) = 2.518, p = 0.133), no overall effect of group on exploration times (F (2,15) = 2.477, p = 0.118) and no interaction between object type and group (F (2,15) = 0.484, p = 0.626).

Comparisons of exploration times between those seen in the Objects Visible task to those in the Objects Hidden task will indicate if the animals' exploration times decrease after completing the Objects Visible task.

A repeated measures (3x4: 3 x group, 4 x Objects (RN Objects Visible; Original Objects Visible; RN Objects Hidden; Original Objects Hidden)) ANOVA show that there is no effect of group on exploration times for either object during both tasks (F

(2,15) = 2.000, $p = 0.170$), no interaction between group and object type during the two tasks (F (6,45) = 1.545, $p = 0.185$), yet there is an effect of object type on exploration times between the two tasks (F (3,45) = 49.360, $p \leq 0.001$).

Alpha corrected (Bonferroni) posthoc paired sample t-tests ($p \leq 0.004$) show that the Sham group explore the habituated object significantly more in the Objects Visible phase than in the Objects Hidden phase (t (7) = 6.311, $p \leq 0.001$) and also for the RN object (t (7) = 4.885, $p = 0.002$). The Partial HPC group, comparable to the Sham group again, also explored the habituated object and the RN object more so in the Objects Visible task (t (4) = 7.051, $p = 0.002$; t (4) = 8.366, $p = 0.001$ respectively). After correctional analyses the HPC group yielded no significant results.

When looking at exploration times it is also worthwhile to note if there is a difference between exploration in the first half of the test phase to the second half of the test phase. It could be possible that the majority of exploration is carried out in this first phase until such a point is reached where the novelty has worn off. If such a point exists then data should be analysed up until this point as this should reflect true object interest. Data from the Sham group in the Objects Hidden phase was used to investigate this theory further as this group consists of the greatest number of animals and will therefore increase the power of analyses. As the test phase was a total of two minutes, this was split up into the first and second minute.

Alpha corrected (Bonferroni) paired-sample t-tests ($p \leq 0.025$) showed that over the 16 days of Objects Hidden, the Sham group showed no significant difference in their preference (D2 scores) for exploring the RN object between the first minute and second minute of the test phase (t (7) = -0.085, p = 0.935). Yet, when looking at raw explorations times (seconds) ($p \leq 0.012$), the Shams actually explore the RN object and the Habituated object significantly less in the second minute compared with the first minute (t (7) = 4.275, p = 0.004; t (7) = 4.139, p = 0.004).

This data serves to highlight that although there may be no significant differences in D2 scores, raw exploration times tell a different story. However, as it has been shown previously that there is a positive correlation between First Turn data and D2 scores, it should be D2 scores that determine when object interest deteriorates and not exploration times. Raw exploration times may still prove useful in determining levels of exploration, considering that D2 scores, as stated previously, can hide the true extent of exploration.

3.2.3 Discussion

The current experiment aimed to investigate the effect of bilateral lesions to the hippocampus on episodic-like memory in a task which allows for recollection and familiarity to be dissociated. It was hypothesised that the HPC lesion group would perform at chance on the first turn (reflecting impaired episodic-like memory) but have intact D2 performance (reflecting intact familiarity) as previous studies have implicated the hippocampus in recollection but not familiarity (Fortin, et al., 2004; Langston & Wood, 2006; Manns, et al., 2003; Sauvage, Fortin, Owens, Yonelinas, & Eichenbaum, 2008). However, despite the successful replication of previous studies using this task (Eacott et al., 2005; Easton et al., 2009) in Chapter 2 with intact animals, the current experiment did not successfully demonstrate episodic-like memory in the Sham group making the failure to demonstrate episodic-like memory in the groups with partial or full hippocampal lesion groups difficult to interpret.

The Partial Hippocampal group consisted of 5 animals that were considered to have insufficient bilateral lesions to the hippocampus based on the criteria outlined previously (see Section 3.2.2.1.1.) Although these animals were grouped separately, it is nevertheless important to consider the implications of such partial lesions on any observed behaviour. One could suggest that those animals with incomplete lesions would behave akin to the Sham group considering the criteria for what constitutes a sufficient lesion. The histology also shows that these partial lesions tend to be more dorsal than ventral in their location. It is apparent from Table 3.1 (see Section 3.2.2.1.1.) that at its most dorsal measurement (Bregma -3.60mm/Interaural 5.40mm), hippocampal cell loss was greater than for the comparable ventral points measured (i.e. Bregma -8.42mm/Interaural 1.58mm). Previous studies have implicated the dorsal, not ventral hippocampus in spatial memory tasks (Bannerman et al., 1999; Bannerman et al., 2002a; Bannerman et al., 2002b; Bannerman et al., 2004; Hock & Busney, 1998; Kjelstrup et al., 2002; McHugh, Deacon, Rawlins & Bannerman, 2004; Pothuizen, Zhang, Jongen-Relo, Feldon & Yee., 2004), although other studies have suggested that the ventral hippocampus may contribute to spatial learning at least under some conditions (De Hoz, Knox & Morris, 2003; Ferbinteanu & McDonald, 2000; Ferbinteanu, Ray & McDonald, 2003). However, the effect of dorsal versus ventral lesions on episodic tasks such as those presented here is not known. In addition, the partial lesions in the current study were not targeted partial lesions and so cannot be considered as either dorsal or ventral. It is therefore not possible with the current data to predict the effect of such partial lesions on episodic memory and any associated interpretations must be treated with caution.

Although the results are not in agreement with previous findings, there are several noteworthy points to discuss that appear to suggest that although none of the three groups show episodic-like memory, it is not due to an ineffective task, but rather it is due to extraneous factors affecting the performance of all three groups. This suggestion stems from some interesting results in both the Objects Visible and Objects Hidden phase of the task. In-depth analyses of not only First Turn scores and D2 scores, but also of exploration times reveal that the Sham group and the Partial HPC group appear to behave comparably throughout the task, with significant differences in performance lying between the Sham and HPC lesion group in the Objects Visible task. This also is taken as validation for the groupings of the animals based on the criteria outlined previously in the chapter.

To summarise, after 16 days of Objects Visible neither the Sham group, the Partial HPC group nor the HPC group showed a preference for turning toward the RN object. However, the Sham group did show an object preference which was a significantly better performance than the HPC group. Animals in the HPC group appeared to behave in the opposite manner and tended to explore the habituated object more so than the RN object, although not significantly so. This may signify outside stressors impacting on performance levels. Performance of the Partial HPC group, although tentatively comparable (due to low numbers) to the Sham group, did not reach above chance levels. Analyses of exploration times during this Object Visible stage again did not yield significant results, although to an observable extent (see Figures 3.16 (section 3.2.2.2.2.) and 3.17 (section 3.2.2.2.4.) to highlight) the HPC group remain fairly distinct with regard to their exploration of the habituated object.

Further analyses in the Objects Visible stage aimed to clarify the relationship between First Turn data and D2 scores as the aforementioned results appear to suggest that they do not always reflect each other. It would be expected for the Sham group that high D2 scores would be reflected in high levels of performance in First Turn data and vice versa. Overall for all three groups over the 16 days there was found to be no relationship between the direction of their first turn and their object preference at exploration. In fact the Sham group approach a significant negative correlation between their average First Turn over the 16 days and their average D2 scores suggesting that despite the fact that they showed a preference for exploring the RN object, they did not turn towards the RN object first.

After 16 days of Objects Hidden neither the Sham group, the Partial HPC group or the HPC group demonstrated episodic-like memory using recall alone. D2 scores reveal that none of the groups show significant familiarity for the RN object. First Turn data and D2 data was significantly correlated for all three groups over the 16 days of Objects Hidden, however it was only the Sham group that approached a positive correlation i.e. continued to explore the RN object after it had made its first turn. Indeed a positive correlation would be hypothesised for the Sham group as unlike the HPC group, both familiarity (D2 scores) and recall (First Turn data) remain intact.

Exploration times show that there are no significant differences or interactions regarding exploration of the objects for each group during the Objects Hidden phase. It was hypothesised that a change in task from Objects Visible to Objects Hidden may increase interest and boost performance. However, when comparing exploration in the Objects Visible phase to that in the Objects Hidden stage, both the Sham and Partial HPC group explore both objects significantly more in the Objects Visible phase. It is possible that the change in task was not novel enough in nature, or that the poor performance in the Objects Visible phase was highlighted in the more difficult Objects Hidden phase.

The Sham group also show no difference in exploration times (D2 scores) between the first and second minute of exploration yet when using raw exploration times (seconds) the Sham group are actually found to explore both objects significantly less so in the second minute compared to the first minute of the test phase. This serves to show that even though there may be significant differences in exploration times this does not necessarily result in a significantly positive or negative D2 score. Even though some of the results from this study appear to suggest that First Turn scores do not always mirror themselves in D2 scores, the significant positive correlation between First Turn and D2 scores, and the fact that significant differences in exploration times do not equate to significant D2 scores, it actually should be D2 scores that determine object familiarity.

Despite the fact that the low numbers of animals contribute to a deficit in power of analyses, the data summarised above still provides a few useful points for discussion. The similarities in the behaviour of the Sham and Partial HPC group and the significant difference found between the Sham and the HPC group in the Objects Visible task appear to validate the histological groupings and suggest the possibility that these partial lesions would not be substantial enough to have a significantly different effect on episodic-like memory. This is also reinforced by the exploratory behaviour of the HPC lesion group noted in the Objects Visible phase of the task. This suggests that the observed parietal damage noted in the coronal sections (see section 3.2.2.1.1) is not representative of all the animals. If this were the case then all animals in both groups should show a comparable deficit.

It is not thought that such damage is a result of the chosen surgical procedure as previous studies (Jones, Pearce, Davies, Good, & McGregor, 2007; McGregor, Good, & Pearce, 2004; Pearce, Good, Jones, & McGregor, 2004) have employed the same surgical procedure successfully. It is also not believed to be a result of seepage of excitotoxin along the injection tracts in the overlying cortex. If this was the case it would be expected that only the associated parietal cortex overlying the dorsal region only would be damaged, yet Figure 3.1 (see Section 3.2.2.1.1.) shows that the damage is not uniformly distributed as where there is most dorsal hippocampal cell loss no such parietal cortex damage is seen. Additionally, the rate of infusion (0.03 µl/min) was considerably slower, and the needle left in place longer, than in many other studies that employed hippocampal lesions, but with no reported cortical damage (e.g. Gilbert, Kesner, & Lee, 2001). It is deemed possible that experimental error, such as mechanically piercing the dura prior to insertion of the needle, may be the cause of the damage to the overlying parietal cortex. In addition, any thinning or loss in density of the temporal lobe may allow for damage post-histology. Although it is not possible to quantify the degree of parietal cortex damage in those sliced horizontally, observations by the surgeon of the perfused brains prior to slicing suggested no severe parietal damage.

The impact of extraneous stressors such as noise on First Turn scores and overall exploration needs to be considered. Indeed the behaviour of the HPC group may be compounded by such issues. In fact there is evidence that infrasound exposure can lead to an impairment of hippocampal related learning and memory (Yuan et al., 2009; Yuan, Long, Mu, Liu, & Chen, 2009). During the current study it was noted that there was building work being carried out in the vicinity of the laboratories, therefore even if the experimenter was not able to hear such noise it is possible that the animals detected such infrasounds and their behaviour was subsequently affected. Considering that the Sham group showed a preference for the RN object during the Objects Visible stage it would have been expected that this performance would then transfer over to the Objects Hidden stage and exhibit itself as episodic-like memory. However, if such noise was detectable to the animals then this may have caused stress induced neophobia and resulted in the unexpected result of the animals preferring to explore the habituated object more so than the RN object during the Objects Hidden stage.

Another interesting point that extends from the post-hoc analyses is the fact that there was found to be a significant decrease in exploration from the Objects Visible to the Objects Hidden stage for both the Sham and Partial HPC group. This could be considered unexpected if one were to theorise that a change in task would lead to a renewed interest in the task. If this were the case then exploration should increase from one stage to another which may then lead to an increase in performance. The Sham group were demonstrating preference for the RN object during the Objects Visible stage and so would have been expected to be able to transfer this performance to the Objects Hidden phase. As this was not the case and performance actually decreased, the assumption that the task was unsuccessful due to extraneous factors is to an extent supported.

The slightly poorer results seen in the replication in chapter 2 combined with the low power of the current study may explain the failure to see significant results here. Despite this task having been replicated on more than one occasion (Easton, Zinkivskay, & Eacott, 2009; Easton, Eacott, Zinkivskay, & Jiménez-Rodriguez, 2006), the current findings seem to highlight the sensitivity of such a task to extraneous factors, preventing the planned investigation into the individual components of episodic-like memory in this task. Awareness of these issues and investigation of the factors which affect performance in this task is of importance to future research.

However, given the difficulties with the current task, it was appropriate to alter the methodology and conduct the behavioural experiments in the open field. It is based the natural tendency of an animal to explore its environment and has also previously been shown to be successful over fewer testing days (Norman & Eacott, 2005) allowing it to be a more robust test of episodic-like memory.

4 WHAT-WHERE-WHICH IN THE OPEN FIELD

4.1 Introduction

Considering the results of Chapter 3 it was deemed appropriate to move from using the E-maze to the Open Field in order to further investigate the effect of bilateral lesions to the hippocampus on episodic-like memory.

The justification for which lies in the fact that it has demonstrated its reliability in previous tasks (e.g. Ainge, et al., 2006; Eacott & Gaffan, 2005; Eacott & Norman, 2004; Langston & Wood, 2006; Norman & Eacott, 2005). In addition as there is no Objects Hidden stage, First Turn data plays no role, therefore any extraneous variables potentially affecting performance should present themselves in exploratory behaviour only. Previous studies have also shown that the Open Field allows for complete experiments to be carried out over shorter periods than the E-maze requires (Norman & Eacott, 2005). This change in procedure will also allow for any reflections to be made regarding what would be the best *modus operandi* for such tasks.

4.2 Experiment 4a

The Open Field arena is a common apparatus used to assess an animals' exploratory behaviour. Although the E-maze can demonstrate episodic-like memory using recall alone using the same animals in the same trial, Eacott and Gaffan (2005) argued that the Open Field to an extent is also able to differentiate between recall and familiarity. As this arena has proved successful in similar tasks (Langston and Wood, 2009) it was deemed a suitable and justified change in methodology. In addition, previous studies (Norman & Eacott, 2005) have also shown that experiments can be carried out successfully over substantially shorter four day periods allowing for potential manipulations to the methodology to be carried out more efficiently.

Despite the change in arena type, there was no change in task type as the results from the previous chapter point to extraneous factors impacting on performance rather than an ineffective task. In addition, if any impairment is seen in this task it would be then possible to conduct tasks of a more simple nature in the hope of pinpointing the location of the impairment to one or possibly more individual components of episodic-like memory.

4.2.1 Methods and materials

4.2.1.1 Subjects

The twenty Dark Agouti rats were the same animals that underwent the surgery detailed in Chapter 3. However, at the end of Chapter 3, two animals from the Partial HPC group were euthanized after developing seizures. Consequently, the Partial HPC group consisted of three animals. Considering the effect that such a small number of animals would have on the power of any analyses conducted, and that Chapter 2 highlighted their similarity to the Sham group, this group was excluded from any further analyses.

4.2.1.2 Apparatus

4.2.1.2.1 Open Field

The Open Field used in this task measured 19.5 x 39.5 x39.5 inches. Made from mdf the walls and the floor were coloured grey. This served as context X. Removable white Perspex walls and a white Perspex floor with a metal mesh covering were inserted over the grey context and held in place by hooks to form context Y.

4.2.1.2.2 Objects

As before, objects consisted of three items (e.g. lego or toys) put together to form a more complex object. Three copies of each object were made, one for use in the acquisition phases and two for use at test.

4.2.1.2.3 Objects and the Open Field

Objects were placed in the maze 10 inches from the side walls and 10 inches from the top and bottom walls at all times. Slight indentations were made in the Open Field for the experimenter to know where exactly to place the objects but were not visible to the animal as objects were placed over them. Rats were placed at the centre point of the maze facing forward (forward is indicated by the green S in Figure 4.1). All object exploration was recorded. The criterion for exploration was the nose of the rat touching the object this. Exploration was measured from video footage using a stop watch.

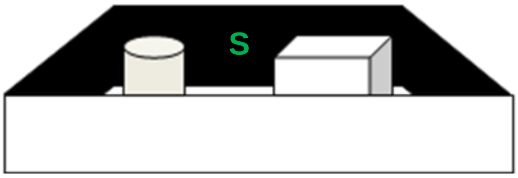


Figure 4.1: Sample Phase 1

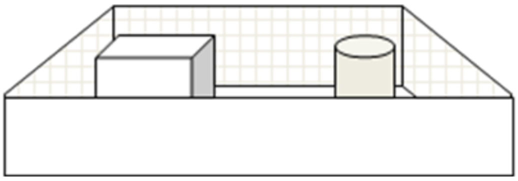


Figure 4.2: Sample Phase 2

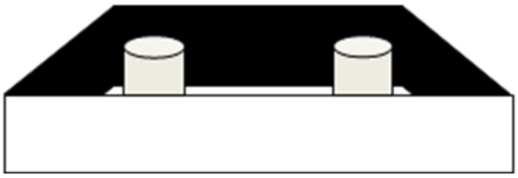


Figure 4.3: Test Phase

Figures 4.1 to 4.3 illustrate the Open Field and the locations of the objects in the two sample phases and the test phase.

4.2.1.2.4 Test Room and Experimenter

The testing room for tasks using the Open Field differed from that used in Chapter 2 and 3 and was larger and contained more workspace. Lighting consisted of two 25w bulbs shone off the walls of the room at an angle to ensure that the open field was equally lit in all areas and there were no shadowed corners. During the task the experimenter was sat out of sight in complete silence. Behaviour was observed on a monitor and recorded for analysis.

4.2.1.3 Design

The same design was used as in Chapter 2 with the additional counterbalancing described in Chapter 3 with regard to the two groups. Counterbalancing was adjusted when an animal was euthanised. The independent variables were therefore object location and context. The dependent variable measure was the amount of time spent exploring the object.

4.2.1.4 Data Collection

The same method of data collection was used as that described in Chapter 2 with regard to exploration.

4.2.1.5 Procedure

4.2.1.5.1 Habituation

Habituation to the new room and apparatus was carried out in stages to keep the stress levels of the animals to a minimum. In total twelve days of habituation were carried out. The first two days exposed the rats in their cage groups to the Open Field for 30 minutes with no objects present. The first day used context Y and the second context X. Days three to four exposed the rats to the Open Field individually for 10 minutes (no objects) and then to the holding cage for 10 minutes in context Y. The mesh floor of context Y for these two days was proving difficult to clean and so a larger mesh floor was used to replace it. Days 5 to 6 followed the same procedure using context X. Days seven to eight used context Y but with the new mesh floor. The final four days (days nine to twelve) followed the same procedure but with objects placed in the Open Field. The context was alternated XYXY.

4.2.1.5.2 Cleaning Procedure and Object Details

The cleaning procedure followed was that used in Experiments 2b and 2c of Chapter 2 (until stated otherwise). Objects used during the sample phases were cleaned after every cage and objects used during the test phase were cleaned after every animal. Habituation cages were cleaned after every cage and these cages were changed after the third cage. The Open Field was cleared of any mess after each animal and was also cleaned at the end of every testing day. Context X was wiped with a dry paper towel and the Perspex Context Y was wiped with alcohol wipes.

4.2.1.5.3 What-Where-Which in the Open Field

After the habituation phase was complete a total of twelve days of What-Where-Which were conducted in the Open Field. This task involved two sample phases and a test phase. For the first sample phase (either in context X or Y) the rats were individually placed in the centre of the open field facing the far wall (see Figure 4.1), at an equal distance from each object. After two minutes they were removed from the open field and placed in the empty habituation cage while the context was changed. They were then returned to the Open Field for another two minutes to explore the objects in the second context with the objects in alternative positions (see Figure 4.2). For example, in context X object A would be on the left and B on the right while in context Y, B would be on the left and A on the right. After the second sample phase the rat was again placed in the empty habituation cage whilst the context and objects were changed. The test phase consisted of two minutes in the open field with either context X or Y and either two copies of object A or two copies of B (counterbalanced over rats and trials). For an illustration of this procedure refer to Figures 4.1 to 4.3.

4.2.2 Results

4.2.2.1 What-Where-Which (12 days)

All statistical analyses reported are 2 tailed. All figure legends include calculated standard error means (SEM) indicated by error bars. Symbol (*) indicates significance ≤ 0.05. Where multiple t-tests are conducted Bonferroni corrections are made.

4.2.2.1.1 D2 Scores

Average D2 scores over the 12 days of What-Where-Which in the open field showed that neither the Sham group (t (7) = 0.632, p = 0.547) nor the HPC group (t (4) = 0.741, p = 0.500) showed a significant preference for exploring the object in the novel what-where-which combination with mean D2 scores of 0.04 and 0.04 respectively. Therefore over these 12 days of What-Where-Which there was no demonstration of episodic-like memory from either of the two groups.

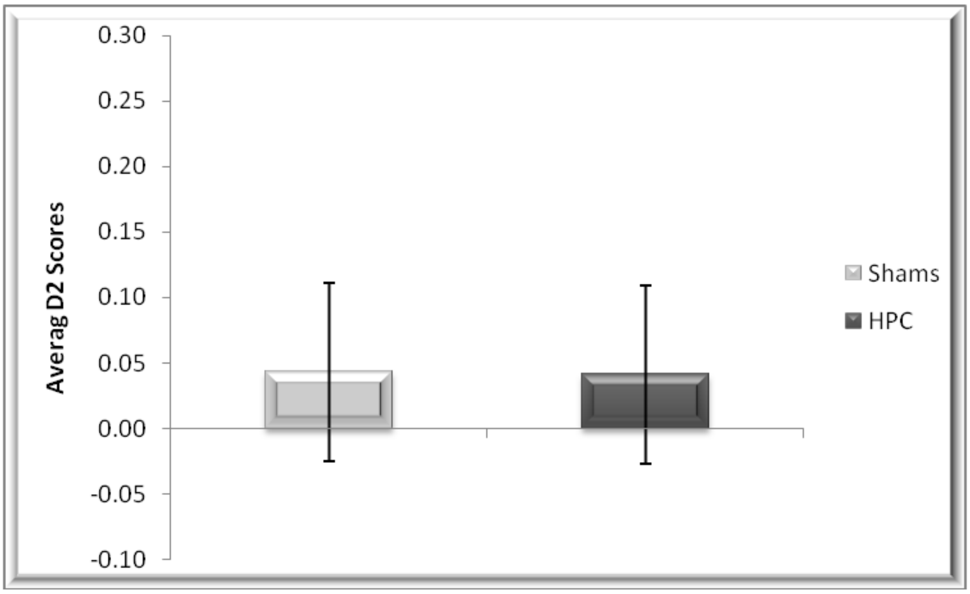


Figure 4.4: Average D2 Scores over 12 days of What-Where-Which (± SEM)

An independent t-test shows that there is no effect of group on average exploration time (t (11) = 0.018, p = 0.986).

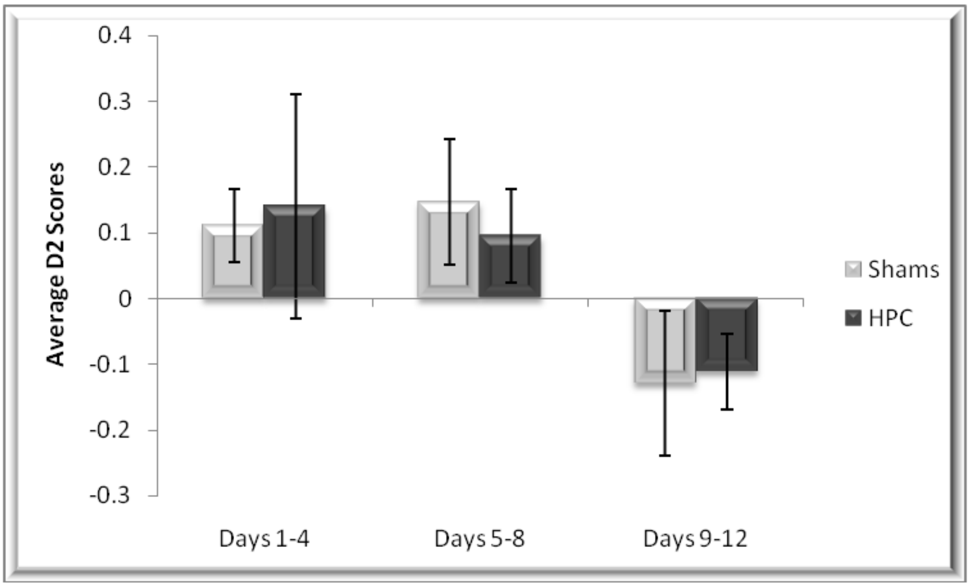


Figure 4.5: Average D2 Scores over 4 day blocks (± SEM)

Analysis of the average D2 scores over three blocks of four days reveals that exploration of the object in the novel what-where-which combination was at chance levels for both groups (see Figure 4.5).

A repeated measures ANOVA (2x3: 2 x group, 3 x block) revealed an effect of block on performance ($F (2, 22) = 4.650$, $p = 0.021$) but no interaction between block and group ($F (2, 22) = 0.116$, $p = 0.891$) and no effect of group on performance ($F (1, 11) = 0.003$, $p = 0.986$).

Alpha corrected (Bonferroni) paired samples t-tests ($p \leq 0.016$) reveal that there was no difference in performance from the first block of four days (days 1 to 4) to the second block of four days (days 5 to 8) ($t (12) = -0.064$, $p = 0.95$). There was however a marginal drop in performance from the first block of four days to the last block of four days (days 9 to 12) ($t (12) = 2.51$, $p = 0.027$) and a significant drop in performance from the second block of four days to the last block of four days ($t (12) = 3.38$, $p = 0.005$).

4.2.3 Discussion

Over the 12 days of What-Where-Which in the Open Field neither group demonstrated episodic-like memory. The nature of the task in the Open Field allows for experiments to be conducted over a minimum of four days. Analyses of the data in blocks of four days failed to demonstrate episodic-like memory in either group, although it is possible with larger group sizes and therefore greater statistical power that the trend observed may have reached significance. However, without such group sizes, this pattern can only be considered a possible trend at best.

The absence of any clear results could be due to a culmination of factors. Differences in variance and group size will also have an effect on such results considering the lower the group size the less powerful any subsequent analyses will be.

Despite this there may still be extraneous factors still having an effect on performance as not only could neither group demonstrate episodic-like memory even over a four day period, but also because overall performance dropped significantly during the last block of four days. However, it was not due to any stress placed upon the animals as there were no indictors of stress such as the animal remaining in a corner or the outskirts of the open field and not venturing into the centre. Despite the observed poor performance in the E-maze, it was hypothesised that a change in testing room may be compounding the issue as the new testing room was substantially larger than the previous room used in Chapters 2 and 3. The fact that the open field was therefore positioned further away from the walls of the testing room may mean that the rats are unable to use any landmarks that may be on the walls to aid their navigation in the open field. If this were the case then the animals would find it more difficult to relate an objects position in the open field relative to its position in space, which in turn may affect the amount of time spent exploring it. Considering the significant drop in overall performance during the last block of four days there are likely to be other factors affecting performance still unaccounted for. However, this issue must be addressed first to determine the level of impact it has had on performance.

In order to determine if landmarks could serve to boost performance of both groups another five days of What-Where-Which were carried out in the Open Field.

4.3 Experiment 4b

Considering the results of Experiment 4a, another five days of What-Where-Which were carried out in the Open Field with some modifications.

4.3.1 Methods and Materials

The same method was followed as described in Experiment 4a. With the possibility that the testing room was not providing the animals with enough landmarks to be able to navigate or position themselves as effectively as before in the open field, landmarks were positioned on two of the testing room walls that were closest to the Open Field. The two landmarks were A5 posters of distinct shapes, a black circle and a black and white striped rectangle. These were positioned at a height on the wall that made them visible from inside the Open Field. On a third wall of the room was a vent that could also act as a landmark. The final wall contained the door which was not visible from inside the open field. Five days of What-Where-Which were carried out with these new landmarks on the walls of the testing room. The first day was used as an habituation period to these landmarks and so only the final four days were analysed.

4.3.2 Results

4.3.2.1 Four days of What-Where-Which

Analysis of D2 scores revealed that over the four days of What-Where-Which the Sham group preferentially explored the object that was in the novel what-where-which location (t (7) = 2.725, p = 0.03) with a mean D2 score of 0.36. The HPC group (t (4) = 1.344, p = 0.25) did not show such a preference with mean D2 scores of 0.12 (see Figure 4.6).

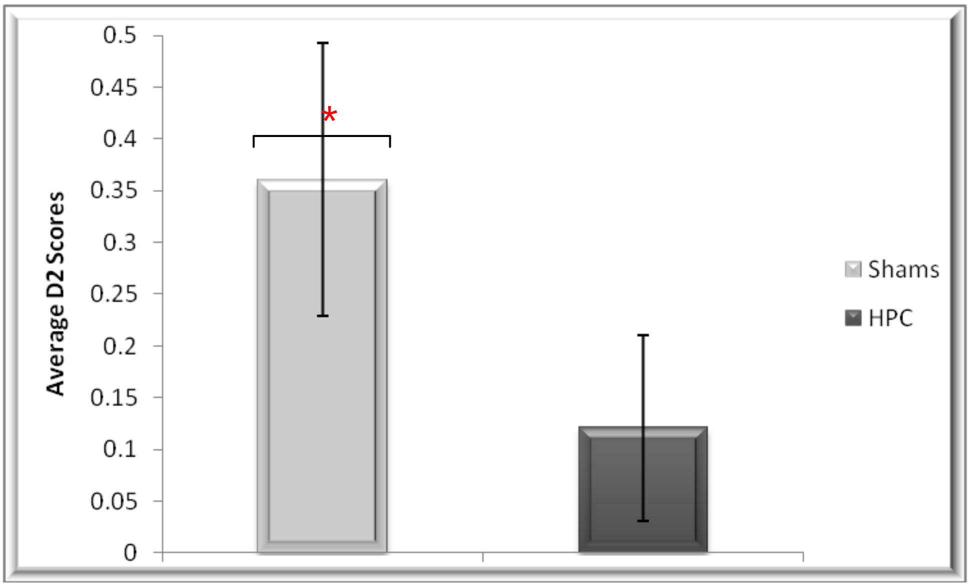


Figure 4.6: Average D2 Scores over 4 days of What-Where-Which (±SEM)

An independent t-test revealed there to be no differences between the exploration of the two groups (t (11) = 1.306, p = 0.218).

Despite the Sham group significantly preferring to explore the object in the novel what-where-which location, a repeated measures ANOVA (2x2: 2 x group, 2 x task (i.e. with or without landmarks)) revealed that there was no significant effect of these landmarks on average exploration (F (1, 11) = 2.577, p = 0.138) and no interaction between group and task (F (1, 11) = 0.921, p = 0.358).

4.3.3 Discussion

Although the results show that there was no significant improvement from Experiment 4a to 4b, the Sham group preferentially explored the object in the novel what-where-which location and so demonstrated episodic-like memory. Although the performance of the HPC group remained at chance levels there was found to be no significant difference in the performance of the two groups. However, unlike the previous experiment the average D2 score of the Sham group was higher than for the HPC group. Therefore, it cannot be concluded that the episodic-like memory as demonstrated in the Sham group and not in the HPC group is a consequence of the lesions to the hippocampus. As explained previously, variance in the groups and group size could certainly have an impact on the results.

Nevertheless, if the hippocampus is more involved in the process of recall, then a control What-Where task which can be solved using familiarity should see both the Sham, and the HPC groups performing above chance. If however, the hippocampus is equally involved in the familiarity circuit, only the Sham group should be performing above chance, whilst the HPC group should remain at chance level. Although without a significant difference shown in the performance of the two groups it is not possible to conclude definitively that any differences in the levels of performance are attributable to the lesions of the hippocampus. It may however provide indicators as to the performance of groups with larger numbers and therefore greater statistical power. Therefore a What-Where task needs to be carried out.

While the What-Where task does not test the component of context, the task must be carried out in either Context X or Context Y. Sixteen days of What-Where were carried out whilst simultaneously investigating if there was a context preference that would affect the results.

4.4 Experiment 4c

Sixteen days of What-Where were conducted to act as a control for Experiment 4b and also to investigate whether or not the type of context i.e. a wooden maze or a Perspex covered maze with a mesh floor affected performance. It would be predicted considering the short delay between acquisition and test, that this control task would show the HPC group performing above chance alongside the Sham group if it is the case that recognition tasks involving familiarity are not hippocampally dependent. As the methodology of the What-Where tasks dictates that it has to be run in only one context, the task was carried out in alternating contexts to determine if any patterns of preference would emerge.

4.4.1 Methods and Materials

Sixteen days of What-Where were carried out in the Open field. As the effect of context was being investigated, the first four days were carried out in Context Y, the next four days in Context X and then eight days were carried out in alternate YXYX contexts.

4.4.1.1 Procedure

The task involved a sample phase and a test phase. The same context was used in both phases. As in the What-Where-Which task (Experiments 4a and 4b) the rats were placed individually in the centre of the open field facing the far wall, equidistant from each object. After two minutes they were removed to the habituation cage (empty) while the objects were changed ready for the test phase. They were then returned to the open field for this test phase for two minutes with either two copies of object A or B, depending on the counterbalancing schedule. In this test phase one of the objects was in a novel position for that context. Following this the rat was then returned to its home cage.

4.4.2 Results

Over the first four days of the What-Where task in Context Y the Sham group preferentially explored the object in the novel what-where configuration with an average D2 score of 0.08, although this did not reach significance (t (7) = 1.136, p = 0.293). However there was no significant drop in performance from Experiment 4b (t (7) = -1.729, p = 0.128). The HPC group however significantly preferred exploring the object that was in the *familiar* what-where configuration with an average D2 score of -0.13 (t (4) = -7.355, p = 0.002) which was a significant drop in performance from Experiment 4b (t (4) = 2.923, p = 0.043). In addition there was a significant difference in the performance of the two groups (t (11) = 2.233, p = 0.047) (see Figure 4.7).

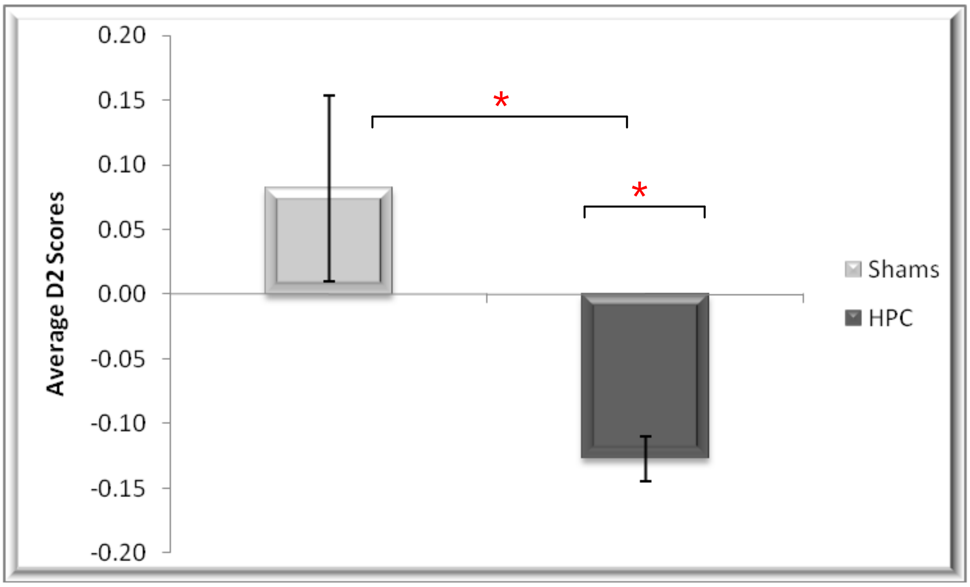


Figure 4.7: Average D2 Scores over days 1 to 4 of control What-Where Context Y (± SEM)

As planned and outlined previously, another four days of What-Where were carried out, this time in Context X to determine if there is any effect of context. The Sham group (average D2 score of -0.03) nor the HPC group (average D2 score of 0.01) significantly preferred exploring the object in the novel What-Where configuration (t (7) = -0.667, p = 0.520; t (4) = 0.101, p = 0.924, respectively). There was also found to be no significant difference in the performance of the two groups (t (11) = -0.457, p = 0.657).

A repeated measures ANOVA (2x2: 2 x Context, 2 x Group) showed no effect of context on performance (F (1, 11) = 0.058, p = 0.814) and no effect of group on performance (F (1, 11) = 1.423, p = 0.258), but it does reveal an interaction between context and group (F (1, 11) = 6.197, p = 0.03).

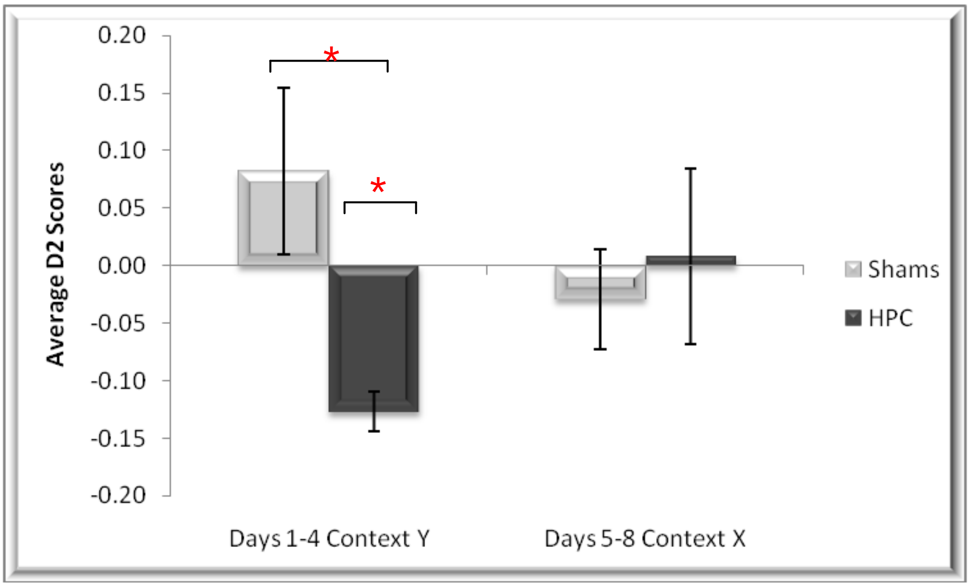


Figure 4.8: Average D2 Scores What-Where Days 1 to 4 (Y) and Days 5 to 8 (X) (± SEM)

Alpha corrected (Bonferroni) paired samples t-tests ($p \leq 0.025$) show that the drop in performance of the Sham group is not significant (t (7) = 2.107, p = 0.073). The HPC group improves in their performance but not significantly so (t (4) = -1.443, p = 0.223) (see Figure 4.8).

The results show that neither group significantly prefer to explore the object in the novel What-Where configuration, in fact the first four days show the HPC group significantly preferring to explore the object in the *familiar* What-Where configuration. The results from the ANOVA suggest that there is an effect of context on performance, yet although the performance of the Sham group drops notably this is not of significance. Group size and variance along with the impact of correctional analyses could be a causal factor. Another eight days of What-Where were carried out as planned to determine if alternating the contexts on a daily basis will have an effect on performance.

These eight days of What-Where using alternate contexts (YX) showed the Sham group were still not significantly preferring to explore the object in the novel What-Where configuration (t (7) = 0.048, p = 0.963). This was also true of the HPC group (t (4) = -0.226, p = 0.832) who, although not significantly so, were exploring the object in the familiar what-where-which configuration instead of the novel one. No significant difference was found between the performance of the two groups over these eight days (t (11) = 0.196, p = 0.848).

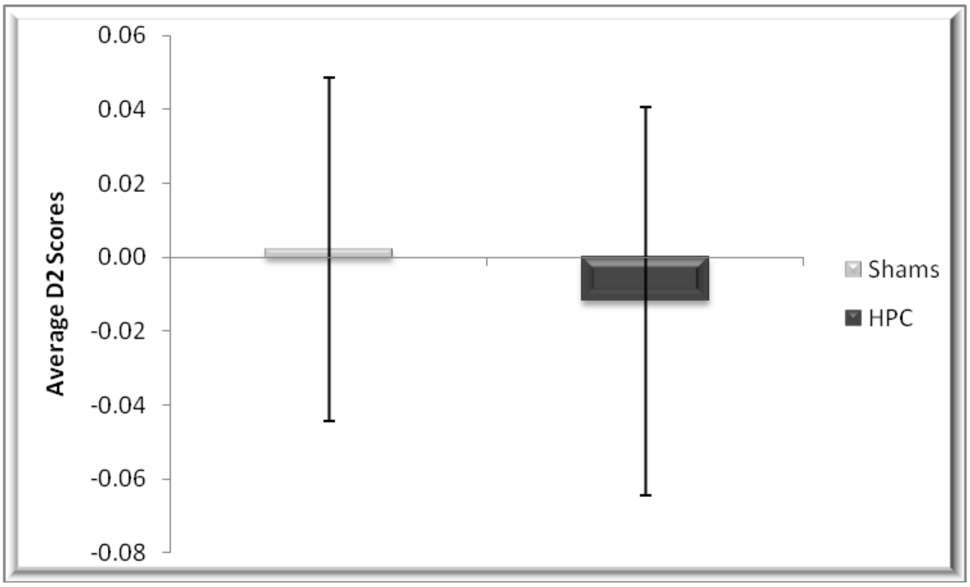


Figure 4.9: Average D2 Scores Days 9 to 16 What-Where Alternate Contexts (± SEM)

When separating the days by context, a repeated measures ANOVA (2x2: 2 x Context, 2 x Group) showed no effect of context on performance (F (1, 11) = 0.823, p = 0.384) and no effect of group on performance (F (1, 11) = 0.038, p = 0.848), and no interaction between context and group (F (1, 11) = 0.067, p = 0.801).

Despite a substantial number of days being carried out on the What-Where task, over the sixteen days as a whole the Sham group were not performing significantly above chance with an average D2 score of 0.01 (t (7) = 0.399, p = 0.702) and nor were the HPC group with an average D2 score of -0.04 (t (4) = -1.082, p = 0.340). There was also no significant difference in the performance of the two groups over these sixteen days (t (11) = 0.952, p = 0.361).

4.4.3 Discussion

Although Experiment 4b demonstrated episodic-like memory in the Sham group but not in the HPC group (despite the fact that there were no significant differences between the levels of performance of the two groups), it was hypothesised that a What-Where task would show both groups performing above chance as the task may be less hippocampally dependent. However, this task at no point for either group in either context, or in alternating contexts, showed memory for What-Where. As the Sham group showed the more complex What-Where-Which episodic-like memory in Experiment 4b, it may be that extraneous factors are affecting performance in the current task. The significant preference of the HPC group for the object in the *familiar* what-where configuration suggests that they are capable of discriminating although with a nonstandard preference. Such preference for familiarity over novelty may be an indicator of stress but none of the typical expressions of stress, such as avoiding the centre of the open field, or defecating, were observed.

Chapter 2 highlighted the sensitivity of the task to extraneous variables such as odour. Although this issue was addressed in Chapter 2, results from parallel studies by other members of the lab group provide results that show their animals performing above chance. The relevance of this is the cleaning method adopted in their studies is different to that of the current study. Cleaning methods of the various members of the lab group vary from minimal cleaning to rigorous cleaning. The importance of this issue to studies such as the current one must not be taken lightly, especially when reviewing the current study’s results. Therefore, an investigation into the different methods of cleaning was warranted and another sixteen days of What-Where were carried out.

4.5 Experiment 4d

The failure of the control What-Where experiment of 4c for both the Sham and the HPC group brought to attention again the issue of extraneous variables having an effect on the task, in particular the issue of odour on the objects and in the maze affecting the exploratory behaviour of the animals. It was thought that this issue had been dealt with to a sufficient degree in Chapter 2, however the failure of Experiment 4c to show memory for What-Where in either group, considering the results of Experiment 4b and the fact that the HPC group were exploring the object in the familiar what-where configuration, could only reflect a flaw in the methodology. As different cleaning regimes were used by different lab members it became apparent that this still was an issue to be contended with. The question of whether the alcohol cleaning wipes were leaving a residue that the animals were averse to was considered. Therefore, two other methods of cleaning the objects and the open field were investigated: One involved limited cleaning while the other was intermediary, bearing in mind the cleaning method already used in the current studies reported here was relatively high. Another sixteen days of What-Where were carried out to investigate these differing methods and the effect they would have on performance of the What-Where task.

4.5.1 Methods and Materials

The same procedure for the What-Where task was followed as outlined in Experiment 4c, the differences lying only in the cleaning method. The context used for the current experiment was Y as it was the most flexible context to use when investigated cleaning method i.e. it can be cleaned or not cleaned. In contrast, due to the porous nature of the wood, not all the odours could be so successfully removed from Context X.

The first four days of What-Where were carried out using a method of cleaning that is to be referred to as the ‘Intermediate’ cleaning method. With this method the objects and test objects were cleaned after every cage with alcohol wipes and the open field wiped clean after the end of each day. The next twelve days of What-Where used a cleaning method (to be referred to as the ‘Minimal’ cleaning method) that required objects to be made one week prior to testing. Once made and cleaned these objects were then not further cleaned until the experiment was finished. Cleaning of the open field was the same as for the ‘Intermediate’ cleaning method which was at the end of each testing day.

The rationale for conducting only four days of What-Where using the ‘Intermediate’ cleaning method and twelve days of the ‘Minimal’ cleaning method was based on the following results which suggested that the ‘Intermediate’ cleaning method was having no discernable effect.

4.5.2 Results

Four days of What-Where using ‘Intermediate’ cleaning method did not result in the Sham significantly preferring to explore the object in the novel What-Where configuration with an average D2 score of 0.003 (t (7) = 0.036, p = 0.972). This was also true of the HPC group whose average D2 score was 0.11 (t (4) = 1.65, p = 0.174) (see Figure 4.10).

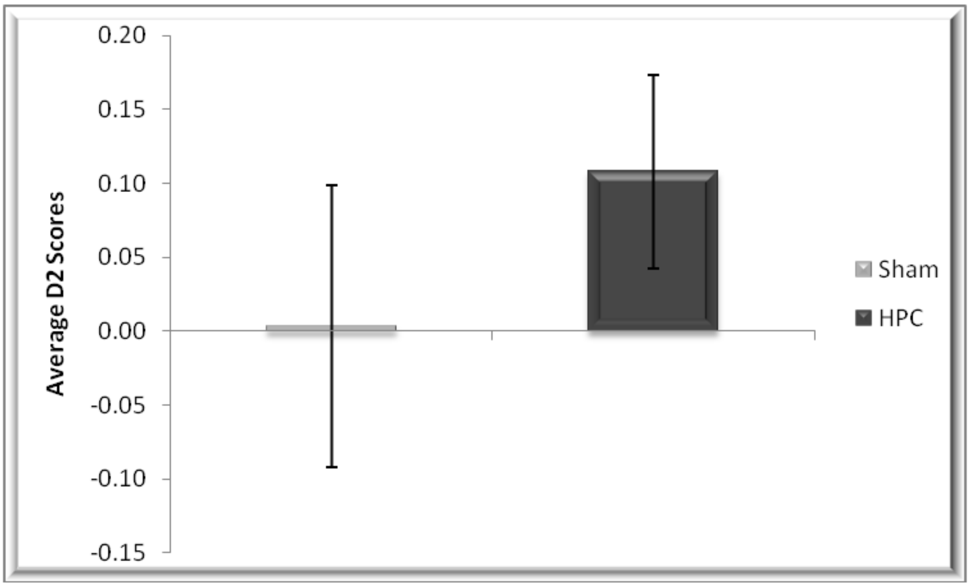


Figure 4.10: Average D2 Scores What-Where 4 days using the ‘Intermediate’ cleaning method (±SEM)

No significant difference was found between the performance of the two groups (t (11) = -0.789, p = 0.447). A repeated measures ANOVA (2x2: 2 x Experiment, 2 x Group) showed that there was no effect of experiment (experiment 4c to experiment 4d) on performance (F (1, 11) = 0.642, p = 0.440) and no interaction between experiment and group (F (1, 11) = 0.870, p = 3.71). Due to this, another 4 days of What-Where were carried out but this time using the ‘Minimal’ cleaning method to determine if this method of cleaning would improve performance.

The change from the ‘Intermediate’ cleaning method to the ‘Minimal’ cleaning method still did not result in the Sham group (average D2 score of 0.03) (t (7) = 0.890, p = 0.403) or the HPC group (average D2 score of -0.05) (t (4) = -0.971, p = 0.386) demonstrating memory for What-Where. There was also no significant difference in the performance of the two groups over these four days (t (11) = 1.314, p = 0.216) (see Figure 4.11).

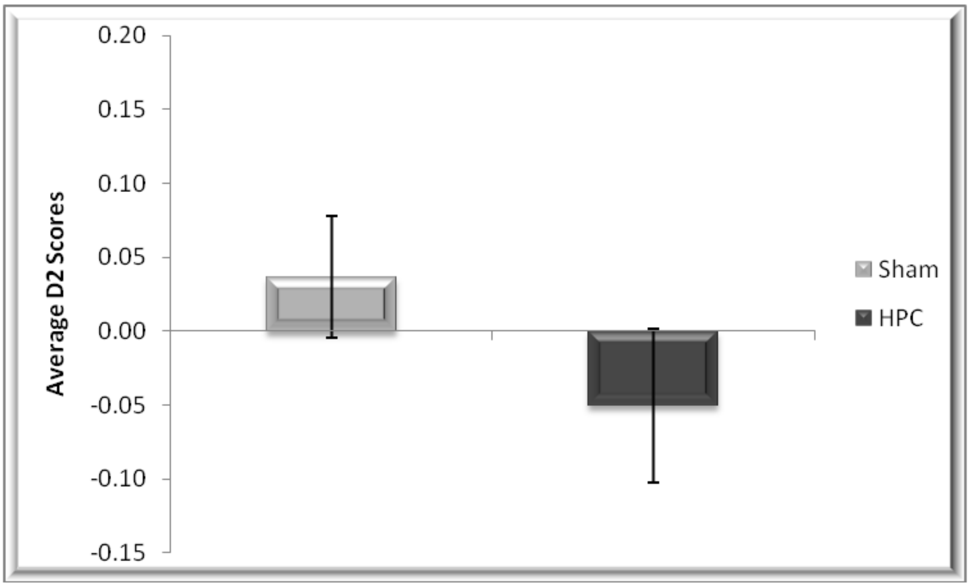


Figure 4.11: Average D2 Scores What-Where 4 days of using the ‘Minimal’ cleaning method (±SEM)

Although the results appear to indicate that the Sham group improve using the ‘Minimal’ cleaning method, a repeated measures ANOVA (2x2: 2 x Group, 2 x Cleaning Method) showed there was no effect of cleaning method on performance (F (1, 11) = 0.782, p = 0.395) and no interaction between cleaning method and group (F (1, 11) = 1.834, p = 0.203).

As the Sham group have improved in their performance, albeit not significantly, another eight days of What-Where were carried out using the ‘Minimal’ cleaning method. The reason for this is because it is imperative to increase the performance of the Sham group to the point where they are demonstrating memory for What-Where. As they were shown to demonstrate memory for What-Where-Which in Experiment 4b they should therefore be able to demonstrate the more simple What-Where memory. Although it is expected that the HPC group should also be able to demonstrate memory for What-Where there still lies the possibility that the hippocampus does play a role in recognition tasks based on familiarity according to previous research (Manns, et al., 2003; Wais, Wixted, Hopkins, & Squire, 2006; Wixted & Squire, 2004), therefore making decisions based on the performance of the HPC group would be misdirected. Eight days of What-Where were carried out using the 'Minimal' cleaning method to determine if performance would increase and/or stabilise.

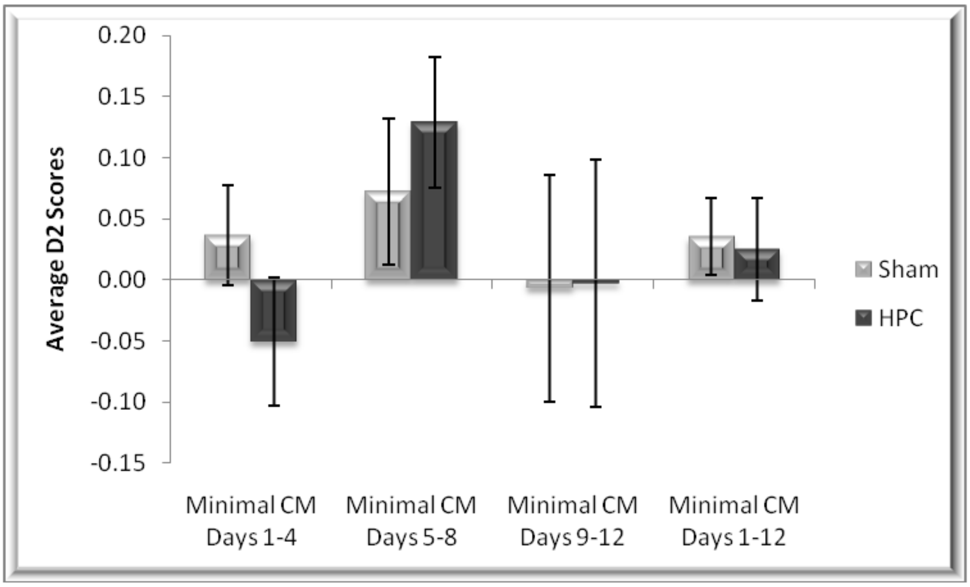


Figure 4.12: Average D2 Scores What-Where over 4 days blocks and as a total of 12 days using the 'Minimal' cleaning method (CM) (± SEM)

A repeated measures ANOVA (3x2: 3 x Block, 2 x Group) show that there is no effect of block on performance (F (2, 22) = 1.249, p = 0.306), no effect of group on performance (F (1, 11) = 0.03, p = 0.867), and no interaction between block and group (F (2, 22) = 0.311, p = 0.588).

Over the 12 days of What-Where using the ‘Minimal’ cleaning method neither the Sham group (average D2 score of 0.04) (t (7) = 1.112, p = 0.303) nor the HPC group (average D2 score of 0.03) (t (4) = 0.601, p = 0.58) show memory for What-Where. There was also no significant difference in the performance of the two groups (t (11) = 0.192, p = 0.657).

However, what Figure 4.12 does appear to show is that over these 12 days as a whole, although performance is at chance, the two groups are more balanced with respect to each other compared to the four days that employed the ‘Intermediate’ cleaning method which showed the HPC group performing better than the Sham group, although not significantly so. Figure 4.12 also shows that performance over time is highly variable. Possible explanations for this variability are addressed later.

4.5.3 Discussion

As the results of the control What-Where task of Experiment 4c did not show memory for What-Where in either the Sham or the HPC group it was hypothesised that this could only be due to a flaw in the methodology. Results from similar studies by other members of the lab group that use different cleaning techniques have shown that this task can be successful. Therefore, further days of the What-Where task were carried to investigate these different cleaning methods.

The first four days of What-Where used a cleaning method (‘Intermediate’) that saw the objects and test objects being cleaned after every cage with alcohol wipes and the Open Field wiped clean after the end of each day. This did not result in either group demonstrating What-Where memory, nor did it results in a significant improvement in performance from Experiment 4c. Therefore, another 4 days of What-Where were carried out, however for these days a ‘Minimal’ cleaning method was adopted. Although the Sham group were seen to improve in their performance and the HPC group deteriorate, this was not of significance. Despite this, another 8 days of What-Where were carried out using this ‘Minimal’ cleaning method.

Over the twelve days of What-Where using the ‘Minimal’ cleaning method, neither group demonstrated memory for What-Where. Splitting the data into blocks of four days to analyse more closely performance over time also resulted in no significant findings. Looking at the data this way however, does highlight the variability of the data over time.

Therefore, the current experiment, the aim of which was to not only act as a control for the What-Where-Which task of Experiment 4b but also to rectify the issues with methodology that were highlighted in Experiment 4c was not successful. However, the ‘Minimal’ cleaning method has been concluded to be the method of choice considering mainly the performance of the Sham group but also the balance of performance of the two groups.

4.6 Experiment 4e (including Experiment 4d)

The previous experiment and Experiment 4a highlighted the variability in the performance of the two groups. Experiments 4a to 4d have attempted to rule out any extraneous factors that may be causing this observed variability, such as change in testing room and cleaning methods, yet the variability is still apparent. Although the open field arena allows for shorter testing periods, the issue of stability and sustainment of performance over time remains important. Is it possible that too many days on the same task is detrimental to performance? Certainly Chapter 2 Experiment 2a saw a successful demonstration of episodic-like memory, however the subsequent Experiment 2b failed to sustain such performance.

As the open field allows for experiments to be conducted over periods of four days, it is possible to investigate both matters simultaneously in a shorter period of time than the E-maze would allow. Therefore, further experiments aimed to investigate performance over time and the effect of a change in task on performance. The tasks used were the What-Where-Which task and the What-Where task. Experiment 4d was included as a starting point to make further use of the data and to maximise the possible analyses.

4.6.1 Methods and Materials

4.6.1.1 Subjects

For the purpose of the following experiments which aimed to investigate performance over time and the effect of task change on performance, the Sham group was split into two sub-groups (Sham group 1 and Sham group 2). This allowed for not only the effect of task change to be observed between the Sham and HPC groups, but also within a group. Numbers within the HPC group were too small to be able to split up. Although the power of statistical analyses were reduced, analyses and observations were still considered worthwhile and valid.

4.6.1.2 Procedure

4.6.1.2.1 Split tasks of What-Where and What-Where-Which

Experiments included both the What-Where-Which task and the What-Where task, the procedure of which has been detailed in Experiments 4a and 4c respectively. In order to investigate the effect of task change and maximise the analyses available, Experiment 4d (12 days of What-Where) was used as a starting point for this investigation. Both groups then changed task to nine days of What-Where-Which (Experiment 4e). The ninth day was not used in the results in order for even blocks to be analysed. Removing the ninth day allowed for the effect of a change in task to be observed from Experiment 4d to Experiment 4e. As performance over time was also to be investigated the Sham group were split into Sham Group 1 and Sham Group 2. Sham Group 1 then continued on the What-Where-Which task for another four days (13 days in total), whilst Sham Group 2 and the HPC group transferred to eight days of What-Where. The What-Where task of Experiment 4d was carried out in context Y due to the fact that this context could be easily cleaned. Therefore, Experiments 4e, 4f and 4g were also carried out in context Y. The procedure/timeline of these tasks is clearly outlined in Figure 4.13.

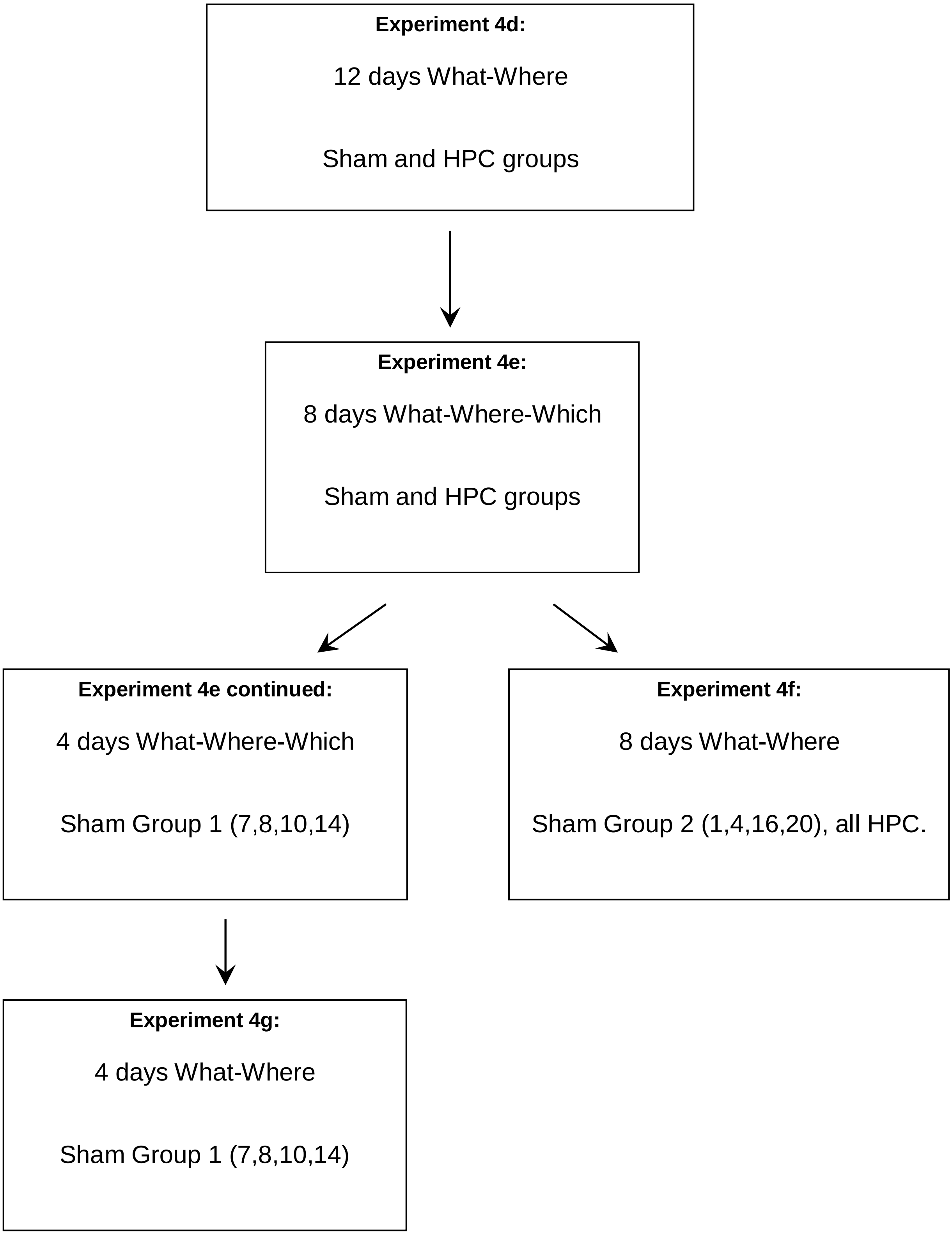


Figure 4.13: Showing the change in tasks for both the Sham and HPC groups.

4.6.2 Results

4.6.2.1 Experiment 4d: Twelve days of What-Where (Sham and HPC groups)

The results of Experiment 4d from the previous chapter showed that over twelve days of What-Where neither the Sham group (t (7) = 1.112, p = 0.303) nor the HPC group (t (4) = 0.601, p = 0.580) showed memory for What-Where. There was also no significant difference in the performance of the two groups (t (11) = 0.192, p = 0.657).

4.6.2.2 Experiment 4e: Eight days of What-Where-Which (Sham and HPC groups)

Both groups then changed task to Experiment 4e and completed eight days of What-Where-Which. The eight days of What-Where-Which did not result in the Sham group (average D2 score of 0.06) (t (7) = 1.351, p = 0.219) or the HPC group (average D2 score of 0.04) (t (4) = 1.000, p = 0.374) demonstrating episodic-like memory. There was also no significant difference in the performance of the two groups (t (11) = 0.232, p = 0.82).

A repeated measures ANOVA (2x2: 2 x Block, 2 x Group) showed that by blocking the data into two blocks of four days (see Figure 5.2) there was no effect of block on performance (F (1, 11) = 2.69, p = 0.614), no effect of group on performance (F (1, 11) = 0.353, p = 0.565), and no interaction between block and group (F (1, 11) = 0.781, p = 0.396) (see Figure 4.14). At no point during any of the blocks of four days did either group’s performance approach significance levels.

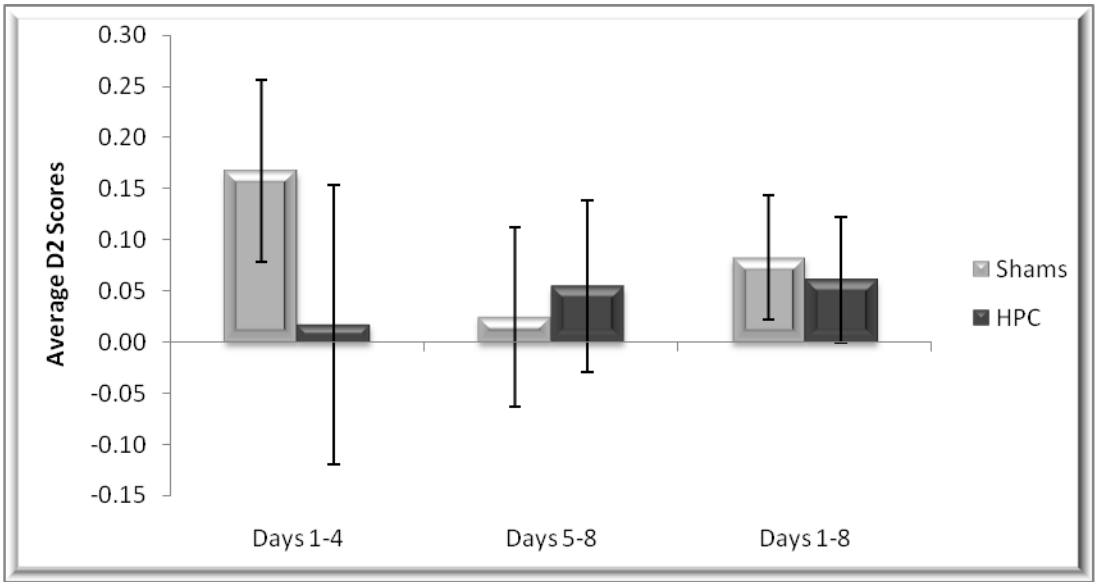


Figure 4.14: Average D2 Scores Experiment 4e: 8 days of What-Where-Which in blocks and in total (± SEM)

4.6.2.3 Experiment 4d to Experiment 4e (Sham Group 1)

4.6.2.3.1 Investigating Task Change

Despite determining that Experiment 4e did not demonstrate episodic-like memory in either the Sham or the HPC group, this would not necessarily mean that the change in task had not improved performance. Figure 4.15 appears to show that to a degree this may be the case for both groups. However, a repeated measure ANOVA (2x2: 2 x task. 2 x group) revealed that the change in task from twelve days of What-Where (Experiment 4d) to eight days of What-Where-Which (Experiment 4e) did not have an effect on performance (F (1, 11) = 0.505, p = 0.492). There was also no effect of group (F (1, 11) = 0.117, p = 0.739) and no interaction between task and group (F (1, 11) = 0.009, p = 0.925) (see Figure 4.15). As a more stringent test of the effect of task change on performance only the last block of four days of Experiment 4d and the first block of four days of Experiment 4e were compared. This also showed that there was no effect of task on performance (F (1, 11) = 0.679, p = 0.427), no effect of group on performance (F (1, 11) = 0.634, p = 0.443), and no interaction between task and group (F (1, 11) = 0.426, p = 0.528).

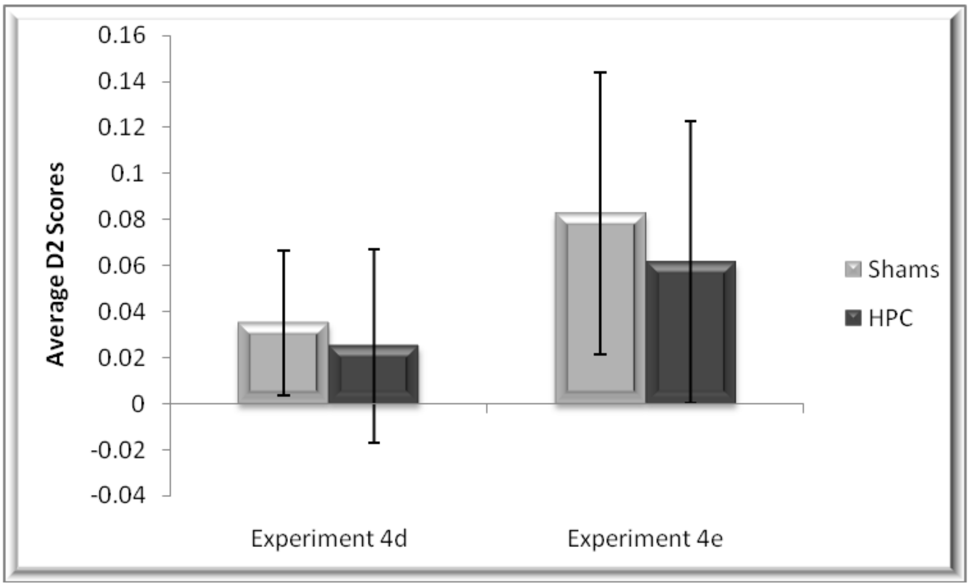


Figure 4.4.15: Average D2 Scores: Experiment 4d to Experiment 4e (± SEM)

4.6.2.4 Experiment 4d to Experiment 4e and 4e continued (Sham Group 1)

4.6.2.4.1 Investigating Task Change

Experiment 4e (continued) saw half the Sham group (Sham Group 1) continuing with the what-where-which task to allow for subsequent analyses regarding performance over time. However, as the task has continued and essentially added another block of four days onto the already existing task of 4e, and also considering that the Sham group had now been split into two groups, it was appropriate to see if this produced any interesting results when compared again to the results from Experiment 4d.

The change in task and the analyses of only Sham group 1 result in a marginal, albeit not significant difference between Experiment 4d and the first block of four days of Experiment 4e (t (3) = 2.772, p = 0.069). Subsequent analyses did not reveal any significant or marginal findings (see Figure 4.16).

4.6.2.5 Experiment 4e continued (Sham Group 1)

4.6.2.5.1 Investigating Performance Over Time

As mentioned previously, one of the aims of the current chapter was to observe more closely the animals' performance over time with regard to its stability or lack thereof. Therefore, Experiment 4e (continued) saw half the Sham group (Sham group 1) continuing with the What-Where-Which task for another four days in order to observe their performance over time. Over the twelve days of What-Where Which (Experiment 4e and 4e continued) Sham Group 1 did not demonstrate episodic-like memory (average D2 score of 0.16) (t (3) = 2.003, p = 0.139). Splitting up the these twelve days into three blocks of four days and conducting alpha corrected (Bonferroni) one-sample t-tests (p ≤ 0.016) reveals that during the first four days of the task the animals that constitute Sham group 1 although not demonstrating episodic-like memory were the closest to approaching significance levels (average D2 score of 0.33) (t (3) = 4.328, p = 0.023). Analyses of the subsequent blocks did not reveal any significant findings.

A one-way ANOVA shows a marginal effect of block on performance (F (2, 11) = 3.576, p = 0.072). As this was marginal, paired samples t-tests were conducted to determine if there were in fact any differences in performance between the three blocks.

Alpha corrected (Bonferroni) paired samples t-tests ($p \leq 0.016$) reveal that there was a significant drop in performance from the first block of four days (days 1 to 4) to the second block of four days (days 5 to 8) (t (3) = 7.107, p = 0.006) and from the first block of four days to the last block of four days (days 9 to 12) (t (3) = 5.031, p = 0.015). There was no difference in performance from the second block of four days to the last block of four days (t (3) = -1.671, p = 0.193) (see Figure 4.16).

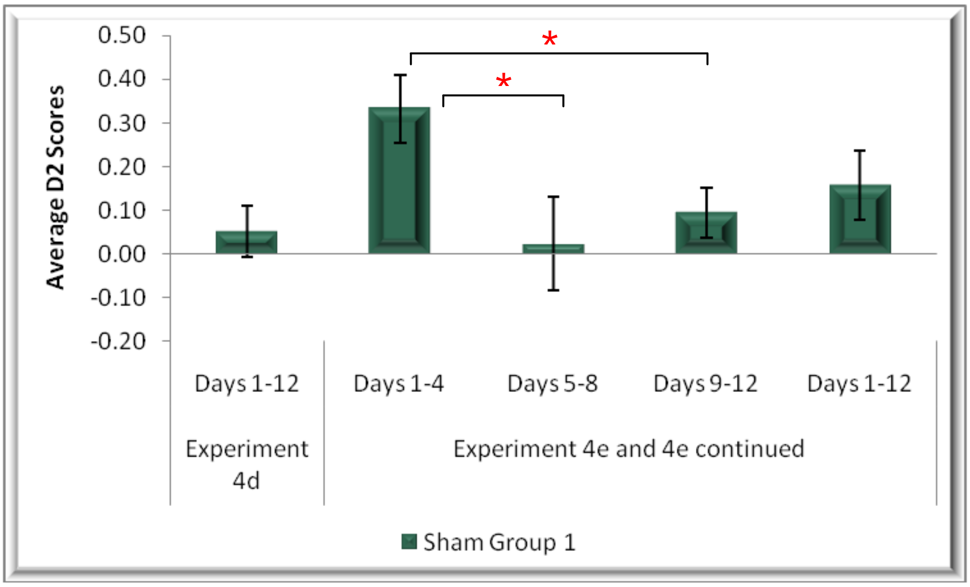


Figure 4.16: Average D2 Scores: Sham Group 1 Experiment 4d to Experiment 4e and 4e continued

4.6.2.6 Experiments 4g (Sham Group 1) including Experiment 4e and 4e continued

4.6.2.6.1 Investigating Task Change

Following the continuation of Experiment 4e, Sham group 1 then changed task to four days of What-Where (Experiment 4g) (refer to Figure 4.13 for clarification of experiments). The change in task did not result in Sham Group 1 showing memory for What-Where over these four days (average D2 score of 0.21) (t (3) = 2.384, p = 0.097). There was also no significant improvement in performance from the last block of four days of Experiment 4e (continued) to Experiment 4g (t (3) = -0.779, p = 0.493) and also no significant improvement from Experiments 4e and 4e continued as a whole (i.e. 12 days) to Experiment 4g (t (3) = -0.371, p = 0.735) (see Figure 4.17).

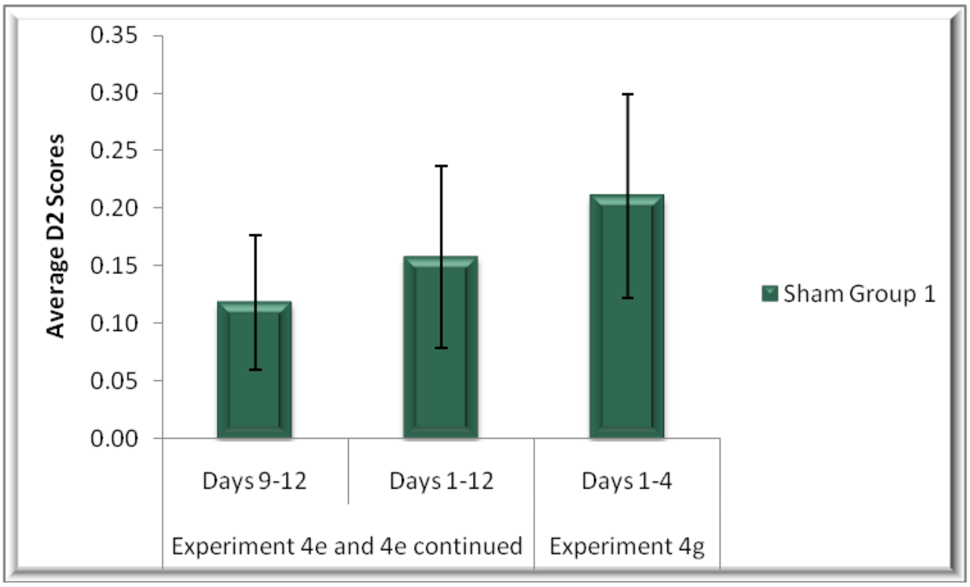


Figure 4.17: Average D2 Scores: Experiment 4e and 4e continued to Experiment 4g (± SEM)

4.6.2.7 Experiment 4f (Sham Group 2 and HPC Group)

Whilst Sham group 1 continued with the What-Where-Which task (Experiment 4e continued), Sham Group 2 and the HPC group changed task after Experiment 4e to eight days of What-Where. This would allow for comparisons to be made between a Sham group and a HPC lesion group but in addition between the two Sham groups. If there exists an issue regarding task change then differences between the two

Sham groups when one group changes task and one remains on a task should be apparent.

Over these eight days no memory for What-Where was observed by Sham Group 2 (average D2 score of 0.05) (t (3) = 0.494, p = 0.655) or the HPC group (average D2 score of -0.007) (t (4) = -0.111, p = 0.917). There was also no significant difference between the performance of the two groups over these eight days of What-Where (t (7) = 0.508, p = 0.627) (see Figure 4.18).

Analysing this data in blocks (2x4 day blocks) via a repeated measures ANOVA (2x2: 2 x block, 2 x group) revealed that there was no effect of block on performance (F (1, 7) = 0.345, p = 0.575), no effect of group on performance (F (1, 7) = 0.492, p = 0.506) and no interaction between block and group (F (1, 7) = 0.258, p = 0.627).

4.6.2.8 Experiment 4e to Experiment 4f (Sham Group 2 and HPC Group)

4.6.2.8.1 Investigating Task Change

A repeated measures ANOVA (2x2: 2 x Experiment, 2 x Group) showed there was no effect of experiment on performance (F (1, 7) = 0.001, p = 0.974), no effect of group on performance (F (1, 7) = 0.001, p = 0.972) and no interaction between group and experiment (F (1, 7) = 0.680, p = 0.437) (See Figure 4.18).

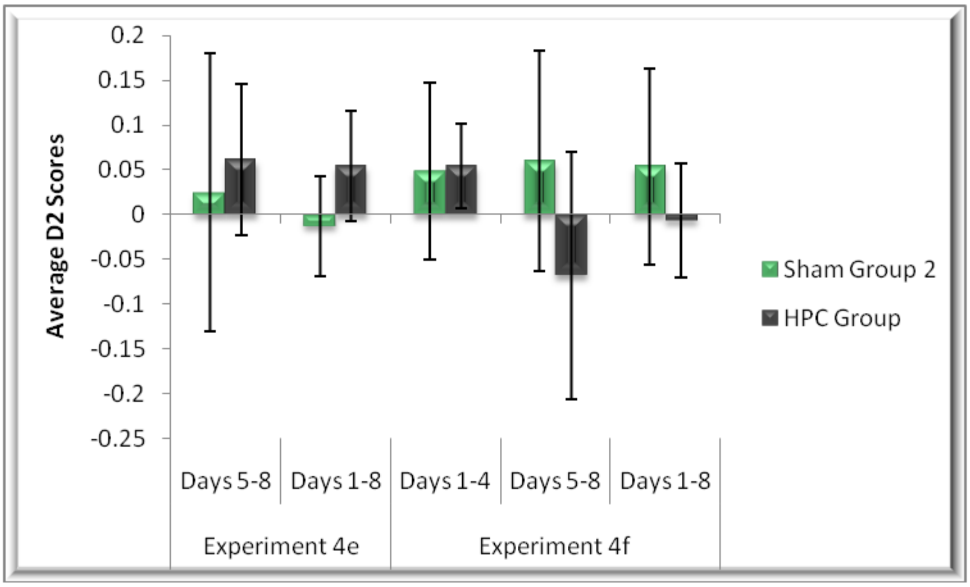


Figure 4.18: Average D2 Scores: Experiment 4e to 4f Sham Group 2 and HPC Group (± SEM)

A repeated measures ANOVA also shows that there was no effect of block (last block of Experiment 4e and first block of Experiment 4f) on performance (F (1, 7) = 0.12, p = 0.917), no effect of group on performance (F (1, 7) = 0.164, p = 0.698), and no interaction between block and group (F (1, 7) = 0.316, p = 0.591).

4.6.3 Discussion

Experiments 4e, 4f and 4g (also including the results of Experiment 4d) aimed to investigate performance over time, and also to investigate the effect of task change on performance. The open field allowed for both these investigations to be carried out simultaneously as any change in task could be carried out over a relatively short period of time (4 days) compared to the E-maze and tasks investigating performance over time could be manipulated in four day blocks.

The Sham group was split up into two groups (Sham Group 1 and 2) so it was possible not only to observe any difference between the Sham and HPC groups but also to observe the differences within a group between those animals that remained on a task for an extended period to those that changed task. The starting point for these investigations was Experiment 4d. As this was a What-Where task carried out over twelve days it allowed for a change in task immediately to What-Where-Which. The results of Experiment 4d showed neither the Sham nor the HPC group demonstrating memory for What-Where. There was also no difference in the performance of the two groups on this task despite the variability in the data observed.

Experiment 4e saw both groups then completing eight days of What-Where-Which. The change in task did not result in episodic-like memory for either group, nor was there a difference in the performance of the two groups. Again, splitting the data into blocks to observe if performance had improved or deteriorated at a specific point during Experiment 4e did not yield any significant results, however, performance of the Sham group did approach significance levels in the first block of four days. The change in task from Experiment 4d to Experiment 4e also led to no significant improvement in performance. Thus far it appears that a change in task is not novel enough to improve performance. One possible reason for this could be that they are too habituated to the tasks to find either novel, despite the change. However, the fact that the Sham group's performance approached significance levels after a change in task despite the low group numbers and the resultant lack of power may allude to a possible trend. If this behaviour is shown to be consistent then it may be that larger group numbers would show a significant improvement in performance following task change. However, if this is not the case then it can only be concluded that there exists a level to which the tasks become ‘over-habituated’.

Sham Group 1 continued with the What-Where-Which task to examine the effect of continuation of testing on a single task. Over the 12 days of Experiment 4e as a whole, Sham Group 1 did not demonstrate episodic-like memory. Moreover, performance fell with continued testing, perhaps again suggesting an over-habituation to the task. However, at the same time it also lends credence to the open field method. Observing such variability over relatively short periods of testing allows for any subsequent manipulations to be made more efficiently.

Although a marginal improvement in performance was found for Sham Group 1 when the task was changed from What-Where (Experiment 4d) to What-Where-Which (Experiment 4e first four days), this was not the case for the subsequent task changes. Again, the marginal results of Sham Group 1, although possibly alluding to a pattern in behaviour, is not strong enough evidence to conclude that a change in task positively affects performance. It may be the case that perhaps both tasks are too familiar to the animals for any change in task to be effective.

Whilst Sham Group 1 were continuing with Experiment 4e and then proceeding to Experiment 4g, Sham Group 2 and the HPC group changed task from Experiment 4e (eight days of What-Where-Which) to Experiment 4f (eight days of What-Where). It appears from the results that a change in task does not significantly improve performance for the Sham groups and interestingly the HPC group appeared equally unaffected. Despite a marginal result from the Sham Group this pattern was not repeated and so it can only be concluded that as the animals have undergone periods of habituation to both tasks, neither appear novel.

4.7 Discussion

The current chapter saw a change in methodology from the E-maze to the open field for several reasons. It was possible that exploration measures might be less vulnerable to extraneous factors such as noise than a critical measure such as first turn. If noise were impacting upon performance then this would be observable in the exploratory behaviour of the animals and it would be possible to rectify such issues more efficiently due to the fact that testing in the open field can be carried out in blocks of four days (Norman & Eacott, 2005).

Experiment 4a sought to demonstrate episodic-like memory using the What-Where-Which task in order to subsequently investigate the individual components of episodic-like memory, akin to the comparison between Eacott and Norman (2004), and Eacott and Gaffan (2005). The results of this experiment were not successful in demonstrating such episodic-like memory in either the Sham group nor the HPC group. Although the Sham group's performance did approach significance in the first block, there were still no significant differences between the performance of the two groups. It may be however, that with larger group sizes and therefore greater statistical power, that the Sham group's performance would reach significance levels and differences between the levels of performance of the two groups may be more notable.

It appeared clear, despite the lack of significant results, that there were still unidentified extraneous factors effecting performance of both groups. During the last block both groups' performance dropped, albeit not significantly so. It was concluded that stress was not the causal factor as such indicators of stress were not present in the animals. Considering the factors that had changed since Chapter 3 when episodic-like memory was demonstrated, it was hypothesised that the change in testing room may in fact be having an effect on performance. It was reasoned in particular that the size and geometry of the testing room may be affecting exploration if the animals are lacking in landmarks that would aid their positioning and navigation in the open field.

Therefore, Experiment 4b saw the addition of landmarks to the walls surrounding the open field. The result was that although there was no significant improvement in performance from Experiment 4a to 4b, the Sham group were now demonstrating episodic-like memory, and the HPC group remained at chance. Due to the fact that no significant differences between the two groups were found, it was not possible to conclude that the lack of demonstration in the HPC group was as a consequence of the lesions to the hippocampus. In order for such a question to be answered it seems clear that larger group sizes are needed to increase the power of analyses. The same argument stands regarding landmarks. It cannot be concluded that the addition of landmarks to the testing room was the cause of the Sham group now demonstrating episodic-like memory as there was no significant improvement in performance from Experiment 4a to 4b, yet future studies using larger group sizes could yield clearer results.

Despite these results, interesting data could still be gleaned from carrying out a control task of What-Where. As recognition based on familiarity is claimed not be hippocampally dependent (Brown & Aggleton, 2001; Fortin, Wright, & Eichenbaum, 2004; Yonelinas, et al., 2002), then the more simple dual association of What-Where should not be impaired. However, previous research has questioned such a suggestion (Manns, et al., 2003; Wais, et al., 2006; Wixted & Squire, 2004). If familiarity is not hippocampally dependent, a control What-Where task should show both the Sham and HPC group performing above chance. However, if one were to support the view that the hippocampus plays a role in recall and familiarity then the results should show the Sham group performing above chance but not the HPC group. Again, significant differences would need to be found between the two groups in order to conclude that this is in fact the case.

Experiment 4c attempted to show evidence for one of the above theories. As the What-Where task necessitated the use of one context alone, an investigation was also carried out in tandem to observe if there were any context preferences. Although the results suggested there was no effect of context on performance, the results unexpectedly showed that neither group were demonstrating memory for What-Where. As the Sham group had shown the more complex What-Where-Which memory in Experiment 4b, it was concluded that a problem lay in the methodology. The performance of the HPC group also supported this suggestion as they were significantly preferring to exploring the object in the *familiar* what-where configuration.

Research (unpublished) from other members of the lab group have shown the What-Where task to be successful in animals of the same strain, using the same objects and in an identical environment. The relevance of this lies in the different cleaning methods adopted by the different members of the group. Although this issue was thought to have been addressed in Chapter 2, it was now thought that it was not only the odour from the animals themselves that were having an effect on the results, but also that the alcohol cleaning wipes used to clean the objects and open field were potentially leaving behind a residue that the animals were averse to. Experiment 4d investigated this by carrying out further days of the What-Where task using two different cleaning methods (Intermediate and Minimal). Neither method resulted in the Sham or the HPC group demonstrating memory for What-Where and nor were there seen to be significant differences in the results due to the different methods. However, the ‘Minimal’ cleaning method was determined to be the most successful due to the fact that the Sham group were seen to improve. Although this was not of significance, it was the performance of the Sham group that needed to be focused on as it is would be this group that would be seen to improve.

Experiment 4d and the previous Experiment 4a also highlighted was the variability in performance over time which has also been noted previously in Chapter 3. Tasks in the open field can be conducted successfully over a period of four testing days as shown in Experiment 4b and does allow for more efficient manipulations to the methodology. However, the issue of stability in performance is an important one, especially when considering the advantages and disadvantages of each type of methodology employed. Previous research has shown that performance can be sustained in the E-maze (Eacott et al., 2005), although the level of performance might plausibly be improved upon. The studies of Chapters 2 and 3 were unable to do that. However, the transfer of this problem over to the open field, which is known to be a reliable task, suggests that there are still unidentified extraneous variables affecting the results. Has the change in methodology to the open field again highlighted the issue of task novelty? The introduction of novel landmarks certainly was successful in boosting performance, but again this was not sustainable. Although this would not explain the results of the What-Where tasks of Experiments 4c and 4d, it is certainly an important methodological aspect that needs investigating further.

Experiments 4e, 4f and 4g (also including the results of Experiment 4d) sought to investigate performance over time, and also to investigate the effect of task change on performance. Results from Chapter 3 and the current chapter brought to light the variability in performance over time. As explained previously, it is important to have a task that is stable over time considering the limitations that lesion groups can place on such experiments. It is also an interesting issue if there were to exist any differences between lesion groups and sham groups and would certainly provide valuable information to future studies of similar vein. Although the low numbers of the groups means that any analyses will have the power compromised, any differences observed may be treated as trends until more powerful analyses can be carried out on larger group sizes. With regard to task change, it was postulated that the novelty or interest of changing task may serve to improve performance due to rats possessing an innate preference for novelty (Ennaceur & Delacour, 1988).

Although this issue was touched upon in Chapter 3, it was thought that the two tasks involved (i.e. Objects Visible and Objects Hidden) were not distinct enough from each other for the change in task to be considered a novelty by the animals.

Using Experiment 4d as a starting point it was found the change in task from What-Where to What-Where-Which did not result in either group demonstrating episodic-like memory. Block analyses also revealed no improvements in performance following the task change.

In order to investigate the stability of performance over time half of the Sham group (Sham Group 1) remained on the What-Where-Which task. Although reducing the numbers of the groups and the power of subsequent analyses, this method does allow for tentative within-group comparisons. Although no demonstration of episodic-like memory was observed, again there was found to be variability in the data with performance dropping as the task continued. Although performance was marginally improved when the task changed from What-Where (Experiment 4d) to What-Where-Which (Experiment 4e first block), this was not the case for subsequent task changes. Sham Group 2 and the HPC group also showed no improvement in their performance when changing task from What-Where-Which to What-Where. In addition there was no demonstration of episodic-like memory from either group in Experiments 4e and 4f as a whole or when blocking the data.

Therefore, despite a marginal result from the Sham group initially, further task changes did not lead to actual significant improvements in any of the groups. In fact the HPC group appeared equally as unaffected by the change in tasks as the Sham group. It cannot be concluded or alluded to (considering the group sizes) that a change in task has a positive impact on performance.

This then begs the question whether or not the habituation period to the tasks is excessive or if in fact the results show the habituation period to be sufficient. An investigation that manipulated habituation periods (although not to the extent that resulted in any stress to the animals) would allow one to observe if this had an effect on future task changes.

The above point also relates to the variability of performance over time which has been noted at several points during the current chapter. Is performance over time variable due to over-habituation, or is it the sensitive nature of the task to extraneous variables (the likes of which have been discussed in the current and previous chapters) that is having the observed effects on performance.

Although tasks in the open field can be more efficiently manipulated when compared to tasks in the E-maze, it too has also proven to be a sensitive task. Such a task needs further attention and manipulation in order to be considered reliable over time. Subsequent investigations of this vein however were not possible due to the author developing an allergy to the rats. The direction of the next chapter therefore takes a drastic turn in its methodology. Is it possible to create similar tasks as those seen in the previous chapters that could be used to investigate episodic-memory in humans? If this were to be possible, comparisons could be drawn between the two and perhaps answer some questions regarding whether or not episodic-like memory in animals is actually a mirror of episodic memory in humans.

5 INVESTIGATING HUMAN EPISODIC MEMORY

5.1 Introduction

The aim of this thesis was to investigate the methodology of episodic (or episodic-like) memory tasks in animals. Previous chapters studied episodic-like memory in non-human animals. The advantage of animal studies is that they allow for a much broader range of investigative techniques (such as the lesion study of Chapters 3 to 4) compared to studies involving normal human participants or neuropsychological patients. However, despite these advantages there still remains the contentious issue of the relationship between episodic-like memory tasks in animals and the experience of episodic memory in humans.

Although Tulving (1972) originally defined episodic memory as the memory for the what, where and when of an episode, he later admitted that this definition was over-simplified and re-defined episodic memory to incorporate three essential components: self, autonoetic awareness and subjectively sensed time (Tulving, 2002). This new definition made demonstrating episodic memory in animals an impossible task due to the fact that there exists no agreed behavioural markers of conscious recollection in animals. The previous chapters however, discussed how Clayton & Dickinson (1998) used Tulving's original (1972) definition to demonstrate what is now referred to as episodic-like memory in animals. This led to further modifications of this definition such as the what-where-which concept (Eacott et al., 2005; Eacott & Gaffan, 2005; Eacott & Norman, 2004) which sees 'which' (as opposed to ‘when’) is the occasion setter that defines an experience as being unique.

So, the question of whether or not episodic memory can be demonstrated in animals has been answered to the extent that episodic-*like* memory can be demonstrated in animals. The extent to which this bears relevance to what is episodic memory in humans however, is still debated. For example, simply knowing what happened, where and when does not necessarily mean that the memory is episodic. Zentall (2005) highlights this point by explaining that just because one knows that the Declaration of Independence was signed in Philadelphia on July 4th 1776 does not mean that this is an episodic memory. This issue has not at the time of writing been directly addressed in that there have been no studies that attempt to take a task that demonstrates episodic-*like* memory in animals in order to determine if this is experienced as episodic memory in humans. Research has tended to focus on human studies which are then adapted to animal studies using the modified definitions of episodic-like memory. Despite the observed variability in the data of previous chapters, Chapter 2 was successful in demonstrating episodic-like memory in animals. The current chapter aims to create a task, comparable to those used in the previous chapters, to investigate if this memory can in fact mirror itself as episodic memory in humans. This would refute claims that episodic memory can only be supported by the human memory system, as no other memory system known possess the necessary features that serve to define episodic memory (Tulving & Markowitsch, 1998).

Creating a task that is comparable to those used in the previous chapters is not simple. The what-where-which and what-where-when tasks are used to show episodic-like memory in animals, but how is episodic memory exhibited in humans? It is important to understand this before attempting to create such a task.

As explained in the General Introduction (section 1.4) dual-process models of recognition memory impart that recognition occurs through two separate memory processes which are clearly distinct: familiarity and recall. Familiarity is considered relatively automatic and more quantitative, reflecting a ‘strength-like’ signal. Recollection however, is regarded as a somewhat slower process as it requires the recovery of memories that relate to the spatial, temporal and interitem context of a particular episode and so is more qualitative in nature (Mandler, 1980). Alternative models, i.e. ‘single-process’ models, view recollection as reflecting the retrieval of strong and detailed memories, whereas familiarity reflects weaker and less detailed memories (e.g. Donaldson, 1996).

Autonoetic awareness is considered a defining property of episodic memory that is expressed through the reliving of a personal episode (Tulving, 1983). Noetic awareness does not require any such self-recollection, only an awareness of familiarity or knowing. For expressions of autonoetic awareness Tulving applied the term ‘remembering’, and for expressions of noetic awareness he applied the term ‘knowing’. Tulving (1985) demonstrated that participants were able to understand the two types of awareness and the differences between them and report them using remember and know responses. Tulving’s Remember/Know procedure has attracted the attention of researchers over the years attempting to develop it further.

Remembering and knowing define general states of awareness, both of which may be broken down into varieties of experiences (Gardiner & Conway, 1999). Remembering can be broken down into more specific source monitoring judgements, know responses however, can be broken down into additional response categories. This allows for guess responses to be reported as such, and just know responses to be reported separately from familiarity. Familiarity was now defined as the feeling of some recent but unremembered encounter and knowing was just simple knowing, However, both still reflect noetic awareness (Conway, Gardiner, Perfect, Anderson, & Cohen, 1997).

The above issue reflects an ongoing debate as to how know responses are interpreted. When knowing is considered the default response, this allows for participants to take advantage and respond know when they do not in fact possess the necessary awareness to justify the response (Strack & Forster, 1995). Early studies using the remember/know procedure discouraged guessing, yet the addition of a guess response as an option is the more sensible route to take (Gardiner & Conway, 1999; Gardiner, Java, & Richardson-Klavehn, 1996; Gardiner, Kaminska, Dixon, & Java, 1996; Gardiner, Ramponi, & Richardson-Klavehn, 1998, 2002; Gardiner, Richardson-Klavehn, & Ramponi, 1997) as allowing for a guess response does not exclude the option of discouraging it. Evidence from these studies suggests that it is the guess responses that reflect various other judgemental strategies and not in fact know responses.

Other developments of the remember/know procedure involve confidence judgements. Several researchers have proposed that remember and know responses reflect varying degrees of confidence with regard to the products of memory retrieval (Donaldson, 1996; Hirshman, 1998; Inoue & Bellezza, 1998). However, this proposition has been shown to be untenable as research that has directly compared both forms of judgement report difference patterns of results (Gardiner, 2001; Gardiner & Conway, 1999; Gardiner & Java, 1990; Holmes, Waters, & Rajaram, 1998; Mäntylä, 1997; Parkin & Walter, 1992; Perfect, Williams, & Anderton-Brown, 1995; Rajaram, 1993; Rajaram, Hamilton, & Bolton, 2002).

What the above literature has served to show is how the remember/know procedure can differentiate between recollection and familiarity. This would therefore be the comparable task to Eacott, et al.'s (2005) study which showed dissociations between recollection and familiarity in the E-maze. The methodology of the procedure has already developed quite dramatically since Tulving (1985) first introduced it. Although there is still debate about how to interpret the data that it provides, the relevance of it here is that it provides a comparable task that can be modified further. This would allow for the proposed investigation into how the what-where-which and what-where-when memory, for example, as shown in chapters 2 to 4 in animals, would present itself in humans, and whether or not the episodic-like memory previously demonstrated would equate to what is episodic memory in humans. In addition, are the individual components of episodic-like memory such as the temporal and contextual components as essential in humans and are they all episodic in nature?

5.2 Experiments 5a

5.2.1 Introduction

Tulving's (1985) remember/know paradigm provides a suitable method (with modifications) for a task to be built around that is comparable to those used in Chapters 2 to 5. This allows for investigations into how such memories as what-where-which and what-where-when would present themselves in humans. Therefore the current chapter developed a questionnaire with an accompanying slide show that probed such memories using the remember/know paradigm.

It was hypothesised that questions probing 'What-Where-Which' and 'What-Where-When' memory should result in similar patterns of data as both types of question are episodic but simply using difference occasion setters to help define the experience as unique (i.e. time or context). The rationale behind this prediction was that episodic memories are reliant on recollection, and if episodic-like memories are truly episodic in nature then they too should rely on recollection processes. Therefore, if participants' memory for 'What-Where-Which' or 'What-Where-When' is questioned they should only report a remember response as these reflect the recollection processes. Consequently these remember responses would be extremely accurate and accompanied by high confidence ratings. The high confidence ratings reflect that a remember response is signifying absolute recollection. If there was no absolute recollection then this would be reported via Guess responses. The proportion of Know responses should be approaching zero as these questions cannot be solved using familiarity alone. If per chance Know responses were to be reported then the accuracy of these responses would be at chance as use of the familiarity circuit here cannot result in the recall of accurate episodic information. It would also be expected that confidence ratings would not be as high as for Remember responses. Non-episodic questions of a ‘What’ nature acted as a baseline reference for the episodic questions. It was predicted that these questions would be qualitatively different from ‘What-Where-Which’ and ‘What-Where-When’ questions as they can be solved using familiarity alone.

5.2.2 Methods and Materials

5.2.2.1 Participants

Twenty nine third year undergraduate students studying neuropsychology took part in the current experiment. There was a mix of males and females with an age range of between 21 and 23 years of age.

5.2.2.2 Apparatus

5.2.2.2.1 Stimuli

Stimuli were taken from a pilot study carried out by undergraduates (see http://images.google.co.uk/imgres?imgurl=http://www.graphicxtras.com/f7/illustrator_symbols_26_gall.png&imgrefurl=http://www.graphicxtras.com/Products/aisymbols_more26.htm&h=2033&w=800&sz=179&hl=en&start=7&um=1&tbnid=Y_iSLyxMUl-OxM:&tbnh=150&tbnw=59&prev=/images%3Fq%3Dunusual%2Bsymbols%26um%3D1%26hl%3Den%26rlz%3D1W1SNYW%26sa%3DN). The stimuli consisted of symbols that were made up of circles of differing sizes and put together to form shapes which were red in colour. See Figure 5.1 for two examples.

Figure 5.1: Examples of the Stimuli used

5.2.2.2.2 Slide Show

A slide show was created using Microsoft Office Powerpoint 2007. The slide show consisted of two instructional slides pertaining to the experiment, and two experimental slides. The experimental slides were made up of a black and white background context (either a chequered background or a zebra print background) that was to mirror the use of contexts in the E-maze and the Open Field. On these backgrounds were nine different symbols/stimuli akin to those shown in Figure 5.1. The stimuli were the same on each experimental slide as were the possible locations of the stimuli, however object-location pairings changed between contexts (see Figure 5.2). Between the instructional slides and the first experimental slide and also between each experimental slide a blank slide was inserted.

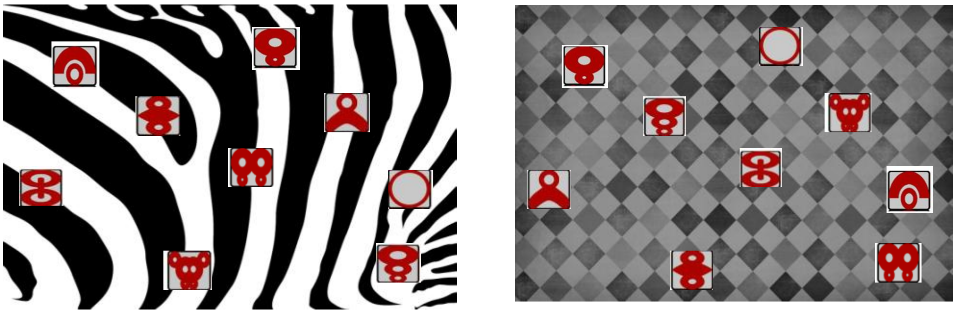


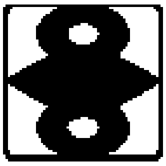
Figure 5.2: The two experimental slides showing the differing background contexts and differing locations of the stimuli

5.2.2.2.3 Questionnaires

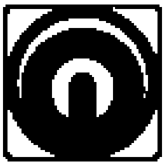
The questionnaires consisted of nine questions. Three of these were questions of a ‘What’ nature (see Figure 5.3), three were of a ‘What-Where-When’ nature (see Figure 5.4) and three of a ‘What-Where-Which’ nature (see Figure 5.5). After each question was presented there were two possible answers, one of which had to be selected. Participants were then asked to select either ‘remember’, ‘know’ or ‘guess’. If the participant selected either ‘remember’ or ‘know’ they were additionally required to give a confidence rating from 1 to 5 (1 indicating low confidence and 5 indicating high confidence). If the participant selected guess they were instructed not to give a confidence rating. There were three versions of the questionnaire, all with the same questions but counterbalanced for order. Questionnaires were printed out in black and white (see appendix).

Q. WHICH OF THESE SYMBOLS HAVE YOU SEEN BEFORE?

A:



B:



Answer (circle your choice):

A B

How did you come to this decision (circle your choice)?

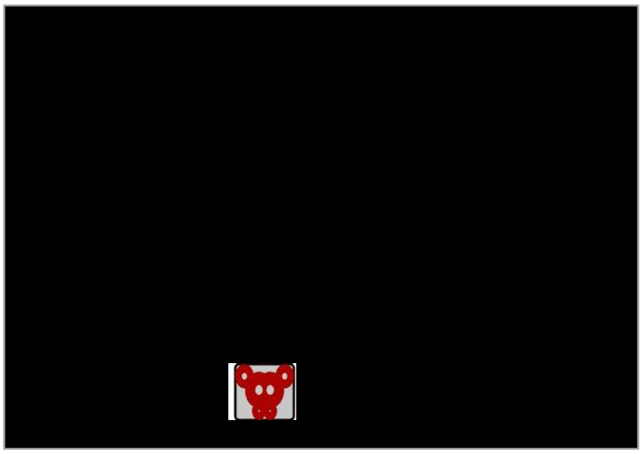
Remember Know Guess

How confident are you of this decision (circle your choice)?

(not confident) 1 2 3 4 5 (confident)

Figure 5.3: Example of a 'What' question

<u>Q. ON WHICH SLIDE DID YOU SEE THIS SYMBOL IS THIS PARTICULAR LOCATION?</u>



Answer (circle your choice):

A: 1ST SLIDE B: 2ND SLIDE

How did you come to this decision (circle your choice)?

Remember Know Guess

How confident are you of this decision (circle your choice)?

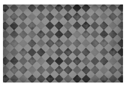
(not confident) 1 2 3 4 5 (confident)

Figure 5.4: Example of a 'What-Where-When' question

Q: ON WHAT BACKGROUND DID YOU SEE THIS OBJECT IN THIS LOCATION?

Answer (circle your choice):

A: ZEBRA B: CHEQURED



How did you come to this decision (circle your choice)?

Remember Know Guess

How confident are you of this decision (circle your choice)?

(not confident) 1 2 3 4 5 (confident)

Figure 5.5: Example of a 'What-Where-Which' question

5.2.2.2.4 Instructions

A sheet of instructions was presented on the top of each questionnaire. This detailed what was required from the participant for the experiment. It also explained in sufficient detail the difference between remember and know (adapted from Geraci & McCabe, 2006; Rajaram, 1993; Wais, Mickes, & Wixted, 2008) and gave examples of each. Participants were informed that they were able to refer back to these instructions at any point during the task. The instructions on the slide show reiterated those on the questionnaire sheet and allowed for any questions to be asked (see appendix).

5.2.2.2.5 Test Room and Experimenter

The current experiment took place in a lecture theatre in the Department of Psychology at the University of Durham. All instructions were given by the experimenter. Silence was observed throughout the duration of the experiment.

5.2.2.3 Design

The task employed a within-participants design. Participants were given one of the three counterbalanced questionnaires, therefore each participant who was sat side by side had a different order of questions.

5.2.2.4 Procedure

After obtaining consent to participate, participants were given one of the three possible questionnaires (as detailed above). They were instructed not to turn over the first page until told to do so. The slide show was then presented. The first two instructional slides were read to the participants which explained the requirements of the task and importantly, what constituted a ‘remember’, ‘know’ or ‘guess’ response. It was also emphasised that participants had to answer every question and also that if they responded ‘guess’ to a question then they were not required to report a confidence rating. Participants were then told they had one minute to read the instruction sheet. After answering any possible questions the first experimental slide was shown (zebra context) for thirty seconds. A blank slide was then presented for one minute followed by the second experimental slide (checked context) for thirty seconds. After the second experimental slide participants were told they could turn over their questionnaires and begin (see Figure 5.6 for a timeline of the slide show). There was no time limit imposed on completing the questionnaire. All timings were strictly adhered to by using a stop watch.

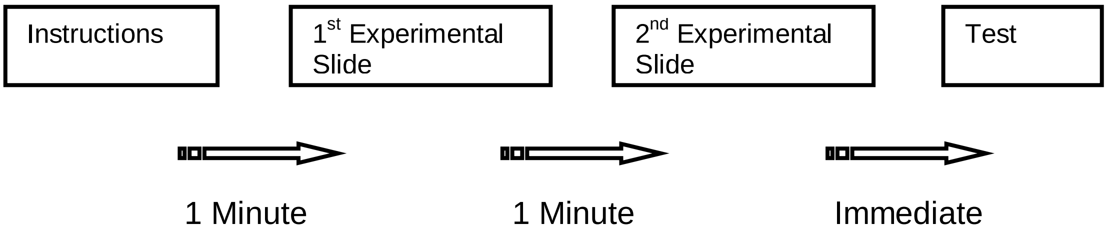


Figure 5.6: Timeline of the Slide Show

5.2.2.5 Data collection

Following the completion of the experiment, the questionnaires were collected, coded and analysed appropriately. Any questionnaires that were not fully completed were excluded. Anonymous codes were kept of all the participants to ensure that no participant was tested again in any future experiments.

5.2.3 Results

The analyses used for the current experiment were of a binomial nature. This was due to the fact that participants could answer either all or none of the questions as either ‘remember’, ‘know’ or ‘guess’ and they are either selected or not selected, therefore only two values can occur, 0 or 1.

Determining if the difference between the proportion of accurate responses was expected by chance alone was determined via these binomial calculations. Average confidence measures were taken from each correct response. Results were analysed using the binomial probabilities outlined above and taken by answer type. Binomials were presented as p values and results were always 1-tailed unless specifically stated otherwise.

5.2.3.1 'What-Where-Which' questions

It was hypothesised that correct responses should be made using Remember (R) judgments *if* the task is episodic in nature due to the fact that such episodic questions can only be accurately answered using recall mechanisms. However, the results show that in fact out of a possible 87 responses only 32 of these (37%) were reported as R responses. In contrast, these questions resulted in 36 Know (K) responses (41%) and 19 Guess (G) responses (22%). Thus, contrary to expectations, 'What-Where-Which' questions actually resulted in marginally more K responses than R responses.

An alternative hypothesis was put forward regarding the possibility that K responses would be reported. If this were to be the case it was predicted that only R responses stemming from the recall circuit would result in above chance accuracy. The accuracy of any K responses reported would be at chance considering that accurate episodic memory cannot be extracted from the familiarity circuit. Therefore, the accuracy of R, K and G in response to 'What-Where-Which' questions was also examined.

For those questions that the participant reported an experience of remembering, the accuracy rate was 91% (29/32) ($p \leq 0.001$). When a 'What-Where-Which' question evoked a feeling of Knowing or resulted in a Guess response the accuracy rate was not significantly different from chance level at 58 % (21/36) ($p = 0.203$) and 53% (10/19) ($p = 0.499$) respectively. Thus, as proposed previously, only those responses that were experienced as Remember resulted in above chance accuracy levels.

Confidence ratings were also reported for R and K responses. It was hypothesised that if K responses were reported for these episodic questions then the confidence ratings would be lower when compared to those associated with R responses.

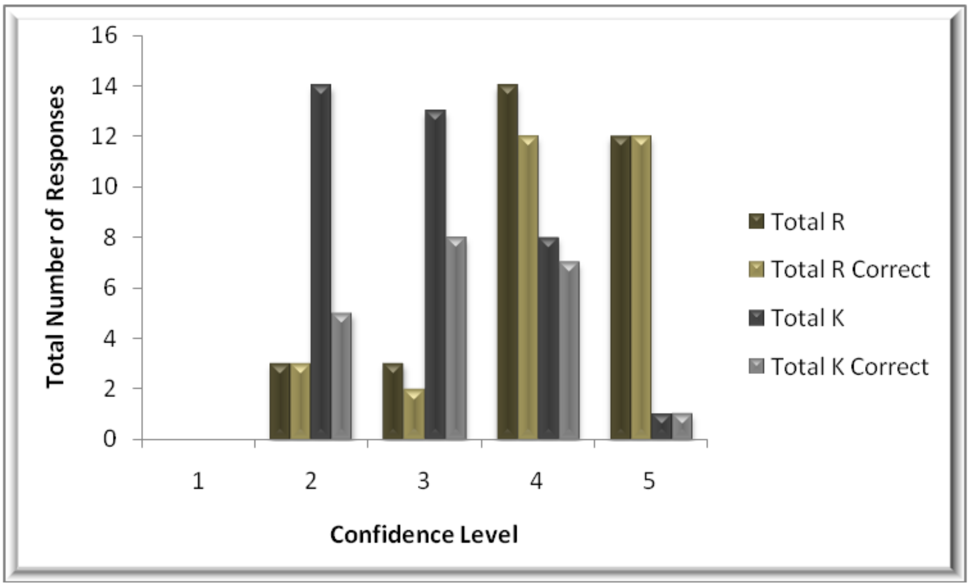


Figure 5.7: What-Where-Which: Total number of responses alongside total number of accurate responses for each confidence level

Figure 5.7 shows the total number of R and K responses and the number of respective accurate responses for 'What-Where-Which' questions. What is apparent from this figure is that ‘total R responses’ and ‘accurate R responses’ are located in the higher confidence ratings (4-5). However, ‘total K responses’ and ‘accurate K responses’ are more widely distributed with the majority constituting the lower confidence ratings (2-3). The distribution of responses and accurate responses for both R and K leads to the question of whether accurate responses are simply a result of confidence. Would R responses be accurate for all reported responses irrespective of the confidence level? Would K responses always be accurate considering they are a reflection of noetic awareness cannot be used to solve an episodic task that requires autonoetic awareness? By examining confidence levels 5 and 4 for example, the proportion of accurate R responses are 100% and 86% respectively. K responses result in accurate responses of 100% and 88% respectively, however, the low number of responses should also be noted (i.e. for confidence level 5 there is only one K response and this response was accurate). It is also apparent that the proportion of accurate K responses seems to decrease alongside confidence levels. Although this can be said for accurate R responses, the proportion of R responses for confidence level 2 was 100% whereas as accurate K responses continued to decrease (36% for confidence level 2). This suggests then that accuracy of R responses is not a matter of confidence but a reflection of the retrieval of an episodic memory as accuracy is high even when a low confidence level is reported alongside it. The proportion of accurate K responses which are seen to decrease with respect to confidence does not necessarily suggest that accuracy is a matter of confidence considering the relatively low number of accurate K responses that are associated with higher confidence levels.

5.2.3.2 ‘What-Where-When’ questions

It was hypothesised that the responses for ‘What-Where-When’ would follow exactly the same pattern as those for ‘What-Where-Which’ questions. However, out of a possible 87 responses, only 48 (55%) of these did participants report a R experience. In contrast, there were 22 K responses (25%) and 17 G responses (20%). However, even though there were more K responses than originally predicted, there were more R responses than K responses for this episodic question.

As for the ‘What-Where-Which’ questions, the alternative hypothesis put forward was that if both R and K responses are produced, it would only be R responses that would result in above chance accuracy. The accuracy of these responses were examined for ‘What-Where-When’ questions and it was found that of those R responses, 96% (46/48) were answered accurately which was significantly above chance ($p \leq 0.001$). Those questions which evoked a feeling of Knowing were answered with an accuracy of 91% (20/22) which was again significantly above chance ($p \leq 0.001$). The accuracy of G responses were at chance (47%, 8/17 $p = 0.5$). Therefore, in contrast to predictions, and also in contrast to the findings from ‘What-Where-Which’ questions, both R and K responses resulted in above chance accuracy.

It was also predicted that the confidence levels reported would be high for R responses and relatively lower for K responses, similar to the results found for ‘What-Where-Which’ questions.

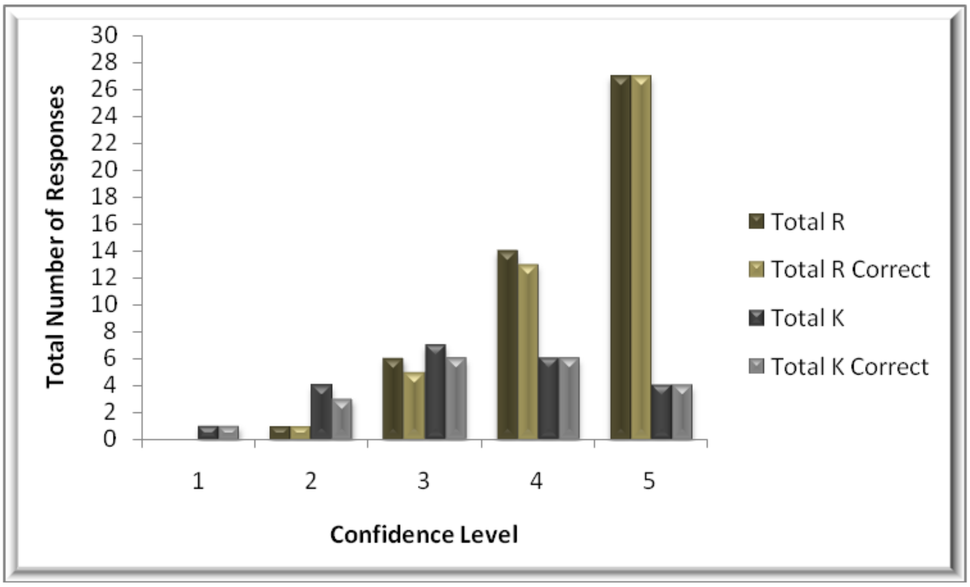


Figure 5.8: What-Where-When: Total number of responses alongside total number of accurate responses for each confidence level

Figure 5.8 shows that the majority of R responses are accompanied by high confidence levels and high accuracy levels. The wide distribution of K responses follows much the same pattern as observed for 'What-Where-Which' questions, with the majority of responses occurring in the average range (2-3). However, what is clearly in contrast to the observations from 'What-Where-Which' questions is that despite the lack of confidence in these responses, the proportion of these K responses that are accurate is surprisingly high. Accuracy of K responses for these questions is high for all confidence levels with the lowest accuracy rate occurring for confidence level 2 (75%), although only one response which was correct was reported for confidence level 1. The distribution of these accurate K responses does not seem to follow the same pattern as that observed for What-Where-Which questions. In fact the pattern is more similar to the distribution of accurate R responses, with high accuracy still observed in the lower confidence levels (1 and 2).

5.2.3.3 'What' questions

The non-episodic 'What' questions resulted in 72 out of a possible 87 responses being reported at R (83%). Responses associated with a feeling of Knowing were lower, with only 13 out of a possible 87 responses (15%), and only 2 G responses were reported (2%). With regard to accuracy, both R (99%, 71/72) and K (100%, 13/13) responses resulted in high accuracy levels ($p \leq 0.001$, $p \leq 0.001$ respectively). Only two G responses (2%) were reported, both of which were accurate (100%, $p = 0.025$).

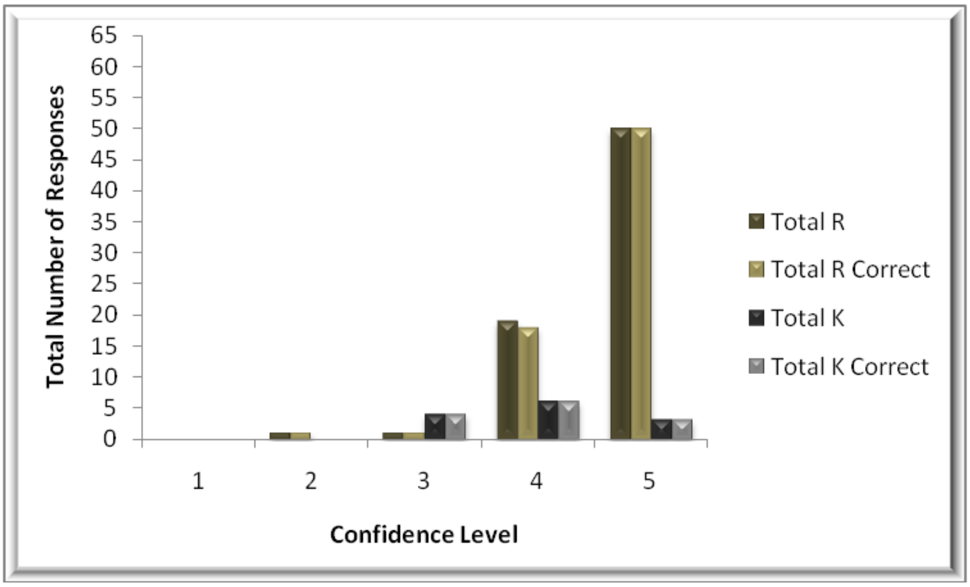


Figure 5.9: What: Total number of responses alongside total number of accurate responses for each confidence level

Figure 5.9 highlights the simple nature of the non-episodic 'What' questions which is reflected in the high confidence and accuracy levels. This is in contrast to the episodic questions of 'What-Where-Which' and 'What-Where-When', despite it being predicted that both episodic questions would be answered using the recall circuits and therefore also resulting in high accuracy and confidence levels. As figures 5.7 and 5.8 demonstrate, this was clearly not the case.

5.2.3.4 Comparisons of question types

It was originally predicted that ‘What-Where-Which’ and ‘What-Where-When’ questions would result in similar patterns of data as both questions probe episodic memory but are simply defining it with a different occasion setter. It was also predicted that responses to these questions would be overwhelmingly of a R nature. As reported previously, what was found was that there were more R responses for ‘What-Where-When’ (55%) questions compared to ‘What-Where-Which’ questions (37%), although as table 5.1 shows, both question types resulted in above chance accuracy rates for these R responses.

Contrary to predictions, participants reported K in response to these episodic questions with more K responses for ‘What-Where-Which’ (41%) than ‘What-Where-When’ questions (25%). An alternative hypothesis that was proposed if K responses were to occur was that the accuracy of these K responses for both episodic questions would be at chance as such episodic questions cannot be solved using the familiarity circuit. As table 5.2 shows, this was the case for ‘What-Where-Which’ questions, however, ‘What-Where-When’ questions resulted in K responses proving to be accurate above the chance level. In fact there was a higher proportion of accurate K responses for ‘What-Where-When’ questions compared to ‘What-Where-Which’ questions.

Questions probing memory for ‘What’ were predicted to be qualitatively different to the episodic questions of ‘What-Where-Which’ and ‘What-Where-When’ as they can be solved using only the familiarity circuit. As reported previously, there was found to be a drop in R responses from ‘What’ questions (83%) to ‘What-Where-Which’ (37%) and ‘What-Where-When’ questions (55%). There was found to be a lower proportion of Know responses regarding ‘What’ questions (15%) reflecting the less complicated, non-episodic nature of the question. With regard to accuracy of responses (see Tables 5.1 and 5.2), ‘What’ questions resulted in a higher proportion of accurate R responses compared to both ‘What-Where-Which’ and ‘What-Where-When’ questions. This was also true of accurate Know responses.

Table 5.5.1: Summarising the results for accurate Remember responses for each question type

Remember Responses			
Question Type	Proportion of Accurate Responses	Percentage Accuracy	Significance Value
What-Where-Which	29/32	91%	**$p \leq 0.001$**
What-Where-When	46/48	96%	**$p \leq 0.001$**
What	71/72	99%	**$p \leq 0.001$**

Table 5.5.2: Summarising the results for accurate Know responses for each question type

Know Responses			
Question Type	Proportion of Accurate Responses	Percentage Accuracy	Significance Value
What-Where-Which	21/36	58%	**$p = 0.203$**
What-Where-When	20/22	91%	**$p \leq 0.001$**
What	13/13	100%	**$p \leq 0.001$**

5.2.4 Discussion

The original hypothesis stated that the episodic questions of ‘What-Where-Which’ and ‘What-Where-When’ would not only result in an overwhelming proportion of R responses and accurate R responses, but that the patterns of data for the two questions types would be comparable due to the fact that both questions probe a triad of episodic memory components with only the occasion setter differing. Confidence levels associated with these responses were also predicted to be high due to the all or nothing nature of the remember experience. If it were to be the case that participants responded K to these episodic questions, then the alternative hypothesis stated that the accuracy of these responses should be at chance level for both question types as episodic questions cannot be solved using the familiarity circuit. Confidence levels associated with these responses should be relatively lower as unlike an experience of remembering, a feeling of familiarity is not absolute. Questions probing memory for ‘What’ would be qualitatively different to the episodic questions as it is possible to solve these questions using familiarity alone.

The results supported the original hypothesis with respect to the fact that the proportion of R responses that were accurate were significantly above chance for both episodic questions, which was also reflected in high confidence ratings. However, the patterns of data differed in that there was found to be a higher percentage of accurate R responses for ‘What-Where-When’ questions compared to ‘What-Where-Which’ questions.

The original hypothesis was not supported however, as for both ‘What-Where-Which’ and ‘What-Where-When’ K responses were also reported, and in the case of ‘What-Where-Which’ questions there were marginally more K responses than R responses. However, small numbers of K responses were also reported for the non-episodic ‘What’ questions. Supporting the alternative hypothesis with regard to these K responses, the accuracy of these in response to ‘What-Where-Which’ questions were at chance. The unexpected result was that when participants responded K to the episodic ‘What-Where-When’ questions, unlike for the ‘What-Where-Which’ questions, the accuracy rate was above chance despite confidence levels not reflecting this.

Interestingly, as the proportion of accurate K responses for ‘What-Where-When’ questions was above chance, in that respect they were more comparable to the results for the ‘What’ questions. As it is not possible to solve an episodic question using familiarity, and if one assumes that ‘What-Where-When’ is indeed an episodic question, then one possible reason for this unusual and unexpected pattern of data may be that participants are also using strength of memory trace to solve the ‘What-Where-When’ questions. This could be possible as in the current experiment there was no delay between the end of the second experimental slide and the start of the test phase. Therefore, it is entirely plausible that in response to ‘What-Where-When’ questions, participants are assigning strong memories to the more recently seen experimental slide and weak memories to the experimental slide that was presented first. This could explain how participants are using a K response to successfully solve an episodic question. The difference in the proportion of R responses could also be explained if participants are using this alternative method to solve the task. Strength of memory trace may lead to a Remember response if the participant is sure the correct answer was located in the first or second experimental slide, even though this would not constitute a Remember response by the definition given to them in the instructions. If a participant is unconsciously using this method, then they would experience a feeling of familiarity but the strength of memory trace would lead to a correct answer.

Whilst examining the results it was also appropriate to determine if the observed results were simply a matter of confidence. Are Remember responses accurate for all confidence intervals, or does confidence determine accuracy? By looking at accurate responses over the confidence intervals patterns emerged for both Remember and Know responses. The proportion of accurate Remember responses for both episodic questions, although seen to decrease over confidence levels 4 and 3, were still highly accurate at the low confidence level of 2. In response to ‘What-Where-Which’ questions, the proportion of accurate K responses decreased alongside confidence levels. This serves to show that R responses are indicating the recall of episodic memory which is absolute in nature as confidence does not appear to wholly affect accuracy of recall. Dual process models (Mandler, 1980) however, and to an extent single process models (Donaldson, 1996), would not expect Remember responses to be accompanied by a low confidence rating as recollection (i.e. Remember) reflects strong and detailed memories. Although it would be expected that K responses should have accuracy at the chance level for all confidence levels in response to episodic questions, the decrease in accuracy of K responses with respect to confidence levels supports the notion that K responses are a reflection of non absolute, non-episodic memory. It is possible to have a slight feeling or a strong feeling of familiarity, however, it is not possible to have slight, yet absolute recall of a memory. The pattern of accurate Know responses for ‘What-Where-When’ questions differed. In fact the pattern was more comparable to that of accurate Remember responses, which showed high accuracy at the lowest reported confidence levels. This also supports the possibility that participants are using another method to solve this episodic ‘What-Where-When’ task and these Know responses may not be reflecting familiarity alone.

In order to investigate whether strength of memory trace is a contributing factor to the observed results, further experiments need to be carried out with the issue of delay being addressed.

5.3 Experiment 5b

5.3.1 Introduction

The previous experiment observed several interesting and unexpected patterns of data. Firstly, it was found that participants were not only responding Remember to the episodic questions of ‘What-Where-Which’ and ‘What-Where-When’ but they were also responding Know. In fact, ‘What-Where-Which’ questions resulted in marginally more K responses than R responses. This was unexpected as in order to solve an episodic task one can only use the recall circuits which are defined by a Remember response. Any alternative responses were expected to be reported as guesses. There were also unexpected differences in the proportion of Remember and Know responses between the two episodic questions. It was originally hypothesised that the patterns of data for both questions would be similar due to the fact that they are both episodic questions with only the occasion setter differing. However, ‘What-Where-When’ questions resulted in more Remember responses in comparison to ‘What-Where-Which’ questions. In addition, those Know responses that were reported for ‘What-Where-When’ questions had an accuracy rate that was found to be significantly above chance which was in contrast to the results for ‘What-Where-Which’ questions but not the non-episodic ‘What’ questions. The alternative hypothesis in Experiment 5a for any Know responses that may occur predicted that accuracy would be at chance for both types of episodic question. As it is not possible to solve such an episodic question using familiarity, it was suggested that participants are also using strength of memory trace to solve these questions. The reasoning behind this suggestion was the fact that there was no delay between the second experimental slide and the test phase of the task, which could make it possible for participants to assign strong memories to the most recently seen experimental slide and weak memories to the first experimental slide and answer the questions accordingly. Therefore, the current experiment addressed this issue by increasing the delay between the second experimental slide and the test phase of the task. This was achieved by having the instructional phase of the task after the second experimental slide, thereby increasing the delay without altering the total length of the experiment. Although it may still be possible to use this strategy to solve the task, the delay should reduce the effectiveness of it. It was predicted that the patterns of data for ‘What-Where-Which questions’ would be similar to those seen in Experiment 5a. Data resulting from ‘What-Where-When’ questions however should result in a drop in accuracy of Know responses from above chance to chance levels reflecting the elimination of strength of memory trace. There may also be a drop in the proportion of both Remember and Know responses which would then be comparable to data from ‘What-Where-Which’ questions.

5.3.2 Methods and Materials

5.3.2.1 Subjects

Thirty eight first year undergraduates studying statistics for psychology took part in the current experiment. There was a mix of males and females with an age range of between 18 and 20 years of age.

5.3.2.2 Apparatus

5.3.2.2.1 Stimuli

Stimuli were the same used as in Experiment 5a.

5.3.2.2.2 Slide Show

The slide show in the current experiment only differed with regard to the location of the instructional slide. For Experiment 5a it was located at the start of the slide show, however, in order to increase the delay between the second experimental slide and the test phase, the instructional slide was now presented after the second experimental slide. This also allowed for the total length of the experiment to be the same as in Experiment 5a.

5.3.2.2.3 Instructions

Due to the different location of the instructional slide (see slide show), the introductory instructions now simply informed participants that they would be presented with two different slides, each of which they needed to concentrate and afterwards they would be given further instructions on how to proceed.

5.3.2.2.4 Questionnaires

Experiment 5a saw three versions of the questionnaire counterbalanced for order. The current experiment introduced three more questionnaires so that not only were questions counterbalanced for order, but also for answer. Consequently the three new questionnaires were identical to the original three but with the answers in the opposite order. There now existed six questionnaires counterbalanced with and between blocks of question types.

5.3.2.2.5 Test Room and Experimenter

As in Experiment 5a, the experimenter was the author, however the testing room changed to a laboratory in the psychology department at the University of Durham.

5.3.2.3 Design

The design was the same as outlined in Experiment 5a but for the addition of three questionnaires that allowed for the counterbalancing of answers.

5.3.2.4 Procedure

The procedure only differed from that described in Experiment 5a with respect to when the participants were presented with the instructional slide. The current task saw participants being presented with an introductory instruction slide (see slide show) followed by the first experimental slide for 30 seconds. After this first experimental slide a blank slide was presented for 1 minute, as in Experiment 6a. The second experimental slide was then presented for 30 seconds, following this 1 minute was taken to present and verbalise the full instructional slide and to inform participants that they could now read the instructions located on top of the questionnaire sheets (see Figure 5.10 for a timeline of the slide show).

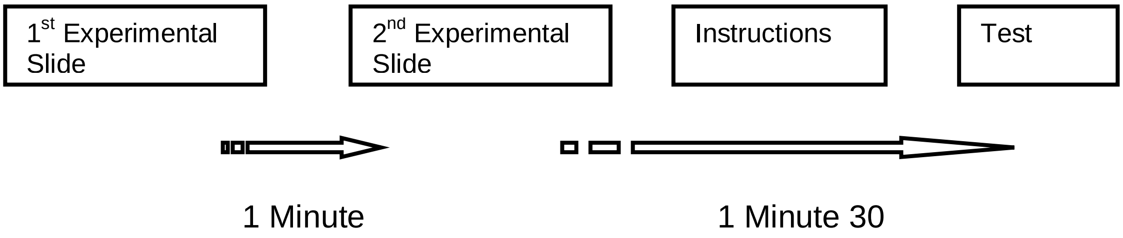


Figure 5.10: Timeline of the Slide Show

5.3.3 Results

Results were analysed the same manner as described for Experiment 5a.

5.3.3.1 ‘What-Where-Which’ questions

Although the focus of the current experiment mainly lies with the data associated with ‘What-Where-When’ questions, it was hypothesised that ‘What-Where-Which’ questions would result in data that was comparable to that observed in Experiment 5a. Yet one unusual aspect of the data from Experiment 5a was the fact that there were marginally more Know (K) responses than Remember (R) responses for ‘What-Where-Which’ questions. However, data from the current experiment shows that out of a possible 114 responses (38 participants x 3 questions) 43 of these were reported as a R experience (38%), whereas only 32 were reported as a K response (28%). This is in contrast to the results of Experiment 5a but at the same time more consistent with the original hypothesis of Experiment 5a. Although K responses were still reported, the proportion of R responses were as expected, higher than the proportion of K responses. In fact the difference in the proportion of R responses from Experiment 5a to the current experiment was marginal, however there was a more noticeable drop in the proportion of K responses. Guess (G) responses were also higher in the current experiment with 37 out of a possible 114 (33%). This again was expected in Experiment 5a as if a participant is not able to recall the episodic information required to answer the question then it follows that they should report a G response.

For those questions that participants reported a feeling of remembering, the accuracy rate was highly significant (79%, 34/43, $p \leq 0.001$). When a feeling of familiarity was experienced, indicated by a K response, the proportion of responses that were accurate was 69%, (22/32) which was significantly above chance ($p = 0.026$). Although this was unexpected as K responses reflecting familiarity should not facilitate the solving of an episodic question, this was seen previously in Experiment 6a in response to What-Where-When questions. The proportion of accurate G responses was at chance (57%, 21/37, $p = 0.254$).

Again, confidence ratings were also reported for R and K responses. It would be expected that a similar pattern of results to Experiment 5a would be observed with the majority of R and accurate R responses constituting the higher confidence levels, although accuracy for lower confidence levels if reported would also be high. It was also expected that K responses would again be widely distributed, as in Experiment 5a, with the majority constituting the lower confidence levels. Accuracy, although found to be significantly above chance in the current experiment, should follow the same pattern as for Experiment 5a, with accuracy decreasing alongside confidence levels.

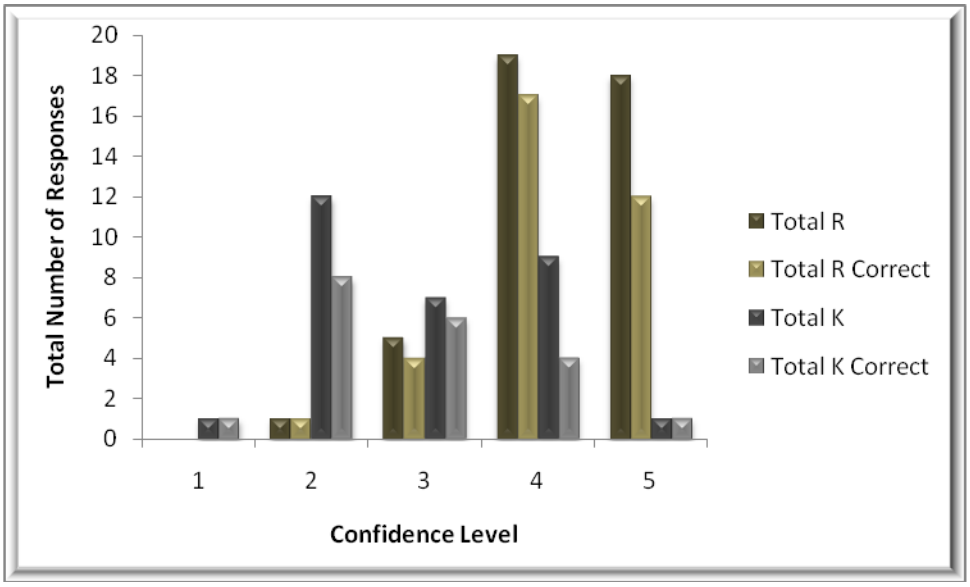


Figure 5.11: What-Where-Which: Total number of responses alongside total number of accurate responses for each confidence level

Figure 5.11 shows the total number of R and K responses and the number of respective accurate responses for 'What-Where-Which' questions. Indeed, the majority of R responses do constitute the higher confidence levels, whereas K responses are more widely distributed. Although accuracy levels for R responses are somewhat lower for each confidence level compared to Experiment 5a, as said before, overall there is no difference in the accuracy rates of the two experiments, and also R responses are still highly accurate at the lowest reported confidence level (e.g. 100% and 80% for levels 2 and 3 respectively). The distribution of accurate K responses does not appear to follow the same pattern as that observed in Experiment 5a. Although accuracy was found to be above chance in the current experiment, accuracy did not increase with confidence (e.g. 67%, 86% and 44% for levels 2, 3 and 4 respectively) in turn suggesting that in fact accuracy is not dependent upon confidence.

5.3.3.2 ‘What-Where-When’ questions

It was hypothesised that the results from the current experiment would see a drop in the proportion of R and K responses from Experiment 5a, that would be comparable to the results from ‘What-Where-Which’ questions. Out of a possible 114 responses, 67 of these were experienced as R (59%) which was only marginally different to the proportion of R responses in Experiment 5a. The proportion of K responses for the current experiment was (27/114, 24%) which again is lower than the proportion of R responses and only marginally different to the proportion reported in Experiment 5a. This was also true of G responses (20/67, 18%).

Despite this, the crucial aspect of the current experiment involved accuracy of responses. The proportion of accurate R responses was still significantly above chance (84%, 56/67 $p \leq 0.001$) although notably lower than observed in Experiment 5a. The proportion of accurate K responses was now bordering on chance (67%, 18/27, $p = 0.062$) which appeared to be a dramatic drop from Experiment 5a as predicted. The current experiment also resulted in a substantially higher proportion of accurate R responses compared to K responses, which fits with the original hypothesis that proposed episodic questions would result in more R than K responses as familiarity cannot be used to solve an episodic task. The proportion of accurate G responses was at chance (65%, 13/20, $p = 0.131$) as predicted originally, and as seen in Experiment 5a.

Confidence ratings were again analysed with respect to the total proportion of R and K responses and the proportion of accurate R and K responses.

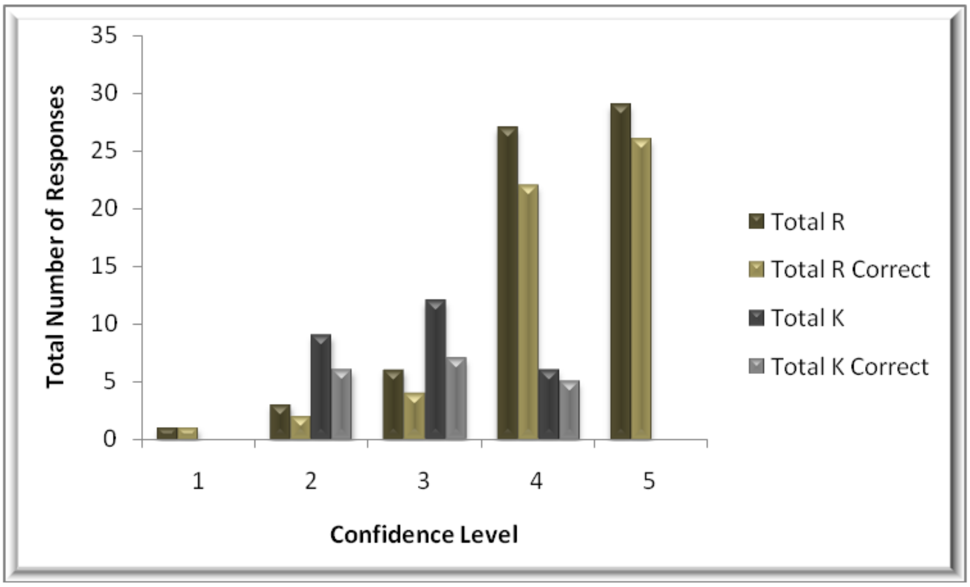


Figure 5.12: What-Where-When: Total number of responses alongside total number of accurate responses for each confidence level

Figure 5.12 shows that R responses follow the predicted pattern in that the majority of responses constitute the higher confidence levels, yet responses occurring for low confidence levels are also found to be highly accurate. However, accuracy for R responses is lower for individual confidence levels (e.g. 82% and 83% for levels 4 and 5) compared to Experiment 5a, however, overall there was a significant drop in accuracy. The proportion of K responses in the current experiment was not as widely distributed as in Experiment 5a. In addition, although accuracy was highest for the highest confidence level reported (i.e. 83% for level 4), this did not then decrease alongside confidence (i.e. 58% and 67% for levels 3 and 2 respectively). The pattern seen here is more comparable to the pattern observed for What-Where-Which questions in the current experiment, again suggesting that accuracy is not a result of confidence.

5.3.3.3 *'What' questions*

The non-episodic 'What' questions resulted in 84 responses being reported as R (74%) which was noticeably lower than Experiment 5a. Responses associated with a feeling of Knowing were substantially lower than the proportion of R responses, with only 24 out of a possible 114 responses (21%), however only marginally different to the results of Experiment 5a. With regard to G responses only 6 out of a possible 114 were reported (5%) which was also similar to the results found in Experiment 5a.

Accuracy was high for both R (96%, 81/84, $p \leq 0.001$) and K responses (92%, 22/24, $p \leq 0.001$), but at chance for G responses (67%, 4/6, $p = 0.344$).

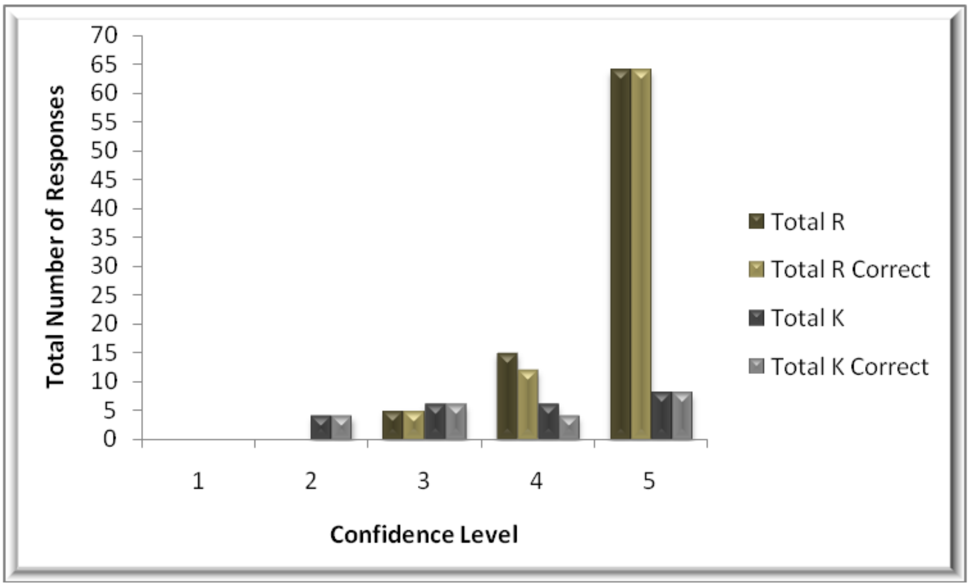


Figure 5.13: What: Total number of responses alongside total number of accurate responses for each confidence level

The high confidence and accuracy levels of Figure 5.13 again highlights the simple nature of the non-episodic 'What' questions and is comparable to the results observed in Experiment 5a and shown in Figure 5.9.

5.3.3.4 Comparisons of question types

It was predicted that with the modifications to the methodology that 'What-Where-Which' and 'What-Where-When' questions would result in more comparable patterns of data that were not so apparent in Experiment 5a. It was predicted that the proportion of R and K responses for 'What-Where-When' questions would be similar to that of 'What-Where-Which' questions, and crucially, the proportion of accurate K responses for 'What-Where-When' questions would drop to chance levels, matching that of 'What-Where-Which' questions.

As seen in Experiment 5a, there were substantially more R responses for 'What-Where-When' (59%) questions compared to 'What-Where-Which' questions (38%), however as before, both question types resulted in above chance accuracy rates for these R responses (see Table 5.3). As expected, as both questions probe episodic memory, there was only a marginal difference between the proportion of these accurate R responses. Unlike the results from Experiment 5a, there was very little difference in the proportion of K responses for 'What-Where-Which' (28%) and 'What-Where-When' questions (27%). Although the accuracy of K responses dropped to chance levels for 'What-Where-When' questions as predicted, accurate K responses for 'What-Where-Which' questions were now unexpectedly just above chance (see Table 5.4). However, the actual difference between the proportion of accurate K responses for 'What-Where-Which' and 'What-Where-When' was very small.

As with Experiment 5a, it was expected that questions probing memory for 'What' would be qualitatively different to the episodic questions of 'What-Where-Which' and

‘What-Where-When’ as they can be solved using familiarity alone. There was found to be a notable drop in R responses from ‘What’ questions to ‘What-Where-When’ questions and a further drop compared to ‘What-Where-Which’ questions. Compared to Experiment 5a, the proportion of K responses was comparable for all three questions types. With regard to accuracy of these responses, ‘What’ questions resulted in a higher proportion of accurate R and K responses compared to both episodic questions (see Tables 5.3 and 5.4).

Table 5.3: Summarising the results for accurate Remember responses for each question type

Remember Responses			
Question Type	Proportion of Accurate Responses	Percentage Accuracy	Significance Value
What-Where-Which	34/43	79%	**$p \leq 0.001$**
What-Where-When	56/67	84%	**$p \leq 0.001$**
What	81/84	96%	**$p \leq 0.001$**

Table 5.4: Summarising the results for accurate Know responses for each question type

Know Responses			
Question Type	Proportion of Accurate Responses	Percentage Accuracy	Significance Value
What-Where-Which	22/32	69%	**$p = 0.026$**
What-Where-When	18/27	67%	**$p = 0.062$**
What	22/24	92%	**$p \leq 0.001$**

5.3.4 Discussion

Considering the results of Experiment 5a, the current experiment modified the methodology with regard to the delay between the second experimental slide and the test phase of the task. It was predicted that this modification would reduce the effectiveness of the strength of memory trace strategy being used to solve the ‘What-Where-When’ questions. It was predicted if only episodic memory was being utilised to solve the ‘What-Where-When’ questions then the results should be more comparable to the results form ‘What-Where-Which’ questions. Therefore, there would be a decrease in the proportion of Remember and Know responses for ‘What-Where-When’ questions and also a decrease in the proportion of accurate Know responses for these questions to chance level. Again, results probing the non-episodic ‘What’ memory would be expected to be qualitatively different to the episodic questions.

The results of the current experiment show that the proportion of Remember and Know responses for ‘What-Where-When’ questions were comparable to those seen in Experiment 5a, and as expected for an episodic question, there was a higher proportion of R responses. Accuracy of these R responses, although lower than seen in Experiment 5a, was still above chance levels. In addition, the accuracy of Know responses was seen to drop from Experiment 5a, resulting in accuracy at chance level. It would therefore appear that increasing the delay between the second experimental slide and the test phase of the task eliminated the use of strength of memory trace to solve these episodic ‘What-Where-When’ questions. This is also reflected in the confidence ratings. Know responses are not as widely distributed as seen in Experiment 5a, nor does the accuracy decrease alongside confidence levels. Remember responses do follow the same pattern as observed in Experiment 5a showing high accuracy as the lowest reported confidence levels. Thus, accuracy is not simply a matter of confidence.

What is interesting is data from ‘What-Where-Which’ questions. There was found to be a notable drop in the proportion of K responses from Experiment 5a resulting in a bigger difference between the proportion of R and K responses within the current experiment, although this difference was not considered substantial. The proportion of Guess responses was also somewhat higher for the current experiment, however there was little difference in the proportion of Know and Guess responses, as originally predicted. If a participant is answering an episodic question they must utilise the recall circuits signified by a Remember response, the proportion of Know and Guess responses would be at chance as familiarity cannot facilitate the recall of an episodic memory. The proportion of accurate Remember responses was significantly above chance, again as expected, but now it was 'What-Where-Which' questions that resulted in Know responses being accurate above chance levels. These accuracy levels, although above the chance level, when considered in regard to the actual proportion of responses was not overtly different to the accuracy levels for 'What-Where-When' questions whose accuracy was at chance. Confidence levels for these responses however, were comparable to the 'What-Where-When' questions of the current experiment and also of the same 'What-Where-Which' questions of Experiment 5a.

When comparing the non-episodic 'What' questions, Experiment 5a saw a higher proportion of Know responses for 'What-Where-Which' questions, but not 'What-Where-When' questions. In the current experiment however, there exists very little difference in the proportion of Know responses from 'What' questions to both the episodic questions. Although importantly, accuracy is significantly higher for 'What' questions as they can be solved through the familiarity circuits. Therefore, although the proportion of responses to do not differ dramatically, accuracy as expected does.

The results of the current experiment were successful in the original aim of reducing the proportion of accurate Know responses for ‘What-Where-When’ questions. Although the current experiment has resulted in the proportion of accurate Know responses for ‘What-Where-Which’ questions now being above chance, as said before, this is not substantially different when considering the proportion of responses to data from ‘What-Where-When’ questions. The importance of the proportions must not be overlooked when applying such binomial statistics. Due to this, the following experiment would aim to collect more data in order to increase the power of the results before any firm conclusions are made. Several minor modifications regarding counterbalancing and colour of stimuli will also be made to the methodology. Analyses of this experiment will be compared to the current experiment and then the two experiments as a whole will be analysed to determine if this has a noticeable effect on the results. Participants in the following experiment will also be of a different year group as it is possible that the first year group used in the current experiment had no experience of the Remember/Know procedure. Those participants who have studied the area may have an unfair advantage over first year participants as their understanding of the differences between Remember and Know would be greater.

5.4 Experiment 5c

5.4.1 Introduction

Experiment 5b appeared to successfully reduce the effectiveness of the strength of memory trace strategy to solve the episodic ‘What-Where-When’ questions. Yet, although there was only a marginal difference in the proportion of accurate Know responses between the two episodic questions, 'What-Where-Which questions resulted in above chance accuracy for Know responses. Before drawing any firm conclusions, it is necessary to keep in mind the actual proportions of accurate responses for both question types. Although the binomial statistics used to analyse the data in this chapter do inform the reader as to whether a proportion is above chance, overall proportions of responses must also be considered as this may affect the overall power of the result. Therefore, the current experiment aimed to gather more data with the intention increasing the power of analysis. As the current experiment also manipulated the methodology with regard to counterbalancing and colour of stimuli, analysis was initially conducted separately to Experiment 5b and then with Experiment 5b.

5.4.2 Methods and Materials

All aspects of the methodology and materials were as described in Experiment 5b with the exception of the manipulations outlined below.

5.4.2.1 Subjects

45 second year undergraduates studying psychology took part in the current experiment. There was a mix of males and females with an age range of between 19 and 21 years of age.

5.4.2.2 Stimuli

Stimuli in the slide show were altered to a grey scale colour that would then be comparable to the questionnaires on which the stimuli were also grey scale.

5.4.2.3 Slide Show

The only aspect of the slide show that was altered was the colour of the stimuli to a grey scale (see Stimuli).

5.4.2.4 Questionnaires

Questionnaires were as described in Experiment 5b. The only alteration was with regard to the counterbalancing of the final block of three questions. This was rectified by altering the answers from either A to B, 1st to 2nd, or Zebra to Chequered. This meant that all questions were balanced for order of question and answer so if participants with the same order of questions were seated next to each other the answers would not necessarily be the same.

5.4.2.5 Test Room and Experimenter

The test room for the current experiment was a lecture theatre in the department of computer science at the University of Durham.

5.4.3 Results

5.4.3.1 'What-Where-Which' questions

Data from the current experiment shows that out of a possible 135 responses (45 participants x 3 questions) 50 of these were reported as a R experience (37%) compared to 47 K responses (35%) and 38 (28%) G responses. Only marginal differences were observed between the proportion of R responses from Experiment 5b to the current experiment. The difference between both K and G responses from Experiment 5b to the current experiment were slightly higher than that of R responses but still relatively inconsequential.

For those responses where participants indicated a feeling of remembering, accuracy was again high (82%, 41/50, $p \leq 0.001$) and of a similar level to the accuracy rate reported in Experiment 6b. Those responses that indicated a feeling of Knowing saw accuracy at chance levels (53%, 25/47, $p = 0.386$) as originally hypothesised and which was also a substantial drop from the levels reported in Experiment 5b which were above chance. This is in agreement with the original hypothesis which states that in response to an episodic question the proportion of accurate R responses would be higher than for any reported K responses, as only recall processes reflected by a Remember response can facilitate the solving of an episodic question. Accurate G responses were also at chance levels (albeit marginal) (55%, 21/38, $p = 0.062$) as seen in both the previous experiments.

Again, confidence levels were reported, however, as the question of whether accuracy was a matter of confidence was answered in Experiment 5b, only the patterns of accuracy and confidence levels were analysed with respect to question type in order to observe any anomalies.

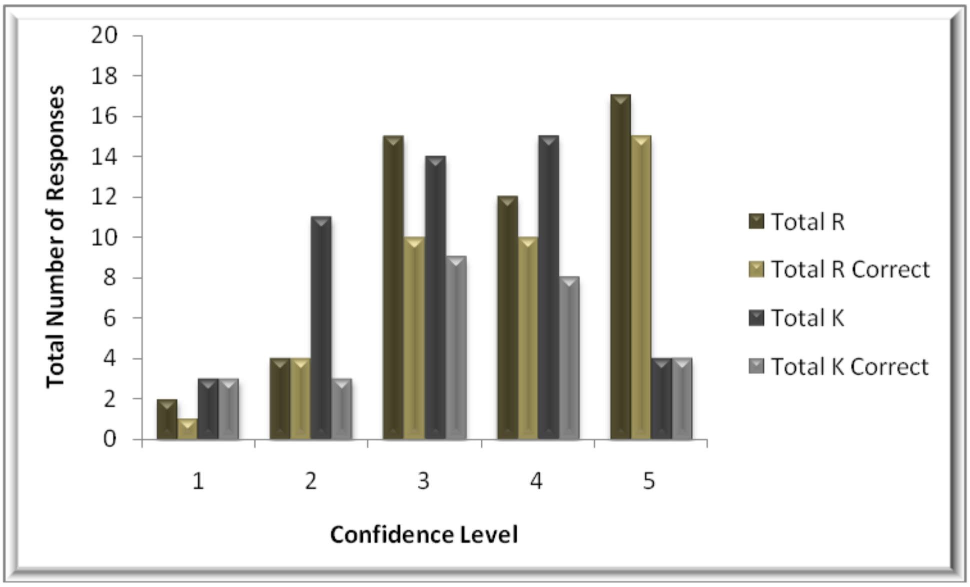


Figure 5.14: What-Where-Which: Total number of responses alongside total number of accurate responses for each confidence level

Figure 5.14 shows a similar distribution of R responses and accurate R responses with respect to confidence levels. The majority of R responses constitute the higher confidence levels and accuracy is high despite a low confidence rating (e.g. 100% level 2). Know responses are again widely distributed, and although accuracy is high for low confidence levels such as level 1 (100%), accuracy for other levels is low in comparison.

5.4.3.2 'What-Where-When' questions

Out of a possible 135 responses, 58 of these (43%) were reported as Remember, 43 as Know (32%) and 34 (25%) as Guess. Although the proportion of R responses was higher than that of K responses in the current experiment, the difference in the proportion of R responses was notably reduced compared to Experiment 5b which inevitably led to an increase in K and G responses.

Of those R responses reported, the accuracy rate was high as originally hypothesised (90%, 52/58, $p \leq 0.001$) and only slightly higher compared to those reported for Experiment 5b. The previous experiment reported the accuracy of K responses at chance level, which would be expected for an episodic question. It was therefore concluded that if strength of memory trace was being used as a strategy to solve these questions in Experiment 5a, that the modifications to the methodology of Experiment 5b rectified this. However, the current experiment shows accuracy of K responses again significantly above chance levels (67%, 29/43, $p = 0.017$), although the proportion of accurate responses did not differ from the previous experiment to the current experiment. As discussed in Experiment 5a and 5b, accuracy of K responses should be at chance reflecting the fact that only the recall circuits (signified by a R response) can solve episodic questions. Guess responses as expected were at chance levels (56%, 19/34, $p = 0.305$) as seen in Experiment 5b. In the current experiment accuracy was also found to be substantially higher when a participant reported a feeling of Remember compared to when a feeling of Know was reported which would be expected for an episodic question that should only be solved using recall.

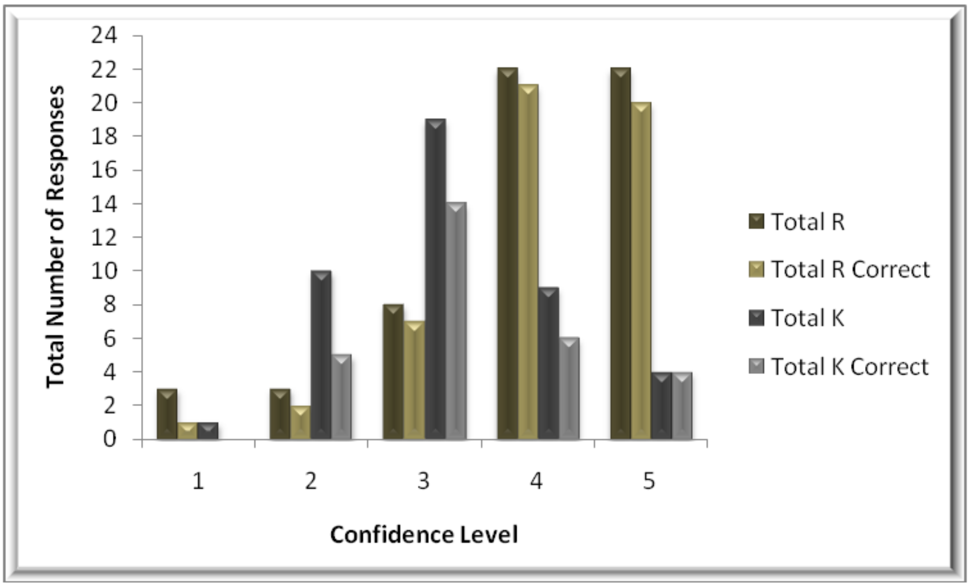


Figure 5.15: What-Where-When: Total number of responses alongside total number of accurate responses for each confidence level

Figure 5.15 shows again the distribution of responses and accurate responses over the differing confidence levels. Remember responses continue to dominate the higher confidence levels and accuracy is high even in the lower levels of confidence. Know responses are widely distributed and accuracy is notably lower.

5.4.3.3 'What' questions

In response to the non-episodic 'What' questions, 87 out of a possible 135 (64%) were reported as a Remember experience, which was again notably higher than the proportion of Know responses (27%, 37/135) and Guess responses (8%, 11/135). The proportion of Remember responses were seen to decrease from Experiment 5b to the current experiment, similar to the results found for 'What-Where-When' questions.

Accuracy for R (98%, p ≤ 0.001) and K responses (95%, p ≤ 0.01) was high as expected due to the fact that this non-episodic question can be solved using recall or familiarity. Accuracy of G responses was found to be above chance in the current experiment (82%, 9/11, p = 0.035).

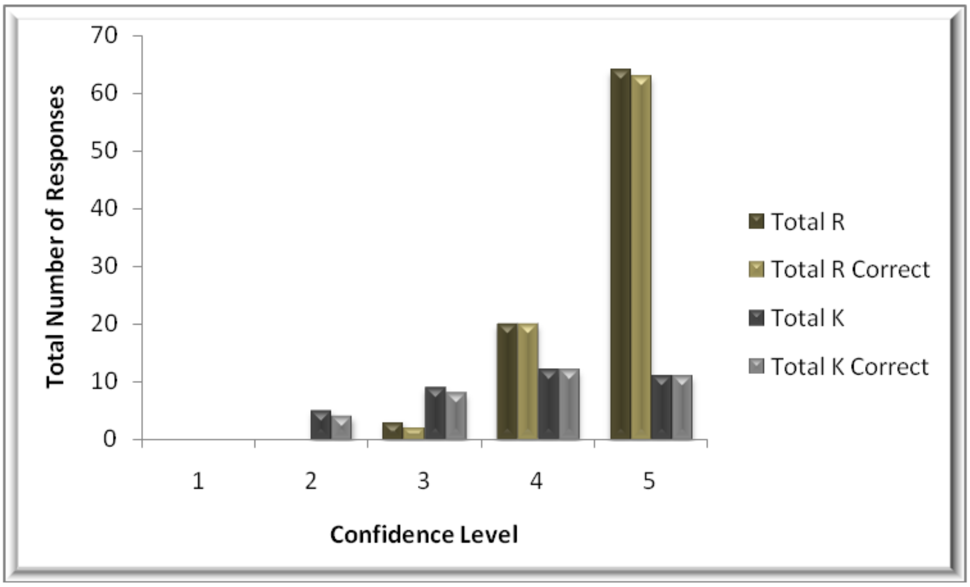


Figure 5.16: What: Total number of responses alongside total number of accurate responses for each confidence level

Figure 5.16 shows the majority of R responses constituting the higher confidence levels with accompanying high accuracy levels. The non-episodic mature of this question is also reflected in the high accuracy levels of K responses.

5.4.3.4 Comparisons of question types

When considering binomial data, as said previously, proportions as well as significance must be taken into account. This was highlighted in Experiment 5b when although the proportion of accurate K responses for 'What-Where-Which' questions was only marginally different to those for 'What-Where-When' questions (69% and

67% respectively), the proportion of accurate K responses for ‘What-Where-Which’ questions was seen to be above chance. For this reason, comparisons between questions types was also carried out by totalling Experiment 5b and 5c to determine if an increase in power resulting from this culmination would yield more concrete results (see Tables 5.7 and 5.8). If this culmination resulted in any differences to the data of Experiment 5c alone it was clearly noted.

As the current experiment aimed to gather more data for analyses purposes, the aims of the current experiment were the same as stated in Experiment 5b. It was predicted that with the modifications to the methodology carried out in Experiment 5b that ‘What-Where-Which’ and ‘What-Where-When’ questions would result in more comparable patterns of data that were not so apparent in Experiment 5a. It was also predicted that the proportion of R and K responses for ‘What-Where-When’ questions would be similar to that of ‘What-Where-Which’ questions, and crucially, the proportion of accurate K responses for ‘What-Where-When’ questions would drop to chance levels, matching that of ‘What-Where-Which’ questions.

The results of the current experiment show that there were again more R responses for ‘What-Where-When’ (43%) questions compared to ‘What-Where-Which’ questions (37%) although the difference in the proportion of these responses were now less pronounced. As in Experiment 5b, both question types resulted in above chance accuracy rates for these R responses (see Table 5.5) with ‘What-Where-When’ questions again resulting in the higher proportion of accurate R responses.

Similar to Experiment 5b, the proportion of K responses for ‘What-Where-Which’ (35%) questions was slightly higher than for ‘What-Where-When’ questions (32%), however the difference was again marginal. Although the accuracy of K responses dropped to chance levels for ‘What-Where-When’ questions in Experiment 5b, accurate K responses in the current experiment were now above chance (see Table 5.6). Pooling the data from both experiments confirmed the accuracy as above chance levels (see Table 5.8).

Accuracy of K responses for ‘What-Where-Which’ questions in Experiment 5b were reported to be above chance, however in the current experiment the accuracy dropped to chance levels (see Table 5.6). Pooling the data again did not see the accuracy above the chance levels, however by looking at Table 5.8 it is clear the added data affected the results. This not only shows the importance of collecting large data sets when applying such binomial statistics, but it also highlights the fact that ‘What-Where-Which’ questions are perhaps being affected by the same strength of memory trace as ‘What-Where-When’ questions but perhaps to a lesser degree.

As stated in the previous experiments, it was expected that ‘What’ questions would be qualitatively different to the episodic questions of ‘What-Where-Which’ and ‘What-Where-When’. The results of the current experiment showed that again ‘What’ questions (64%) resulted in more R responses than ‘What-Where-Which’ questions (37%) and ‘What-Where-When’ questions (43%). There were however less K responses for the non-episodic ‘What’ questions (27%) compared to ‘What-Where-Which’ questions (35%) and ‘What-Where-When’ questions (32%).

With regard to accuracy, 'What' questions resulted in more accurate R responses than both 'What-Where-Which' questions and 'What-Where-When' questions. There was also a higher proportion of accurate K responses for 'What' questions compared to 'What-Where-Which' and 'What-Where-When' questions despite the lower proportion of overall K responses. Therefore, as predicted, non-episodic 'What' questions appear to differ qualitatively from the episodic questions of 'What-Where-Which' and 'What-Where-When' in all aspects analysed.

Table 5.5: Current Experiment: Summarising the results for accurate Remember responses for each question type

Remember Responses			
Question Type	Proportion of Accurate Responses	Percentage Accuracy	Significance Value
What-Where-Which	41/50	82%	**$p \leq 0.001$**
What-Where-When	52/58	90%	**$p \leq 0.001$**
What	85/87	98%	**$p \leq 0.001$**

Table 5.6: Current Experiment: Summarising the results for accurate Know responses for each question type

Know Responses			
Question Type	Proportion of Accurate Responses	Percentage Accuracy	Significance Value
What-Where-Which	25/47	53%	**$p = 0.386$**
What-Where-When	29/43	67%	**$p = 0.017$**
What	35/37	95%	**$p \leq 0.001$**

Table 5.7: Experiments 5b and 5c totalled: Summarising the results for accurate Remember responses for each question type

Remember Responses			
Question Type	Proportion of Accurate Responses	Percentage Accuracy	Significance Value
What-Where-Which	75/93	81%	**$p \leq 0.001$**
What-Where-When	108/125	86%	**$p \leq 0.001$**
What	166/171	97%	**$p \leq 0.001$**

Table 5.8: Experiments 5b and 5c totalled: Summarising the results for accurate Know responses for each question type

Know Responses			
Question Type	Proportion of Accurate Responses	Percentage Accuracy	Significance Value
What-Where-Which	47/79	60%	**$p = 0.057$**
What-Where-When	47/70	67%	**$p = 0.003$**
What	57/61	93%	**$p \leq 0.001$**

5.4.4 Discussion

The results of the current experiment were surprising in that previously it was thought that the manipulations to the methodology of Experiment 5b had decreased the effectiveness of the strength of memory trace strategy in solving the episodic 'What-Where-When' questions. Although the current experiment saw the proportion of accurate K responses for 'What-Where-When' questions above the chance level, the proportion of accurate K responses for 'What-Where-Which' questions were now at chance level even when data from both Experiment 5b and the current experiment were pooled. However, the culmination of the two experiments appeared to have an observable effect on this data. It was previously suggested that this could be due to other strategies such as strength of memory trace being used to solve these tasks, suggesting that strength of memory trace is still affecting both episodic questions but perhaps affecting ‘What-Where-Which’ questions to a lesser degree.

Due to the fact that this current experiment has not entirely resolved this issue, it seems appropriate and logical to conduct a further experiment to determine if it is indeed this strategy that participants are using in conjunction with actual episodic memory to solve the ‘What-Where-Which’ and ‘What-Where-When’ questions.

The following experiment will consist of two studies. The first of which will attempt to emphasise any strength of memory trace strategy being used by increasing the delay between the two experimental slides. It would be expected that participants will be able to remember the last experimental slide more so than the first and therefore if strength of memory trace is used it should result in accurate Know responses for both questions being above chance levels. The second of the two studies shall reduce the delay between the two experimental slides but increase the delay between these and the test phase. Strength of memory trace should therefore decay due to the delay and both slides should be remembered relatively equally.

5.5 Experiment 5d

5.5.1 Introduction

The results of Experiments 5a suggest that participants were using alternative strategies to solve the episodic ‘What-Where-When’ questions as the proportion of accurate Know responses were highly significant. As such questions cannot be solved using the familiarity circuit, it was hypothesised that strength of memory trace was being utilised to retrieve the necessary information to answer the questions correctly. Experiments 5b and 5c attempted to decrease the effectiveness of such a strategy by increasing the delay between the last experimental slide and the test phase of the task. Both experiments still resulted in accurate Know responses above the chance level for either the episodic ‘What-Where-When’ or ‘What-Where-Which’ questions. If the unexpected results of the previous experiments are caused by participants using this strength of memory trace and no alternative strategy, increasing the delay between the two slides should then encourage the use of this strategy and result in significantly high proportions of Know responses and accurate K responses for both episodic questions (the results of experiment 5b and 5c to an extent suggest that ‘What-Where-Which’ questions are also affected).

In contrast, by decreasing the delay between the two experimental slides and instead placing the extended delay after the second experimental slide, strength of memory trace theoretically should have decayed relatively equally for both experimental slides. What the results should show is episodic memory with no interference from strength of memory trace. This would be reflected in, as predicted originally in Experiment 5a, that for both episodic questions R responses should be highly accurate and K and G responses should be at chance level. Results from the non-episodic ‘What’ questions should again be qualitatively different to the results from the episodic questions.

Considering the above the current experiment involved two conditions which manipulated the length of the delay between the two experimental slides.

5.5.2 Methods and Materials

All aspects of the methodology and materials were as described in Experiment 5c with the exception of the manipulations outlined below.

5.5.2.1 Participants

5.5.2.1.1 Condition 1: Long Delay

Thirty five third year undergraduates studying psychology took part in the current experiment. There was a mix of males and females with an age range of between 20 and 22 years of age

5.5.2.1.2 Condition 2: No delay

Twenty six third year undergraduates studying child health psychology took part in the current experiment. There was a mix of males and females with an age range of between 20 and 22 years of age.

5.5.2.2 Slide Show

The only aspect of the slide show that was altered was the delay between the two experimental slides.

5.5.2.2.1 Condition 1: Long Delay

The ‘long delay’ condition required a 2 minute 30 second delay in which the instructions were presented. The test phase was presented immediately after the second experimental slide. The total length of the experiment was not altered (see Figure 5.17).

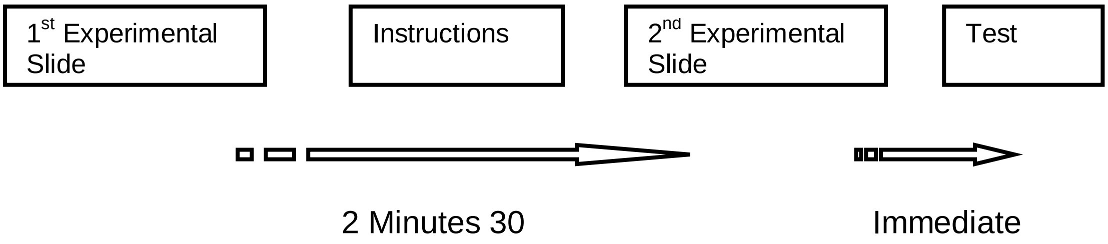


Figure 5.17: Timeline of the slideshow

5.5.2.2.2 Condition 2: No delay

The ‘no delay’ employed a one second delay between the two experimental sides and a 2 minute 30 second delay plus the time allocated for instructions after the second experimental slide and before the test phase of the task. The total length of the experiment was not altered (see Figure 5.18).

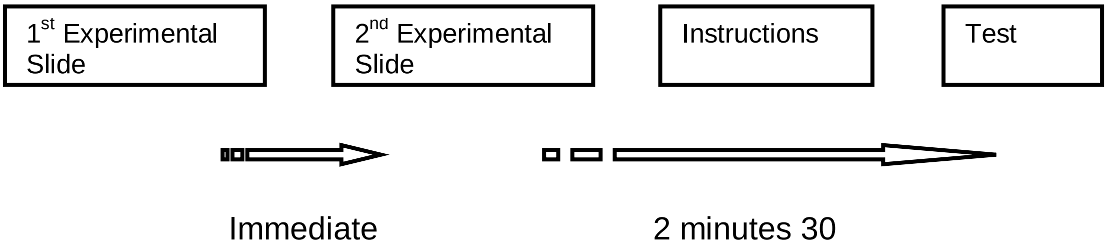


Figure 5.18: Timeline of the Slideshow

5.5.2.3 Test Room and Experimenter

5.5.2.3.1 Condition 1: Long Delay

The test room for this condition was a lecture theatre in the department of psychology at the Stockton campus of the University of Durham.

5.5.2.3.2 Condition 2: No delay

The test room for this condition was a lecture theatre in the department of physics at the University of Durham.

5.5.2.4 Design

The task employed a between-participants design with different participants in each condition, as outlined above.

5.5.3 Results

5.5.3.1 'What-Where-Which' questions

5.5.3.1.1 Condition 1: Long Delay

Out of a possible 105 responses (35 participants x 3 questions) 38 of these were reported as a Remember experience (36%), compared to 41 Know responses (39%) and 26 Guess responses (25%). If in fact strength of memory trace is being employed as a strategy in the current experiment then it would not necessarily be surprising that there would be a higher proportion of K responses than R responses as it may be considered an easier strategy to use.

Accuracy of R responses was found to be significantly above chance (76%, 29/38, p = 0.001), and as expected accurate K responses were also significantly above chance (71%, 29/41, p = 0.006). The proportion of accurate G responses was logically at chance (62%, 16/26 p = 0.163) as even if strength of memory trace was used as well as actual episodic memory to solve the task, G responses would be unaffected.

Confidence levels were again examined to determine if altering the methodology to specifically allow for strength of memory trace to be employed would have an effect on these confidence ratings and also on the confidence of accurate responses.

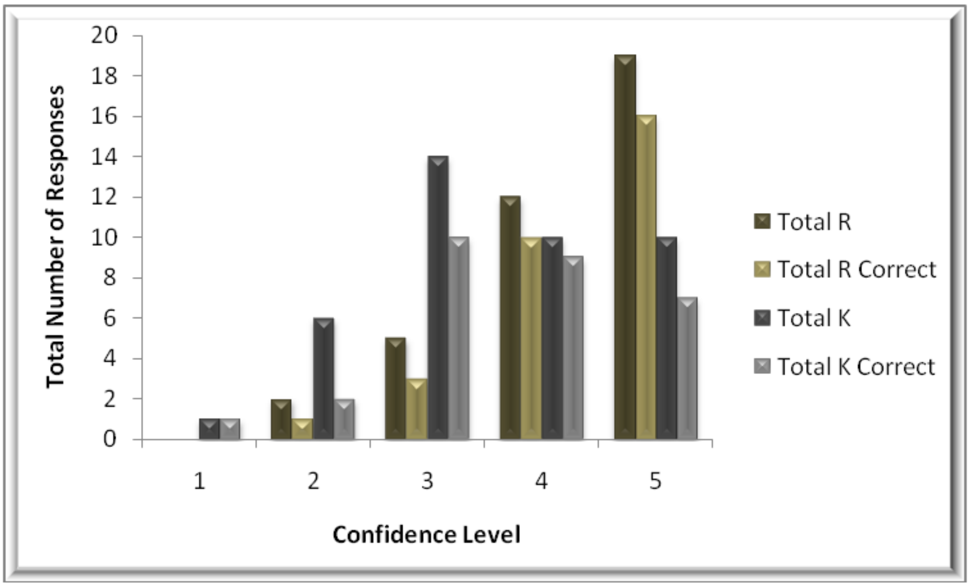


Figure 5.19: What-Where-Which: Total number of responses alongside total number of accurate responses for each confidence level

Figure 5.19 shows that R responses follow the familiar pattern of constituting the higher confidence levels, however accuracy is now seen to increase alongside confidence (e.g. 50% accuracy for level 2 compared to 84% accuracy for level 5). Know responses are more widely distributed with respect to confidence levels, however accuracy does not follow confidence levels (e.g. 71% level 3, 70% level 5).

5.5.3.1.2 Condition 2: No Delay

Out of a possible 78 responses (26 subjects x 3 questions) 20 of these were reported as R (26%), 31 as K (40%) and 27 (35%) as G responses. As well as R responses constituting the least proportion, accuracy of R responses were found to be at chance levels (60%, 12/20, p = 0.251), which was also the case for K responses although marginal (65%, 20/31, p = 0.075), and G responses (52%, 14/27, p = 0.5). Confidence levels were again reported with respect to the total number of responses made and the proportion of accurate responses.

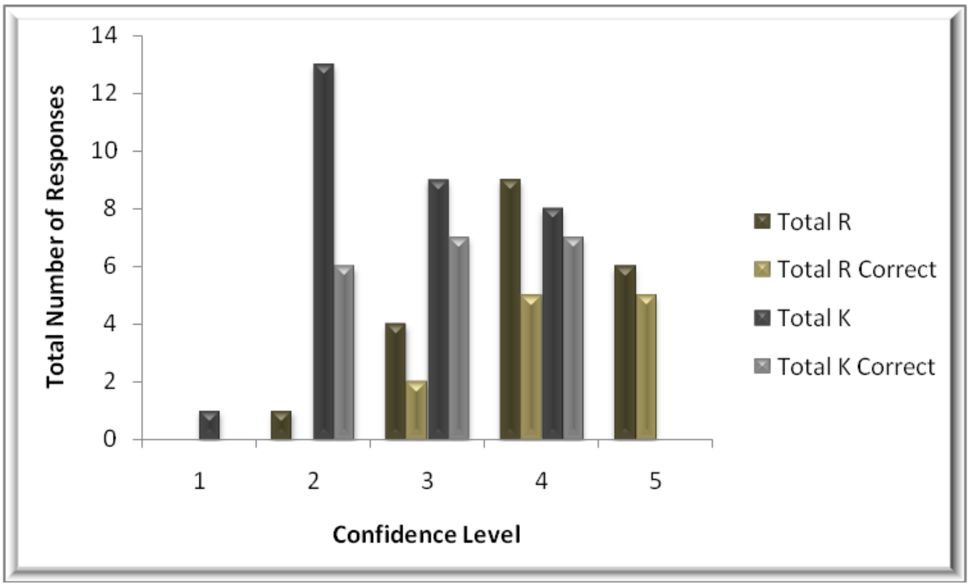


Figure 5.20: What-Where-Which: Total number of responses alongside total number of accurate responses for each confidence level

Figure 5.20 shows confidence for R responses and accuracy of these responses not as high as previously observed (e.g. 83% level 4). Confidence for Know responses is still varied yet appears to increase alongside confidence.

5.5.3.1.3 Condition 1 (Long Delay) v Condition 2 (No Delay)

The elimination of the delay between the two experimental slides appeared to reduce the proportion of R responses (36% to 26%), however these responses were not reflected in K responses (39% to 40%) but in fact reflected in a increase in G responses (25% to 35%). This could be explained if the lack of a delay between the two experimental slides is causing a mergence of the two slides into one episode. This confusion would then be reflected in G responses. Accurate R responses found to be above chance in Condition 1 (Long Delay) also dropped to chance levels in Condition 2 (No Delay) (76% to 60%). This was also the case for K responses (71% to 65%). The proportion of accurate G responses remained at chance levels (62% to 52%). Although it may be expected that accuracy would decrease in Condition 2 (No Delay) as strength of memory trace should be more difficult to employ as an additional strategy, it should still be expected that in response to these episodic questions accuracy of R responses would be above chance reflecting episodic memory. As suggested before, it is possible that the lack of delay between the two experimental slides is not allowing for the two experimental slides to be separated into two episodes and consequently the two are merging into one confusable memory.

5.5.3.2 'What-Where-When' questions

5.5.3.2.1 Condition 1: Long Delay

Out of a possible 105 responses, 'What-Where-When' questions resulted in 43 Remember responses (41%) compared to 40 (38%) Know responses. Guess responses constituted 22 out of the 105 responses (21%). It was previously hypothesised that if only episodic memory was being used to solve these episodic tasks that there should exist no difference between the proportion of R and K responses as neither can facilitate the solving of an episodic task. As the data shows, this difference was minimal.

With regard to accuracy, R responses were found to be above chance levels (88%, 38/43 p ≤ 0.001), as were accurate K responses (70%, 28/40 p = 0.008). Similar to the results reported for ‘What-Where-Which’ questions, there was a higher proportion of accurate R responses compared with K responses. Accurate G responses were at the chance level as expected (59%, 13/22, p = 0.261).

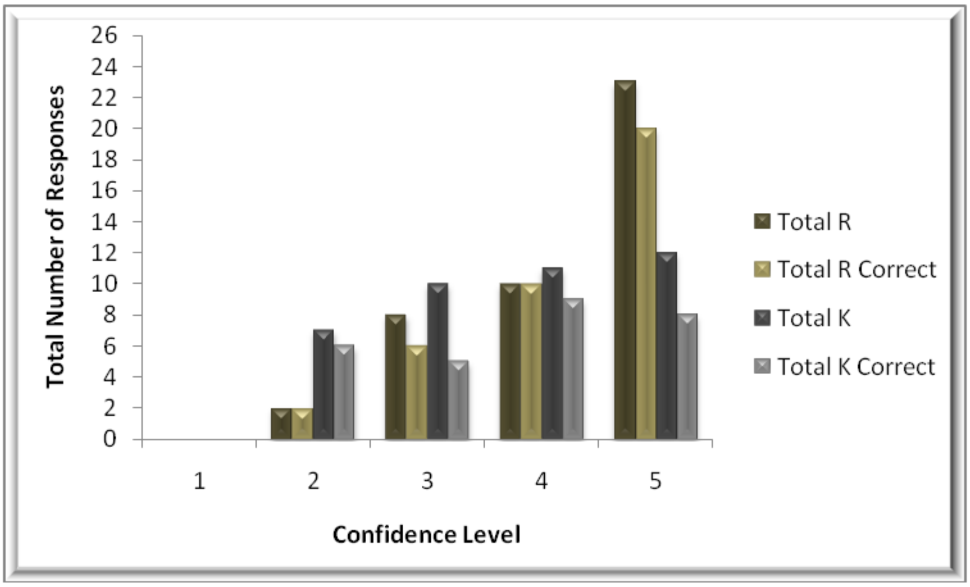


Figure 5.21: What-Where-When: Total number of responses alongside total number of accurate responses for each confidence level

Figure 5.21 shows that the majority of R responses are accompanied by a high confidence rating, with accuracy being high even when confidence is low (e.g. 100% level 2). Those responses indicated a feeling of Knowing are not as widely distributed as seen previously, yet accuracy is still varied whether confidence is considered high or low (e.g. 86%, level 2; 67%, level 5).

5.5.3.2.2 Condition 2: No Delay

Out of a possible 78 responses to ‘What-Where-When’ questions 30 of these were reported as a Remember experience (39%), 27 reported as a feeling of Knowing (35%), and 21 were reported as Guesses (27%). Again, the difference between the proportion of R and K responses was minimal.

Unlike the results reported for ‘What-Where-Which’ questions, this condition resulted in accuracy for R responses above the chance levels (87%, 26/30, $p \leq 0.001$), as was the accuracy for K responses (78%, 21/27, $p = 0.004$). The proportion of accurate G responses remained at chance (62%, 13/21, $p = 0.192$).

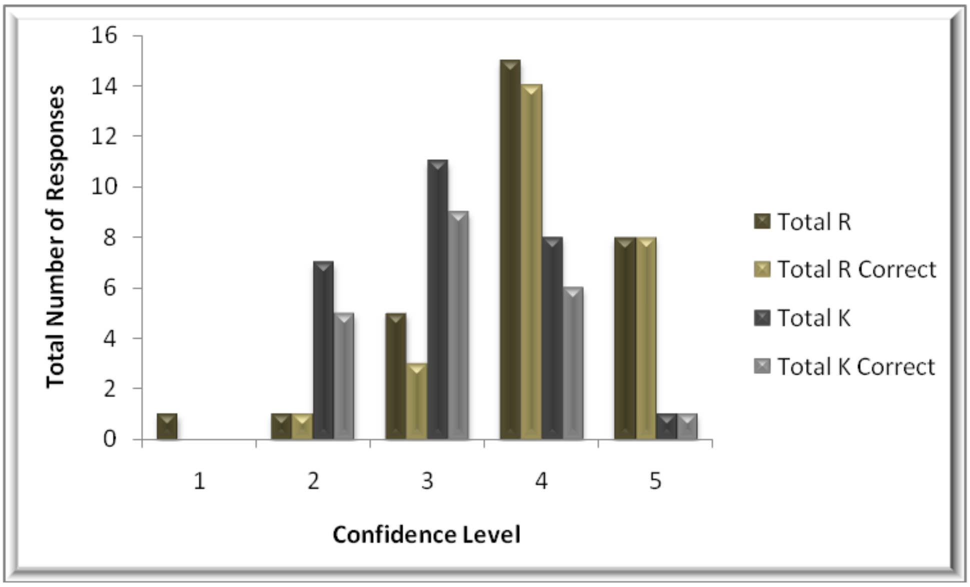


Figure 5.22: What-Where-When: Total number of responses alongside total number of accurate responses for each confidence level

Figure 5.22 above shows R responses again slightly less confident than seen in previous experiments, although accuracy is still high. There is a more familiar pattern of K responses with regard to confidence levels, which sees K responses slightly more distributed than for ‘What-Where-Which’ questions in the current experiment, however accuracy was lower.

5.5.3.2.3 Condition 1 (Long Delay) v Condition 2 (No Delay)

The elimination of the delay between the two slides did not result in a drop in R responses (41% to 39%) as was seen for ‘What-Where-Which’ questions. However, K responses (38% to 35%) and G responses (21% to 27%) were comparable from one condition to the other, which as detailed previously, was the case for ‘What-Where-Which’ questions. In addition, G responses were seen to again increase in Condition 2 (No Delay) suggesting that the two experimental slides are becoming confusable. Accuracy of R responses was found to be similar from one condition to the other (88% to 87%). It would be expected that the elimination of the delay between the two experimental slides would reduce the effectiveness of other strategies being employed to solve these episodic questions and so accuracy, although predicted to remain above chance, should notably drop. Not only was this not the case but the proportion of accurate K responses (70% to 78%) was seen to increase from Condition 1 (Long Delay) to Condition 2 (No Delay) suggesting that there are still other strategies being used to solve these episodic tasks. Accurate G responses (59% to 62%) remained at chance.

5.5.3.3 'What' questions

5.5.3.3.1 Condition 1: Long Delay

These non-episodic questions resulted in 65 out of 105 responses being experienced as Remember (62%), compared with 33 K responses (31%) and 7 G responses (7%).

Accuracy for R responses was highly significant (95%, 62/65, $p \leq 0.001$), as were accurate K responses (88%, 29/33, $p \leq 0.001$) and G responses (100%, 7/7, $p = 0.008$). As in previous experiments accuracy of these responses is always seen to be high, therefore any alternative strategies being used to solve the episodic questions may not be observable or potentially necessary in these non-episodic questions.

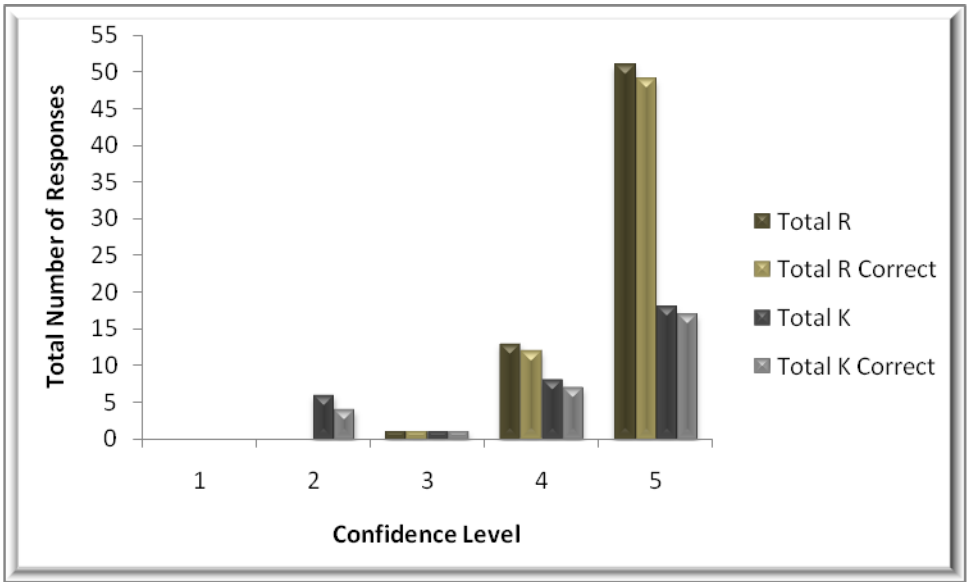


Figure 5.23: What: Total number of responses alongside total number of accurate responses for each confidence level

Figure 5.23 shows that the majority of both R and K responses are highly confident and also highly accurate, however the figure also highlights the notable difference in the proportion of R and K responses.

5.5.3.3.2 Condition 2: No Delay

Out of a possible 78 responses for the non-episodic ‘What’ questions, 51 were reported as a Remember experience (65%), 22 were reported as a feeling of Knowing (28%) and 5 were reported as Guess responses (6%).

Accuracy for these non-episodic questions were highly significant when reported as a R experience (98%, 50/51, $p \leq 0.001$). Accuracy was also above chance when a feeling of Knowing was reported in response to a ‘What’ question (91%, 20/22, $p \leq 0.001$). Accurate G responses were found to be at chance levels (40%, 2/5, $p = 0.5$).

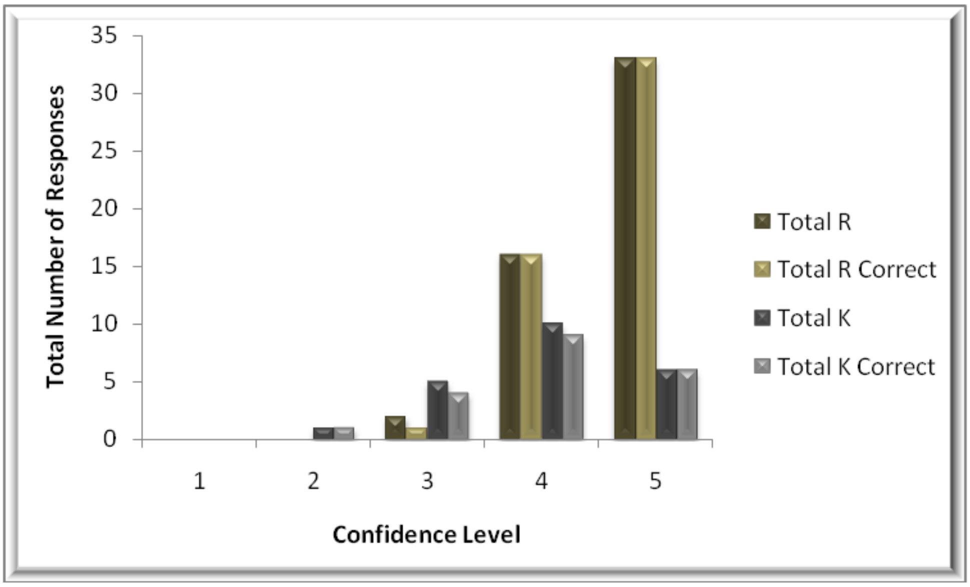


Figure 5.24: What: Total number of responses alongside total number of accurate responses for each confidence level

Figure 5.24 above shows the majority of responses being reported as R and also constituting the higher confidence levels. Accuracy of these responses is also visibly high. Responses indicated as a feeling of Knowing are slightly more distributed, however the high levels of accuracy are notable.

5.5.3.3.3 Condition 1 (Long Delay) v Condition 2 (No Delay)

The elimination of the delay between the two slides did not notably affect the proportion of R responses (62% to 65%), K responses (31% to 28%) or G responses (7% to 6%).

Accuracy of R responses was not seen to differ dramatically from Condition 1 (Long Delay) to Condition 2 (No delay) (95% to 98%). Although there is a slight increase in the proportion of accurate R responses, it may be that the more simple, non-episodic nature of the task is unaffected by the lack of a delay between the two experimental slides. Alternatively, it may also be that strength of memory trace is not the only alternative strategy being employed to solve the tasks. Accuracy of K responses were also not dramatically difference from one condition to another, but again, were seen to increase slightly despite the lack of a delay in Condition 2 (88% to 91%). Guess responses however, were seen to drop to chance levels from Condition 1 (Long Delay) to Condition 2 (No Delay) (100% to 40%).

5.5.3.4 Comparison of Question Types

5.5.3.4.1 Condition 1: Long Delay

There was found to be no substantial differences in the proportion of R responses for ‘What-Where-Which’ questions (36%) and ‘What-Where-When’ questions (41%) which would be expected for the two similar episodic questions despite the fact that in this condition other strategies are being encouraged to solve the tasks. This is also true when comparing the proportion of K and G responses for ‘What-Where-Which’ questions (39% and 25 % respectively) and ‘What-Where-When’ questions (38% and 21% respectively). Accuracy of R responses were found to be notably higher for ‘What-Where-When’ questions compared to ‘What-Where-Which’ questions, although accuracy for both were above chance levels (see Table 5.9). However, with regard to accurate K responses the differences were minimal (see Table 5.10).

Although Condition 1 allows for strength of memory trace to be used to solve the episodic questions, data from the non-episodic ‘What’ questions should still differ due to their more simplistic nature. It was found that ‘What’ questions (62%) resulted in more R responses than ‘What-Where-Which’ (36%) and ‘What-Where-When’ questions (41%). However, the differences between the proportions of K responses for ‘What’ questions (31%) compared to ‘What-Where-Which’ (39%) and ‘What-Where-When’ questions (38%) were minimal. Guess responses were substantially lower for ‘What’ questions (7%) compared with ‘What-Where-Which’ (25%) and ‘What-Where-When’ questions (21%). Accuracy of R and K responses were higher for ‘What’ questions compared with ‘What-Where-Which’ and ‘What-Where-When’ questions (see Tables 5.9 and 5.10) as seen in pervious experiments confirming the prediction that there are differences between the non-episodic and episodic questions.

Table 5.9: Condition 1 (Long Delay): Summarising the results for accurate Remember responses for each question type

Remember Responses			
Question Type	Proportion of Accurate Responses	Percentage Accuracy	Significance Value
What-Where-Which	29/38	76%	**$p = 0.001$**
What-Where-When	38/43	88%	**$p \leq 0.001$**
What	62/65	95%	**$p \leq 0.001$**

Table 5.10: Condition 1 (Long Delay): Summarising the results for accurate Know responses for each question type

Know Responses			
Question Type	Proportion of Accurate Responses	Percentage Accuracy	Significance Value
What-Where-Which	29/41	71%	**$p = 0.006$**
What-Where-When	28/40	70%	**$p = 0.008$**
What	29/33	88%	**$p \leq 0.001$**

5.5.3.4.2 Condition 2: No Delay

There was found to be more R responses for ‘What-Where-When’ questions (39%) compared to ‘What-Where-Which’ questions (26%) and accuracy was also higher. In fact accuracy of R responses for ‘What-Where-Which’ questions was at chance (see Table 5.11). It would be expected that even though strength of memory trace may not be as useful in this condition, that accuracy would still be above chance levels reflecting recall of episodic information in response to the episodic question.

Although the proportion of accurate R responses for ‘What-Where-When’ questions were above chance (see Table 5.11), the fact that accurate K responses were also above chance (see Table 5.12) suggests that it is not only episodic information that is being used to solve the tasks. As this is not the case for ‘What-Where-Which’ questions it suggests that alternative strategies for these questions are less effective. However, results from previous experiments do suggest an effect still exists (e.g. see Experiment 5b).

The proportion of R responses for the non-episodic ‘What’ questions (65%) was found to be substantially higher compared to ‘What-Where-Which’ (26%) and ‘What-Where-When’ questions (39%). Those responses reported as an experience of Knowing were lower for the non-episodic ‘What’ questions (28%) compare to for ‘What-Where-Which’ (40%) ‘What-Where-When’ questions (35%). There were dramatically less G responses for ‘What’ questions (6%) when compared with ‘What-Where-Which’ (35%) and ‘What-Where-When’ (27%) questions. Accuracy of R responses was found to be higher for the non-episodic ‘What’ questions when compared to ‘What-Where-Which’ and ‘What-Where-When’ questions, despite accuracy for ‘What-Where-When’ questions also being above chance levels (see Table 5.11). There were also more accurate K responses for ‘What’ questions compared to both episodic questions (see Table 5.12). Although this would be expected as the non-episodic ‘What’ questions can be solved using familiarity alone, the fact that accurate K responses for the episodic ‘What-Where-When’ questions are also above chance suggests that other strategies are still being employed to solve the tasks.

Table 5.11: Condition 2 (No Delay): Summarising the results for accurate Remember responses for each question type

Remember Responses			
Question Type	Proportion of Accurate Responses	Percentage Accuracy	Significance Value
What-Where-Which	12 out of 20	60%	**$p = 0.251$**
What-Where-When	26/30	87%	**$p \leq 0.001$**
What	50/51	98%	**$p \leq 0.001$**

Table 5.12: Condition 2 (No Delay): Summarising the results for accurate Know responses for each question type

Know Responses			
Question Type	Proportion of Accurate Responses	Percentage Accuracy	Significance Value
What-Where-Which	20/31	65%	**$p = 0.075$**
What-Where-When	21/27	78%	**$p = 0.004$**
What	20/22	91%	**$p \leq 0.001$**

5.5.4 Discussion

The aim of the current experiment was to investigate further the use of strength of memory trace as a strategy in solving episodic questions. This was achieved by manipulating the delay between the two experimental slides. Condition 1 (Long Delay) emphasised the delay between the two experimental slides. Therefore, if strength of memory trace is being employed, then strong memories would automatically be assigned to the last and most recently seen experimental slide and weak memories to the first experimental slide. It was expected that the additional strategy used to solve the episodic questions would result in accuracy of Know responses for both types of episodic questions being above chance levels. This would confirm the use of an additional strategy being employed to solve such an episodic task as according to definition, using Know to solve episodic tasks does not reflect recall of episodic memory. Considering the manipulation of the delay it would be plausible for this strategy to in fact be strength of memory trace. If this is indeed the case, then results from Condition 2 (No Delay) should show results more in keeping with the original hypothesis which states that episodic questions can only be solved using Remember responses as this is a reflection of the recall of episodic information. Having no delay between the experimental slides but instead having an extended delay after the second experimental slide and before the test phase, should result in a decay of memory trace with both slides having equal memory strengths and so showing similar patterns of data.

Results from the first condition (Long Delay) were as predicted for both types of episodic question with the proportion of accurate Know responses being significantly above the chance level. However, as seen in the previous experiments, there are still differences between the two episodic questions. For example, the difference between the proportion of accurate R and K responses for ‘What-Where-Which’ questions was not that great, yet for ‘What-Where-When’ questions the difference was more substantial. In fact the proportion of accurate R responses was notably higher for ‘What-Where-When’ questions compared to ‘What-Where-Which’ questions yet the difference found between the proportions of accurate K responses between the two question types was minimal. In certain instances data from ‘What-Where-When’ questions are more comparable to the data from the non-episodic ‘What’ questions.

Although the results were as predicted for Condition 1 (Long Delay), what is becoming clear is that the episodic questions of ‘What-Where-Which’ and ‘What-Where-When’ are being affected in different ways. The results from Condition 2 (No Delay) emphasise this fact. The elimination of the delay resulted in not only a higher proportion of Know responses compared to Remember responses for ‘What-Where-Which’ questions but also accuracy of those Remember and Know responses were at chance. Although this may be expected for Know responses, it was thought that participants should certainly still be able to use episodic memory to solve these tasks which would be reflected in above chance accurate Remember responses, yet these were found to have dropped from Condition 1 which used a long delay. Data from ‘What-Where-When’ questions showed the familiar higher proportion of Remember responses compared to K responses that had not been affected by the change in methodology. Accurate Remember and Know responses remained above chance levels. It is apparent that manipulation of the delays between the experimental slides has had differing effects on what should be similar episodic questions, to the extent that some data from ‘What-Where-When’ questions, such as the proportion of Know responses, is more akin to the data from the non-episodic ‘What’ questions. If only episodic information were being used to solve ‘What-Where-When’ questions then the proportion of accurate K responses should be at chance level as originally predicted.

One possible explanation for the fact that ‘What-Where-When’ questions seem to be less affected by the lack of a delay in Condition 2 compared to ‘What-Where-Which’ questions is that perhaps the two experimental slides were too confusable when presented one immediately after another. This may not affect ‘What-Where-When’ questions due to the fact that the temporal aspect of them is more relatable to humans than the contextual aspect would be. Humans arrange their daily lives according to a temporal framework. Context in this experiment may not be as relatable as perhaps the context was not virtual enough in nature. Participants were not placed in an environment in which they could ‘experience’ the two differing contexts, instead they had to essentially remember a pattern upon which stimuli were presented. This relates to the issue of space, the different ways in which it is processed and represented and its subsequent impact upon neuropsychological testing in humans. The processing of egocentric spatial relations (static object-to-self) are thought to be mediated by the medial superior-posterior areas, whilst allocentric spatial coding (object-to-object) necessitates the additional involvement of the right parietal cortex, the ventral visual stream and the hippocampal formation (Zaehle, Jordan, Wüstenberg, Baudewig, Dechent, & Mast, 2007). The relevance of this difference becomes apparent when one considers that the process of extracting spatial information from navigating through an environment will differ from the process of extracting that information from a two-dimensional map. Equally, scene and landmark information stored as retinotopic snapshots (e.g. presented using pictures) will differ from that stored as a consequence of navigating through the environment.

It therefore seems that although strength of memory trace may be contributing the observed results, there are clearly other factors playing a role. The unexpected differences between the two episodic questions inform us that the nature of the episodic memory in humans is not a simple one. Although only one component of episodic memory was manipulated, namely the occasion setter, it was assumed that what was being measured was still true episodic memory according to previous definitions. However, it now appears that perhaps the definitions concerning episodic-like memory in animals cannot be directly translated back to humans.

When contemplating the possible problems with the methodology, as mentioned previously concerning context, several questions are raised. With respect to human methodology, what actually is ‘Which’? Does ‘Which’ equate to ‘Where’ or is ‘Which’ a component or even specifier of ‘Where’. When humans consider a context it usually encompasses a place or a location, therefore are ‘Which’ and ‘Where’ bound together and so measuring the same component of episodic memory? For example, a place of work could be considered as contextual cue but also as a cue for location. In addition, an office in a work place could be considered as a contextual cue for the general location i.e. where. This issue concerning appropriately defining the individual components of episodic memory was also discussed by Eacott and Easton (2009) when they sought to determine the absolute nature of ‘when’. Perhaps before attempting to understand the strategies that humans use to solve episodic tasks such as the ones reported in the current chapter, the individual components of episodic memory need to be understood more fully, with respect to their role in everyday life.

5.6 Discussion

The current chapter aimed to investigate whether what is considered by definition as episodic-like memory in animals, can be translated back full circle to episodic memory in humans. The previous experimental chapters have detailed the use of tasks such as ‘What-Where-When’ and through manipulation of the occasion setter shown episodic-like memory in animals using the ‘What-Where-Which’ task. It was asked therefore, if applying a comparable task in humans would result in similar patterns of data with regard to recollection and familiarity. In addition, would the manipulation of the occasion setter in humans prove as inconsequential as it appears to be in animal studies (considering episodic-like memory has been successfully demonstrated using both occasion setters) or are these individual components of episodic memory in humans too critical to manipulate?

The Remember/Know paradigm (Tulving, 1985) was employed as this allowed for recollection and familiarity to be dissociated, just as Eacott et al.’s (2005) study demonstrated possible in the E-maze. It was expected that results from Experiment 5a would show that the two episodic questions would be answered using Remember responses as these reflect recollection of episodic memory. Accuracy of these responses would therefore also be high. Accompanying confidence ratings were predicted to be high for those Remember responses for the same reason. As Know responses reflect familiarity, and episodic questions cannot be answered using the familiarity circuit, the proportion of these responses were predicted to be low, to the point of approaching zero. However, it was also offered that if Know responses were to occur, that the accuracy of such responses would be at chance. The non-episodic

‘What’ questions were predicted to be qualitatively different to the two episodic questions due to their simple nature and the fact that they can be solved through familiarity as well as recall.

What became apparent from Experiment 5a, was that not only were participants responding Know to the episodic questions but in response to the ‘What-Where-When’ questions, the accuracy of these responses were significantly above chance and no different to the accuracy of responses from ‘What’ questions. In addition, there appeared to be clear differences in the results for ‘What-Where-When’ and ‘What-Where-Which’ questions, despite both hypothetically probing episodic memory. Analyses determined that accuracy of responses was not a matter of confidence (i.e. high confidence does not equate to high accuracy) as Remember responses were accurate even when a low confidence rating was reported reflecting the all or nothing nature of the Remember response. As familiarity is not so absolute, accuracy would be expected to decrease alongside confidence. This was the case for accuracy of Know responses for ‘What-Where-Which’ questions, however ‘What-Where-When’ questions demonstrated high accuracy of Know responses despite low confidence ratings, a pattern comparable to Remember responses. This suggested that perhaps participants were using another strategy to solve the episodic ‘What-Where-When’ questions. It was hypothesised that this strategy was strength of memory trace. As there was no delay between the presentation of the last experimental slide and the test phase of the task, participants could be assigning strong memories to the more recently seen experimental slide and weak memories to the experimental slide seen first.

Experiment 5b investigated this hypothesis further by increasing the delay between the last experimental slide and the test phase of the task. Although not totally eliminating the possible use of such a strategy, increasing this delay decreases its effectiveness. It was predicted that ‘What-Where-Which’ questions would produce similar patterns of data as seen in Experiment 5a. ‘What-Where-When’ questions however, should according to the hypothesis, see a reduction in accurate Know responses from above chance to chance levels reflecting the diminished memory trace. In addition, it was thought that the proportion of Remember and Know responses would also drop to be comparable to data from ‘What-Where-Which’ questions. Interestingly, although this hypothesis held true for ‘What-Where-When’ questions, the manipulation to the methodology resulted in the proportion of accurate Know responses for ‘What-Where-Which’ questions being above chance levels. Although this was unexpected, the proportion of accurate Know responses for both episodic questions were only marginally different from one another, highlighting how the proportion of results must be taken into account, especially when applying such binomial statistics.

This consideration led to Experiment 5c which aimed to increase the power of analyses. Analysing the results separately and then together with Experiment 5b did not provide any clear explanations for the patterns in data observed, however the data still suggested that other strategies were being used to solve the episodic tasks. It was therefore deemed necessary to conduct another experiment that would specifically try to show if indeed strength of memory trace was being employed as a strategy to solve the episodic questions.

The aim of Experiment 5d was to confirm the use of strength of memory trace by manipulating the delay between the two experimental slides. Condition 1 encouraged the use of this strategy to solve the episodic tasks by emphasising the delay between the two experimental slides. If strength of memory trace was being employed then this would be reflected in significantly high proportions of Know responses and accurate Know responses for both episodic questions. Condition 2 aimed to confirm the first condition by doing the opposite, i.e. discouraging the use of strength of memory trace by reducing its effectiveness. This was achieved by virtually eliminating the delay between the two experimental slides resulting in a relatively equal decay of memory for both slides. With regard to this condition, the original hypothesis of Experiment 5a was put forward. Remember responses for both episodic questions would be highly accurate, and K and G responses would be at chance level. Results from the non-episodic 'What' questions would again be qualitatively different to the results from the episodic questions.

Although Condition 1 resulted in the expected high proportion of accurate Know responses for both episodic questions, there still existed fundamental differences between them. Condition 2 highlighted this point. Results from 'What-Where-Which' questions appeared to be affected by the elimination of the delay with the proportion of accurate Remember and Know responses being at chance level. Whereas the proportion of accurate Remember and Know responses from 'What-Where-When' remained significantly above chance. In addition there was a higher proportion of accurate K responses compared to R responses for these 'What-Where-Which' questions, yet for 'What-Where-When' questions there was a higher proportion of R responses. Therefore, it cannot be concluded that it is purely strength of memory trace that is having the observed effect on the results. One crucial question that stems from the data of the current chapter is why are two seemingly comparable episodic questions producing such differing results?

As said previously, it would be more sensible to attempt to answer this question before carrying out any further manipulations to the methodology. The original aim of the current chapter was to determine if the tasks that have demonstrated episodic-like memory in animals as described in the previous chapters, can be translated to tasks in humans and result in similar patterns of data that could be considered as episodic memory in humans. In addition, it was questioned whether manipulating individual components of episodic memory would prove of consequence or not in human tasks as such manipulations have proven inconsequential in animals (Eacott et al., 2005; Eacott & Gaffan, 2005; Eacott & Norman, 2004). The results from the current chapter certainly seem to suggest that the translation of tasks from animal methodology to human methodology is not straight forward and it in fact could be *because* the individual components of episodic memory in humans are critical and perhaps not as interchangeable and flexible as seen in animal tasks. The results of the final experiment in this chapter led the author to question the individual components of episodic memory in humans. It was suggested that when humans consider a context it usually encompasses a place or a location, therefore are the components of ‘Which’ and ‘Where’ different labels for the same component or is ‘Which’ a more specific form of ‘Where’? The example given previously considered a place of work. This place of work could either be considered a cue for location or as a contextual cue. Furthermore, an office in a work place could be considered a specific contextual cue for a more general location i.e. ‘where’.

This issue of appropriately defining the individual components of episodic memory has also been discussed within the realms of episodic-like memory in animals (Eacott & Easton, 2009; Eacott & Norman, 2004). The nature of ‘When’ is purported to have several difference applications. It can refer to a regular time slot (e.g. morning or afternoon), a point in time that has reference to another point in time (e.g. yesterday or the first/second time) or it can refer to an absolute point in time (i.e. a time that has no associations with another point in time e.g. when I went to hospital) It has been suggested that if an animal can only demonstrate memory of whether an episode was more or less recent (or first or second) but not demonstrate memory for the more absolute episode, then it may be that what is presumed to be a demonstration of an integrated memory for ‘what’, ‘where’ and ‘when’, is actually more an evaluation of the strength of memory for ‘what-where’ (Eacott & Easton, 2009). Data in the current chapter has certainly suggested that this is in fact what is happening. Yet, why would this additional strategy of strength of memory trace appear to affect ‘What-Where-When’ questions more so than ‘What-Where-Which’ questions? One potential answer to this is that because humans readily organise their lives according to a temporal framework (Roberts, 2008) and consequently are extremely accurate at judging time instances, the ‘When’ component may be more susceptible to the interference of other strategies such as strength of memory trace (Friedman, 1993). The observed differences between the two episodic questions may also be further exacerbated by the fact that context in the current chapter was not virtual enough to be differentiated. Context was simply two differing patterns of background which in reality is not applicable. As discussed previously, the process of extracting spatial information from navigating through an environment will differ from the process of extracting that information from a two-dimensional map. Equally, scene and landmark information stored as retinotopic snapshots (e.g. presented using pictures) will differ from that stored as a consequence of navigating through the environment. In that sense, 'What-Where-Which' memory as demonstrated animals is perhaps the more true to the definition. With recent technological advances the experimental use of virtual reality (VR) paves the way for dealing with such issues (for a review see Burgess, 2002; Burgess, Maguire, & O'Keefe, 2002) and would be an appropriate method for further investigating the current study. In addition, future investigations could also avoid failures of independence between observations if for example, each participant were given one question each, however this would therefore require substantially more participants. Another possibility would be to ask the participants more questions, however the design of this method would have to take into account limitations in memory. In addition, as more questions would require different stimuli the issue of then encoding these stimuli differently would have to be addressed.

The results of the current chapter cannot rationally lend support to either dual-process (e.g. Atkinson & Juola, 1974) or single-process models of recognition memory (e.g. Donaldson, 1996) when considering the aforementioned issues. However, the results can possibly be considered with respect to the ongoing debate as to whether episodic-like memory in animals is a reflection of episodic memory in humans. In fact, the current chapter could even question the purity of episodic memory in humans considering how adept we are at using other strategies to solve such tasks. The current chapter appears to have successfully translated a task that investigates episodic-like memory in animals to a task that investigates episodic memory in humans. Predictions were relatively accurate concerning 'What-Where-Which' questions, however the series of experiments showed how other strategies can be used to solve the episodic tasks. Therefore, despite successful predictions, it cannot be entirely certain that data from the 'What-Where-When' questions in particular were purely episodic. It now seems that there is a role reversal, with the definition of human episodic memory being questioned. As discussed in previous chapters, the definition of episodic-like memory in animals has been given much attention (Clayton & Dickinson, 1998; Eacott & Easton, 2009; Eacott & Norman, 2004) and stringent criteria have been applied with regard to what constitutes an occasion setter as being unique. With respect to the above discussion regarding what is 'which' and what is 'when', perhaps more stringent criteria need to be applied before investigating human episodic memory in a similar manner.

6 GENERAL DISCUSSION

6.1 Introduction

The aim of this discussion is to summarise the findings and conclusions presented in this thesis. The findings will be summarised and discussed with respect to the surrounding literature. Furthermore, the implications of such findings and their potential impact on future research will be addressed.

This thesis sought to explore two different methodological approaches to episodic memory. The first approach aimed to demonstrate episodic-like memory in animals by replicating the task of Eacott, Easton, & Zinkivskay (2005) with the further aim of investigating the effect of bilateral lesions to the hippocampus on episodic-like memory. The second approach aimed to create a comparable task for investigating human episodic memory on the basis that if episodic-like memory as demonstrated in the animal tasks is indeed a true reflection of human episodic memory then the results from these studies should reflect one another.

6.2 Summary of Findings

The results of Chapter 2 were successful with regard to replicating Eacott et al.'s (2005) study demonstrating episodic-like memory in the rat using recollection alone, despite the fact that performance in this study was significantly poorer compared to the original. Subsequent experiments within this chapter however, highlighted potential methodological issues (e.g. interference of odour cues, stability of performance over lengthy testing periods) that impact on such spontaneous tasks.

Chapter 3 investigated the effect of bilateral lesions to the hippocampus on episodic-like memory using Eacott' et al.'s task which was successfully replicated in Chapter 2. Although the analyses within this chapter lacked power due to histological groupings, there were nevertheless some interesting points for discussion. The results of this chapter were not in agreement with previous findings as none of the three groups showed evidence of episodic-like memory. In depth analyses of the three groups led to the conclusion that this was not due to an ineffective task but due to extraneous factors (e.g. noise, context differences) impacting upon the performance of the animals. Observable differences (although not significant) were noted in the exploratory behaviour of the Hippocampal lesion group compared to the Sham group, whilst similarities were noted between the Sham and the Partial Hippocampal group. This not only lends credence to the histological groupings but supports the claim that the damage to the associated parietal cortex observed in one of the animals was not representative of them all. Analyses of D2 scores and raw exploration times in both phases of the experiment also highlighted the importance of D2 scores in determining object familiarity.

Due to the methodological issues highlighted in the previous chapters and the fact that D2 scores were deemed to be the most appropriate measure of object familiarity, Chapter 4 employed the use of an Open Field arena to further investigate the effect of bilateral lesions to the hippocampus on episodic-like memory in animals. Previous research has provided evidence that such a task can to an extent differentiate between recall and familiarity using lesion data (Eacott & Gaffan, 2005). Although in the initial experiment of this chapter performance of the Sham group approached significance levels, there remained no significant differences between this group and the Hippocampal lesion group. The addition of landmarks to the testing room resulted in the Sham group successfully demonstrating episodic-like memory whilst the Hippocampal lesion group remained at chance levels. However, as there was no significant difference between the two groups it was not possible to conclude that this was as a result of the lesions to the hippocampus, although again this lends credence to the histological groupings and potential issues surrounding damage to the parietal cortex. As the following control task showed neither group demonstrating memory for the more simple ‘what-where’ task, it was concluded that a problem with the methodology still remained. Subsequent experiments within this chapter investigated cleaning methodology (i.e. with regard to objects and the arena), the stability of performance over time, and the effect of task change on performance. Although the Sham group appeared to be more affected by a change in task, there was still clear variability in the data over lengthy testing periods, emphasising the sensitivity of these tasks.

Chapter 5 aimed to investigate whether applying comparable ‘What-Where-When’ and ‘What-Where-Which’ tasks to human investigations of episodic memory would result in similar patterns of data with regard to recollection and familiarity. By analysing the results of Experiment 5a it became apparent that participants were using another strategy to solve the episodic ‘What-Where-When’ questions. The remainder of the experiments in this chapter aimed to confirm the use of strength of memory trace as a strategy for solving these episodic questions. Results from the final experiment in this chapter suggested that other strategies were also being employed. In attempting to answer the question as to why two such seemingly comparable episodic questions were producing such differing it was suggested that memory for ‘What-Where-When’ was more susceptible to interference from other strategies such as strength of memory trace. Issues surrounding the appropriateness of context were also discussed with respect to the results from the ‘What-Where-Which’ questions. It was concluded that further investigations were needed to apply more stringent criteria with regard to what is ‘which’ and what is ‘when’, akin to the stringent criteria observed in comparable animal studies of episodic memory.

6.3 Episodic-like Memory in Animals

Although the findings of Chapters 2 to 4 were only partially successful with respect to their original aims the results that stem from these studies provide several points worthy of further discussion, in particular when considered alongside the results of Chapter 5.

As summarised above, Chapter 2 was successful in its replication of Eacott, Easton and Zinkivskay’s (2005) task demonstrating episodic-like memory using recollection alone whilst also refuting claims by Hampton and colleagues (2005) that the episodic-like memory demonstrated in scrub jays (e.g. Clayton & Dickinson, 1998) is a result of specific selection pressures faced by food-storing birds. Yet if one is to claim that such demonstrations of what-where-which memory are comparable to human episodic memory then it is important to address how the task in question incorporates the three criteria of episodic-like memory deemed essential by Clayton, Bussey, and Dickinson (2003) (see section 1.8 of General Introduction) i.e. content, structure, and flexibility.

The criterion of content is fulfilled if one considers ‘which’ to simply be a broader occasion setter than ‘when’ (Easton & Eacott, 2008). It includes memory for what happened, where it happened, and in this case, on which occasion, with respect to the recollection of a past episode.

In addition to the content criterion, Clayton and colleagues maintain that the components of what, where, and which must form an integrated structure. Attempts to retrieve any one component of an episode will result in automatic retrieval of the remaining components. The lack of an integrated structure would result in an animal being unable to discriminate between different episodes that share common features. Clayton, Yu, & Dickinson (2001) provide evidence that the what, where, and when components in their study are integrated, with one component (either what or where) binding the other two together in memory. In the task of Eacott et al. (2005) replicated in Chapter 2, knowing only what the object is that needs to be searched for will not aid in its recovery, nor will knowing what the object is in addition to knowing which context is present. The what-where-which task in the E-maze can only be solved through the integration of memories regarding what was located where and in what context.

Finally, the criterion of flexibility must also be addressed. Clayton, Bussey, and Dickinson (2003) argue that declarative memories are reliant on the flexible utilisation of memorised information, and can be updated when new information is acquired. Tasks attempting to demonstrate episodic-like memory must preclude the possibility that a semantic strategy is being used to solve the task i.e. rule-based learning. As detailed in the General Introduction (see section 1.8.4) a series of studies by Babb and Crystal (2005, 2006a, 2006b) were criticised for their experimental paradigms which involved an extensive number training trials that could result in such rule based learning (Cheke & Clayton 2010; Clayton and Russell, 2008). Although the same could be said for Clayton and Dickinson's (1998) study with scrub jays (Easton & Eacott, 2008), as explained previously, the number of training trials differed considerably. This issue is reminiscent of Zentall et al.'s (2001) notion of the *unexpected question* whereby he proposes that documenting episodic-like memory requires a demonstration that the animal is able to report on a recent event when no expectation for a report was required (i.e. to answer an unexpected question). The what-where-which task in the E-maze has no specific learnt element. Furthermore, the behaviour is not reinforced by food nor is there training beyond habituation to the experimental procedure. Sixteen trials of Objects Hidden were carried out in Experiment 2a as opposed to the 80 training trials that Babb and Crystal use for their long/short delay procedure (2006b). Therefore, the likelihood of the animals learning about an unexpected question are considerably reduced. Easton and Eacott (2008) argue that the experience in the sample phases of the task is merely a reflection of their natural exploratory behaviour. In addition, as during the sample phases the animals are unaware of which object they will be habituated to, and in which context they will be tested in at the point of exploration, good performance at test relies on flexible use of the memory for the initial acquisition phase.

It has been reasoned therefore that the task of Eacott et al. (2005) that was replicated in Chapter 2 successfully demonstrates and fulfils the criteria of episodic-like memory as proposed by Clayton and colleagues (2003). Moreover, as this task is able to dissociate recollection and familiarity in the same animals in the same trials, it lends support to dual-component theories of recognition memory which state that recollection and familiarity are separate and independent mental processes (e.g. Atkinson & Juola, 1974; Jacoby, 1983a, 1983b; Jacoby & Dallas, 1981; Mandler, 1980; O'Reilly & Norman, 2002; Tulving, 1985). Despite providing further evidence for the presence of episodic-like memory (as defined by what-where-which) in non-human animals, there has been some criticism surrounding the appropriate definition. Cheke and Clayton (2010) suggest that although the 'which' component is phenomenologically more akin to human episodic memory, it cannot be extricated from the elements of 'what' and 'where' and so 'which' could be acting as a specifier for 'where' i.e. a place of work could be considered a contextual cue (which) or a cue for location (where). They suggest therefore that the component of 'when' is essential in validating the memory is for a specific episode as opposed to timeless factual information regarding spatial distinctions. Yet Eacott and Easton (2009) point out that although episodic memory is in this respect the memory for the spatial arrangement of objects (what-where), what is crucial is linking this memory content to a particular past episode (which). This broader definition of episodic memory therefore views 'which' not as a context or background but as a means of identifying a particular episode not excluding any temporal identifiers. Eacott and Easton suggest that “the cue words what, where and which should not themselves be over analysed, merely acting as a short-hand description of the content of the memory” (p. 2277).

Yet whether episodic-like memory is evidenced by demonstrations of what-where-when or what-where-which, there still exists the fundamental question of whether or not this is relatable to human episodic memory. Certainly there are those who suggest that such memories bear no relevance to human episodic memory (Suddendorf & Busby, 2003; Suddendorf & Corballis, 2008). In attempting to answer this question it becomes pertinent to address the issue of why such an ability in non-human animals would have evolved. It has been argued that the evolutionary advantage of episodic memory may lie in the planning for future events as opposed to the recalling of past ones (Clayton, Bussey, & Dickinson, 2003; Suddendorf & Corballis, 2007). Certainly in the case of scrub-jays caching has been shown to be affected by food perishability and competition (Clayton, Dally, Gilbert, & Dickinson, 2005; de Kort et al., 2007). More recently, it has been reported that scrub-jays can differentiate from its current and future motivational state, and can cache different food types accordingly (Correia, Dickinson, & Clayton, 2007; Raby, Alexis, Dickinson, & Clayton, 2007), challenging the Bischof-Köhler hypothesis which claims that it is only humans who can anticipate future needs (see Suddendorf & Corballis, 1997). However, whether this ability has evolved specifically for those species that cache or whether it has evolved for different reasons is still being questioned (see Grodzinski & Clayton, 2010). Cheke and Clayton (2010) warn however, that the falsification of the Bischof-Köhler hypothesis may detract research from focusing on the true nature of animal prospection. Acting for a motivational state in the future over one in the present does not necessarily prove the existence of episodic future thinking particularly considering that studies with human participants fail to provide such evidence (Bone, Hey, & Suckling, 2009).

Another way of discerning whether or not such episodic-like memories are a true reflection of episodic memory in humans is to study the underlying neural substrates of the associated memory systems. Chapter 3 addressed this issue by investigating the effect of bilateral lesions to the hippocampus on episodic-like memory. If recollection is hippocampally dependent and familiarity is independent of this, relying not on the hippocampus but on a distinct system involving the perirhinal cortex of the temporal lobe and the medial dorsal nucleus of the thalamus (Aggleton & Brown, 1999; Brown & Aggleton, 2001; Fortin, Wright, & Eichenbaum, 2004; Mayes, Holdstock, Isaac, Hunkin, & Roberts, 2002; Yonelinas, et al., 2002), then performance in the E-maze task which can dissociate the two, should reflect this. The results from Chapter 3 (see section 6.2) were unexpected. Despite the results of Chapter 2, no demonstrations of episodic-like memory were observed in any of the three groups, including the Sham group, although it was expected that the HPC group would perform at chance levels as previous studies have implicated the hippocampus in recollection and/or familiarity (Fortin, et al., 2004; Langston & Wood, 2006; Manns, et al., 2003; Sauvage, Fortin, Owens, Yonelinas, & Eichenbaum, 2008; Wais, et al., 2006; Wixted & Squire, 2004). In addition, the behaviour of the Partial HPC group was more comparable to the Sham group, therefore although no conclusions regarding the effect of bilateral lesions to the hippocampus on episodic-like memory could be confidently drawn, the effect of such partial lesions can be questioned.

Histological analyses showed that the nature of the partial lesions were more dorsal than ventral despite not being targeted as such. Yet it is the dorsal, not ventral hippocampus that has been implicated in spatial memory tasks (Bannerman et al., 1999; Bannerman et al., 2002a; Bannerman et al., 2002b; Bannerman et al., 2004; Hock & Busney, 1998; Kjelstrup et al., 2002; McHugh, Deacon, Rawlins & Bannerman, 2004; Pothuizen, Zhang, Jongen-Relo, Feldon & Yee., 2004), although this is not a ubiquitous view (De Hoz, Knox & Morris, 2003; Ferbinteanu & McDonald, 2000; Ferbinteanu, Ray & McDonald, 2003). Therefore, as the Partial HPC group appeared more comparable to the Sham group, is it then that the dorsal lesions were not sufficient enough to produce a significant memory deficit? Disagreement within this area stems partly from the fact there is no independent and objective criteria defining what exactly constitutes the dorsal and ventral hippocampus. Bannerman and colleagues (1999) suggested that the dorsal hippocampus be considered as 50% of total hippocampal volume starting at the septal pole, with the ventral hippocampus constituting the remaining half. However, this was not based on any independent or objective criteria. The current study adopted a more stringent criteria based on previous studies (Broadbent, Squire & Clark, 2004; Jones et al., 2007). The similarity of the Partial HPC group to the Sham group as opposed to the HPC lesion group appear to lend support to Broadbent and colleagues (2004) who reported that only near complete lesions (75-100%) were sufficient to produce a deficit in object recognition memory and that larger hippocampal lesions are needed to impair recognition memory than are needed to impair spatial memory. Future studies may wish to also consider genomic-anatomic evidence which suggests that there are in fact three (certainly molecular) domains, namely dorsal, intermediate, and ventral which possess clear neuronal connectivity patterns (Dong, Swanson, Che, Fanselow, & Toga, 2009). Only by clarifying the boundaries of these domains will arbitrary definitions stop being imposed and hopefully inconsistencies in behavioural evidence will subsequently be reduced.

Irrespective of the debate as to whether episodic memory and other forms of declarative memory have shared neural substrates (Squire et al., 2004) or whether episodic memory alone is reliant on a dissociable neural network (Aggleton & Brown, 1999), the role of the hippocampus is considered vital. Episodic tasks have been shown to be significantly impaired in patients with damage to the hippocampus and fornix (Aggleton et al., 2000; Scoville & Milner, 1957; Squire & Zola, 1996) suggesting reliance on the hippocampal system. This has also been shown to be the case in non-human animals (Easton et al., 2009; Langston & Wood, 2006). This would therefore suggest the what-where-which memory probed in the episodic-like tasks is at least in some way, analogous to human episodic memory.

6.4 Episodic Memory in Humans:

As this thesis is one that places attention on methodology, the final chapter aimed to address the issue as to whether episodic-like memory in animals, as demonstrated in previous chapters (see Chapters 2 and 4), is analogous to the experience of episodic memory in humans. At the point of testing, no such study had considered the application tasks of tasks specifically created to investigate episodic-like memory in animals to human participants in order to determine if similar patterns of data would emerge. The remember/know procedure (Tulving, 1985) was the chosen methodology for the final chapter as it was deemed comparable to the task of Eacott et al. (2005) in which recollection and familiarity were dissociable. Experiments within this chapter manipulated the remember/know procedure in order to investigate how what-where-which memory as shown in previous chapters, and what-where-when memory would present themselves in humans. In addition, this would allow for observations to be made regarding the level of importance that occasion setters, such as temporal and contextual ones, hold in human episodic memory.

Several interesting issues emerged out of the series of experiments in Chapter 5, most notably was the issue that other strategies such as strength of memory trace were being used to solve the episodic questions, in particular the what-where-when questions. This has clear implications for the continuing debate surrounding whether remember and know judgements are a reflection of recollection and familiarity respectively (e.g. Kelley & Jacoby, 1998; Yonelinas, 2001b) lending support to dual-process models of recognition memory, or if in fact they are a reflection of different degrees of memory strength (e.g. Donaldson, 1996; Dougal & Rotello, 2007; Dunn, 2004, 2008; Hirshman & Henzler, 1998; Slotnick & Dodson, 2005; Shimamura & Wickens, 2009) as suggested by the signal-detection account. Although the idea that remember/know judgements may reflect different degrees of memory strength as opposed to different memory processes was originally recognised by dual-process theorists (e.g. Gardiner, 1988), a variety of empirical dissociations were used to refute the strength-based interpretation (e.g. Gardiner & Java, 1990; Geraci, McCabe, & Guillory, 2009). However, in a comprehensive review of the literature, Dunn (2004) showed that the majority of findings that were once considered problematic for the signal-detection point of view are in fact fully compatible with it. Furthermore, Dunn (2008) suggested that it is not the case that the signal-detection model can explain any outcome, rather many experiments have produced results that would be impossible to reconcile with a signal-detection model but can be explained by a dual-process account.

The question remains therefore, as to whether the results from the novel remember/know task adapted in Chapter 5 can lend support to either of these theories. In the standard dual-process interpretation of remember/know judgements, a remember judgement is made when recollection occurs (i.e. recollection is an either/or categorical process) and is characterised by high confidence and high accuracy. A know judgement is made when familiarity occurs and is accompanied by lower confidence levels and chance levels of accuracy. The signal-detection interpretation states that a remember judgement is made when memory strength exceeds a high criterion and know judgements when the strength of the memory signal only exceeds the next lower criterion (Donaldson, 1996). Remember judgements are almost invariably made with higher confidence and higher accuracy than are know judgements (Wixted & Stretch, 2004). The results from the series of experiments Chapter 5 cannot claim to lend support to either interpretation for several reasons. Firstly, a dual-process interpretation of the results fails to explain the high proportion and high accuracy levels of know responses for the episodic questions and the differences that were apparent between them. Although it was reasoned that strength of memory trace could be contributory factor, the results from Experiment 5d (Condition 2) in which the use of this strategy was discouraged, produced similar results, particularly for what-where-when questions. Considering this, it was concluded that other unidentified strategies, in addition to strength of memory trace, may be having an effect on the results. Secondly, a signal-detection interpretation of the results also does not explain the observed differences between the two episodic questions. Although Wixted (2009) suggests that adopting a signal-detection view of remember/know judgments does not have to result in the dismissal of the dual-process view of recognition memory (see also Wixted & Mickes, 2010), he does admit that the lack of neuropsychological evidence is a hindrance in the acceptance of signal-detection models.

What is clear from the results of Chapter 5 is that strategy as well as task needs to be taken into consideration (Squire, 2004). As discussed in the General Introduction (see section 1.9) the issue of strength of memory trace is not restricted to human data (e.g. Kart-Teke et al., 2006). It may be that because the temporal aspect of an episode is reported to be the most difficult to recall (Clayton, Bussey, & Dickinson, 2003; Clayton & Russell, 2009; Suddendorf & Corballis, 2007; Tulving, 2005), that such strategies are more available. Although at the time of testing the idea of applying episodic-like tasks to gather human data was novel, a recent study by Holland and Smulders (2010) (see also Hayne & Imuta, 2011) employed the use of a what-where-when task to investigate human episodic memory. Unlike the task in

Chapter 5 which was based on the Remember/Know procedure, their task was based on Clayton & Dickinson's scrub-jay task in which participants had to hide different coin types (what) in different locations (where) on two different occasions (when). The participants in the study were either instructed to memorise the what-where-when information or they were unaware of the fact that their memory would be tested. From the results the authors suggest that although episodic memory was being used to solve the task, they admitted that some aspects of the task could be solved by using different or additional memory systems. Furthermore the authors conclude that the most episodic aspect of the task is linking objects to location, rather than any temporal aspect.

A crucial difference between the task of Holland and Smulders (2010) and the task used in Chapter 5, is that their task does not allow for the dissociation between recollection and familiarity and so cannot easily dissociate between any episodic and semantic memory systems being utilised. Although they refute the possibility that strength of memory trace is being used as a strategy, the issue of strategy is again apparent here. In addition, such a hide-and-seek task allows reliance to be placed on the capacity to store memories for what was hidden, where and when it was hidden, rather than episodically recalling the information.

Such studies as those detailed in Chapter 5 and above have important implications in the study of other non-verbal populations such as infants. Although it has been claimed that semantic memory precedes episodic memory in evolutionary and developmental terms (Tulving, 2005; Suddendorf & Corballis, 2007b), this becomes difficult to assess considering that human episodic memory is said to involve mental time travel and communicating such a process in the absence of a verbal report proves difficult. Hayne and Imuta (2011) also use a hide-and-seek task to examine episodic memory in three and four year old children, both verbally and behaviourally. Interestingly, when using both techniques, the component of ‘when’ proved the most challenging. Although this may be reflecting that the ability to recall things in order requires processes that do not develop until later on (Friedman, 2005), it may also reflect that the ability to use alternative strategies such as those discussed do not precede this development. Concentrating on developing non-verbal tasks for example by modifying the task in Chapter 5, would allow for further investigation into the appropriate definition of episodic memory and the strategies that can be used to solve such tasks. Furthermore, it would allow for the development of a universal test of episodic memory that is not restricted by language or culture.

6.5 Conclusions

Within this thesis episodic-like memory defined as what-where which has been successfully demonstrated and has been shown to fulfil the three criteria of episodic-like memory deemed essential by Clayton, Bussey, and Dickinson (2003) i.e. content, structure, and flexibility. However, issues surrounding methodology prevented conclusions being drawn as to the effect of bilateral lesions to the hippocampus on episodic-like memory as is defined here. What is apparent from Chapters 2 through 4, is that the methodology of such animals studies is extremely sensitive in nature, an issue that is finally being addressed in the literature (Albasser et al., 2010). This is an important point to consider as without careful observation and in depth analyses of the results, a true interpretation of the behaviour cannot be made, nor can theoretical perspectives be attached.

The final chapter of this thesis also highlighted certain methodological sensitivities that are common to animal tasks (e.g. Kart-Teke et al., 2006). Despite manipulations to the methodology of the final chapter, it was clear that alternative strategies were being employed to solve the task and importantly such strategies were having differing effects on relatively similar episodic questions. One of the original questions put forward in the General Introduction was whether or not manipulating individual components of episodic memory would prove of consequence in human studies considering this has been shown not to be the case in animal studies (Eacott et al., 2005; Eacott & Gaffan, 2005; Eacott & Norman, 2004). Initially it seems that the translation of episodic-like tasks in animals to episodic tasks in humans is not straight forward and perhaps not relatable. However, the author suggests that there are explanations for this.

The issue of ‘what is when’ (see General Introduction, Section 1.9) has received considerable attention in the animal literature yet is only beginning to be questioned in comparable human literature (Holland & Smulders, 2010). If there exists the possibility that an inappropriate definition of ‘when’ can inadvertently facilitate the use of alternative strategies then such what-where-when memory is not truly episodic (Eacott & Easton, 2009). The benefit of using the what-where-which task (Eacott et al., 2005; Eacott & Norman, 2004) in Chapters 2 through 4 was that it did not allow for such criticisms (although see Cheke and Clayton, 2010). Yet the results from Chapter 5 tentatively suggest in humans at least, that such alternative strategies can affect memory for what-where-which also. If the difference between ‘when’ and ‘which’ is that they are merely two forms of an occasion setter then it would be expected that alternative strategies would affect both components equally. However, as humans readily organise their lives according to a temporal framework (Roberts, 2008) the ‘when’ component may be more susceptible to the interference of other strategies such as strength of memory trace (Friedman, 1993). This is particularly pertinent considering that the temporal aspect of an episode is the most difficult to recall (Clayton, Bussey, & Dickinson, 2003; Clayton & Russell, 2009; Suddendorf & Corballis, 2007; Tulving, 2005) and may therefore necessitate the use of alternative strategies. Perhaps future studies may wish to address the question of not only ‘what is when’, but also ‘what strategy’.

It may be that such differences in the defining the occasion setter may have differing evolutionary advantages for humans compared to animals. If this is the case, then the question as to whether episodic-like memory in animals is in fact relatable to episodic memory in humans is somewhat of a moot point. The underlying principles of episodic memory may be similar and in addition underlying neural substrates may concur, but the overall applications will always differ.

Although it is clear that both animal and human studies have served to further our knowledge of episodic memory and the underlying neural substrates, this thesis has highlighted how future investigations must consider the exact definition of not only episodic memory as a whole, but also the definition of the individual components of episodic memory. If such consideration is not taken, and if Squire’s (2004) warning about the importance of strategy is not heeded then as seen in previous tasks (e.g. Kart-Teke et al., 2006), conclusions will always be limited.

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Appendix 1

Recognition memory is associated with two different kinds of awareness: REMEMBERING and KNOWING.

REMEMBERING: When you **recollect** something you have consciously experienced at that time. You are also able to consciously recall all aspects of the event e.g. location, time of day.

KNOWING: When recognising something brings about a feeling of **familiarity.** You feel confident that this experience is familiar but you are unable to consciously recall any aspects of the said event e.g. you will not know where this feeling of familiarity comes from.

REMEMBERING = RECOLLECTION OF A MEMORY INCLUDING RELATED INFORMATION

Example: You bump into someone in town and you specifically remember them from a party you went to the other night.

KNOWING = FAMILIARITY OF A MEMORY WITH NO EXTRA RELATED INFORMATION

Example: You bump into someone and feel as though you know their face from somewhere but can’t quite place where you have seen them before.

BEFORE YOU COMPLETE THE QUESTIONS PLEASE MAKE SURE YOU UNDERSTAND THE DEFINITIONS ABOVE. FEEL FREE TO REFER BACK TO THESE AT ANY POINT.

YOU WILL HAVE **9** QUESTIONS TO ANSWER THAT WILL INVOLVE:

1: Answering the question.

2: Stating whether you remember or know.

** There will be times when you feel that you do not know what the answer is – in this case circle **GUESS***.

3: State how confident you are of your answer (1=Not Confident – 5=Confident). If you choose the guess option you do not need to rate your confidence level.

Please think carefully when you are answering all aspects of these questions.

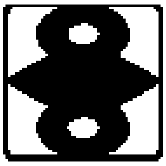
Please create the following code that will be specific to you (The first 2 letters of your surname, the month of your birth, and the first 2 letters of your place of birth – e.g. Smith, August, Plymouth = SM08PL).

Your code:………………………………………….

Signature: ………………………………………….

Q1. WHICH OF THESE SYMBOLS HAVE YOU SEEN BEFORE?

A:



B:

Answer (circle your choice):

A B

How did you come to this decision (circle your choice)?

Remember Know Guess

How confident are you of this decision (circle your choice)?

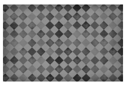
(not confident) 1 2 3 4 5 (confident)

Q2: ON WHAT BACKGROUND DID YOU SEE THIS OBJECT IN THIS LOCATION?

Answer (circle your choice):

A: ZEBRA

B**:** CHEQURED



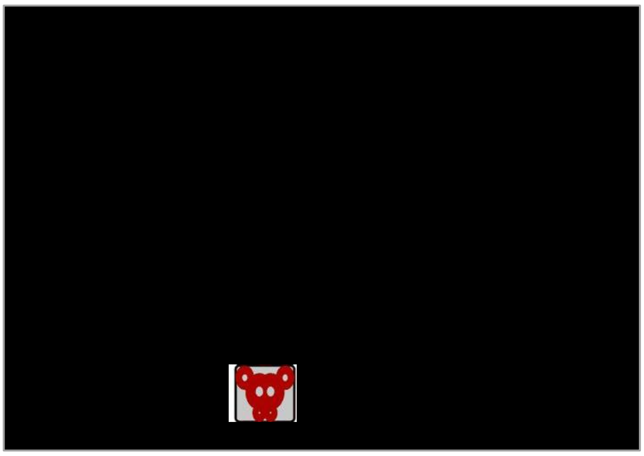
How did you come to this decision (circle your choice)?

Remember Know Guess

How confident are you of this decision (circle your choice)?

(not confident) 1 2 3 4 5 (confident)

<u>Q3. ON WHICH SLIDE DID YOU SEE THIS SYMBOL IS THIS PARTICULAR LOCATION?</u>



Answer (circle your choice):

A: 1ST SLIDE B: 2ND SLIDE

How did you come to this decision (circle your choice)?

Remember Know Guess

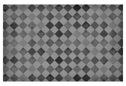
How confident are you of this decision (circle your choice)?

(not confident) 1 2 3 4 5 (confident)

Q4. ON WHAT BACKGROUND DID YOU SEE THIS SYMBOL IN THIS PARTICULAR LOCATION?

Answer (circle your choice):

A: ZEBRA B: CHEQURED



How did you come to this decision (circle your choice)?

Remember Know Guess

How confident are you of this decision (circle your choice)?

(not confident) 1 2 3 4 5 (confident)

Q5. ON WHICH SLIDE DID YOU SEE THIS SYMBOL IN THIS PARTICULAR LOCATION?

Answer (circle your choice):

A: 1ST SLIDE B: 2ND SLIDE

How did you come to this decision (circle your choice)?

Remember Know Guess

How confident are you of this decision (circle your choice)?

(not confident) 1 2 3 4 5 (confident)

Q6. WHICH OF THESE SYMBOLS HAVE YOU SEEN BEFORE?

A:

B:

Answer (circle your choice):

A B

How did you come to this decision (circle your choice)?

Remember Know Guess

How confident are you of this decision (circle your choice)?

(not confident) 1 2 3 4 5 (confident)

Q7. ON WHICH SLIDE DID YOU SEE THIS SYMBOL IN THIS PARTICULAR LOCATION?

Answer (circle your choice):

A: 1ST SLIDE B: 2ND SLIDE

How did you come to this decision (circle your choice)?

Remember Know Guess

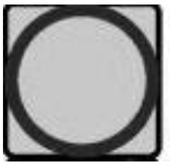
How confident are you of this decision (circle your choice)?

(not confident) 1 2 3 4 5 (confident)

Q8. WHICH OF THESE SYMBOLS HAVE YOU SEEN BEFORE?

A:

B:



Answer (circle your choice):

A B

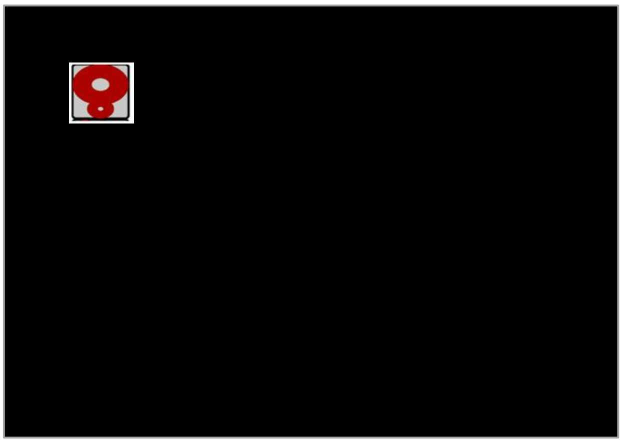
How did you come to this decision (circle your choice)?

Remember Know Guess

How confident are you of this decision (circle your choice)?

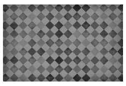
(not confident) 1 2 3 4 5 (confident)

Q9. ON WHAT BACKGROUND DID YOU SEE THIS SYMBOL IN THIS PARTICULAR LOCATION?



Answer (circle your choice):

A: ZEBRA B: CHEQURED



How did you come to this decision (circle your choice)?

Remember Know Guess

How confident are you of this decision (circle your choice)?

(not confident) 1 2 3 4 5 (confident)