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The impact of selective attention and action on episodic memory

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The Impact of Selective Attention and Action on Episodic Memory

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Thesis submitted for the degree of Doctor of Philosophy

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"As it is, the professors give too many lectures and the students listen to too many. Or pretend to; really they do not listen, however attentive and orderly they may be. The bell rings and a troop of tired-looking boys, followed perhaps by a larger number of meek-eyed girls, file into the classroom, sit down, remove the expressions from their faces, open their notebooks on the broad chair arms, and receive. It is about as inspiring an audience as a roomful of phonographs holding up their brass trumpets. They reproduce the lecture in recitations like the phonograph, mechanically and faithfully, but with the tempo and timbre so changed that the speaker would like to disown his remarks if he could."

- **EDWIN E. SLOSSON** (1910, p. 250) -

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For the past 6 years, it has been a pleasure to perform research and learn within the field of cognitive science and new media.

I would like to thank my PhD supervisors, who made it possible for me to carry out my research, and allowed me the flexibility to develop my own ideas.

Much of the work done in this PhD is related to the field of psychology, a body of knowledge of which I had no experience before starting. I would like to thank Dr. Paloma Mari-Beffa for her support and guidance as, without her, I would not have accomplished as much as I did. I would also like to express my thanks to Prof. Astrid Ensslin and Dr. Eben Muse, in particular for their early support in helping me find a topic that matched my skill and interest.

Thanks also to my friend Beth Nicole who helped me with my English grammar during the writing of the thesis. Without her, all my tenses would be wrong.

Thank you as well to all my friends, flatmates, and work colleagues for helping me collect data for all my experiments; the data collection was a tedious process to perform whilst being a part-time student.

Finally, I would like to thank the *Second Life* online community for helping me with the setting up of the virtual experiment, and a big thank you to Dr. Robert Gittins for lending me some virtual space on the *Second Life* Bangor Island.

Components of this thesis have been communicated as follow

Presentations

Laurent, X., & Mari-Beffa, P. **(**2013, July 3). *Role of Selective Attention and Action on Episodic Memory,* Talk given at the Experimental Psychology Society Meeting, Bangor, UK.

Laurent, X. (2013, May 13). *Virtual Worlds and Cognitive Science*, Presentation given to Computer Gaming Across Cultures: Perspectives from Three Continents, Bangor, UK

Laurent, X. (2012, March 13). *Episodic Memory and Selective attention*, Presentation given to undergraduate students at the School of Psychology, Wrexham, UK

Laurent, X., & Mari-Beffa, P. (2012, January 3). *Reuniting conflicting views on the role of action on episodic memory: Role of selective attention on memory encoding using the WWW task*. Poster presented at the Experimental Psychology Society Meeting, London, UK.

Laurent, X. (2011, July 7). *Episodic Memory Study A Behavioural and Computational Approach.* Poster presented at the 26th Annual Conference of the Psychology Postgraduate Affairs Group (PsyPAG), Bangor, UK.

Laurent, X. (2011). *Virtual Environments and Cognitive Science*, Talk given at the Creating Second Lives: Blurring Boundaries Conference, Bangor, UK

Laurent, X. (2008). *Virtual Environments Meet Artificial Intelligence*, Presentation given at the Creating Second Lives: Reading and Writing Virtual Communities Conference, Bangor, UK.

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SUMMARY OF PHD

In 1972, Endel Tulving coined the term “episodic memory”, with reference to the process used to link the many different types of information constituting an event into a spatio-temporal context, which can be retrieved later. In this thesis I investigate what type of information is encoded in episodic memory while performing selective attention and action tasks.

Over seven experiments, I look at the impact of various experimental conditions on the recall accuracy (free, recognition and cue) of episodic memory that includes object identity, spatial and temporal recall, since only very few studies have considered these three components together. My approach is novel as most other studies have used traditional attention experimental tasks to understand how information is selected. Specifically, I use episodic-like memory tests to dissociate the impact of active and passive encoding states on memory, which in turn allows me to observe the phenomenon of distractor suppression encountered during the retrieval of previously encoded information.

In general, results across several experimental conditions strongly indicate that memory superiority under passive mode could be related to the incidental encoding of irrelevant information. This effect is mostly found when memory is immediately tested (short delay) and disappears some time later following a retroactive interference task. Distractors competing for an action receive a stronger suppression than those, which are not. The results are in agreement with selective attention studies, which suggest that distractors prevent from becoming the target of the action. The results highlight the role of action on episodic encoding, demonstrating that using an active state of encoding does not increase the amount of information to encode (enhancement of targets), but reduces the numbers of non-relevant information stored in this trace (suppression of distractors).

BACKGROUND

How my PhD came alive?

I have an engineering background, having studied and worked in the field of electrical and mechanical engineering, but for the last 13 years have transferred my skills to the world of digital media and e-learning, and studied for a Master in Digital Art. In 2006, I also achieved a Master in Business and General Management.

I have always enjoyed learning, and therefore decided to pursue a PhD to expand my knowledge and discover new horizons whilst also working full-time. Since most of my work is involved in web technology, I approached the School of Creative Media and Studies with a few ideas for a PhD proposal. I wanted to work on something that I enjoyed reading and learning about, and was advised that I needed to choose carefully, and ensure that my chosen subject still fascinated me in 5 years' time. Therefore, I submitted my first proposal to the School in mid-2007 - I was interested in studying the field of Artificial General Intelligence (AGI).

In my research work, I proposed to look at virtual environment worlds to test an AGI engine developed by Novamente LLC, a US firm developing Artificial General Intelligence technology with projects applied to virtual worlds. I wanted to use their *Novamente AI Engine* (NAIE) to focus on different infantile cognitive tests on object recognition applied to artificial intelligent agents in simulated worlds like *Second Life*. Indeed, with the rapid development of computer processing power, online virtual and 3D gaming worlds have become more and more realistic, making them increasingly attractive for the end user. However, virtual agents that inhabit these worlds are still very primitive and hardly convincing as they can only give the illusion of mental states, when they are uncontrolled by humans.

I was - and still am - interested in current ideas in the field of Artificial General Intelligence (AGI) applied to cybertechnology. These ideas are based on the broad ideas of the Singularity (e.g. Kurzweil, 2005), which assumes that humans, with the help of improved technology, will manage to produce human-level Artificial Intelligence or even higher types of intelligence in the near future. To help us reach this human AI, one route is to work within cyberspace worlds and educate simple embodied AGI systems so as to enable them to interact with the virtual environment and human-controlled agents. A modernised version of Jean Piaget's (1954) theory of child cognitive development can be applied to teaching virtual baby avatars, and developing them into fully-grown intelligent adults capable of conscious states. For example, AI researchers for instance at Novamente LLC or the Rensselaer AI & Reasoning lab have developed cognitive architecture systems, some of which can be "plugged" into 3D environments and achieve a basic level of cognition. Object permanence tests relating to Piaget and reasoning about the thoughts of others are some examples. However, the research was in an early stage of development and still largely experimental.

My plan was to design cognitive tests within virtual worlds, and investigate whether some tests are more appropriate than others, whilst also investigating whether the results highlight some of the strengths and weaknesses of the AI system or the simulated environment used. In the long run, as Dr Goertzel from Novamente LLC mentioned, these studies would also contribute to a larger synthesis of modern developmental psychology applicable to both Human and Artificial Intelligence (private correspondence).

To learn more about the topic, I assisted in a few conferences on AGI in the USA and the UK; I undertook extensive reading, and presented seminars to students about the topic. I also submitted a paper for peer review in the journal of *Gaming and Virtual Worlds,* of which I am also an editorial board member. However, as time passed, I felt a bit overwhelmed with the necessary technical programming in AI necessary to help in this field, and I found it difficult to narrow down a topic compelling enough for the PhD. I had to find something more specific.

As I had already read extensively about Artificial Intelligence and cognitive architecture, I decided to focus my attention on one specific area related to the design of a cognitive architecture: memory - more precisely, procedural memory. I decided on the topic of the measurement of procedural skills from kinesthetic learners in a computer-based simulated environment, and to investigate how the research could influence the design of an embodied artificial intelligent agent interacting in a virtual world. The idea was more specific, but involved research into fields where I had no experience such as behavioural study and psychology. Both my supervisors, Prof. Astrid Ensslin and Dr. Eben Muse, recommended that I seek help from the School of Psychology.

After a couple months, I managed to contact Dr. Paloma Mari-Beffa in the School of Psychology, and asked her to look at my research idea. She was interested and her skills led me to a more feasible path for what became an explorative PhD. Therefore, we decided to focus on episodic memory and selective attention.

From that time on, I had to learn a lot as I knew very little about the topic (well, hardly anything!). On the menu was episodic memory, selective attention, priming etc. I also had to become more experienced in the field of statistics, although I had the basics covered from knowledge attained during my previous studies. I had also never performed any experimental studies containing participants, and so had to learn how to use tools like *Eprime* (Psychology Software Tools, 2002) and how to deal with recruitment. My confidence really started to grow, which became apparent in my research in late 2009.

By the end of 2012, I had tested approximately 320 participants with complex experiments between subjects and between groups; a large amount of data has been collected and is available for further analysis such as dprime, recognition test, gender, age group, various interactions or response time. The process was often difficult and took time and, as I was working full-time, it was difficult to find time during the day to meet students, so I had to do this in the evenings and weekends. I tried to keep the testing conditions in similar, quiet environments; either at my home, my office or other university locations whenever possible.

Overall, I really enjoyed the PhD experience, and became so involved with it that I considered it a pleasure, not a chore. If I were to undertake it again as a part-time student, I may choose to do some things differently, e.g. taking into account the commitment necessary to test participants in the field of behavioural psychology, or even choose a research topic that is already defined as I spent the first two years of my PhD going in the “wrong” direction.

OVERVIEW OF CHAPTERS

This thesis is split up into five main chapters, not including the literature review and discussion; there are a total of seven experiments spreading over the five chapters. Across the seven experiments, I have kept the same independent variables and same type of measure where I computed accuracy for full episodic recall as well as for each component of episodic memory ("what", "where" and "when"). Different encoding conditions were also set up - active mode (performing a motor action) vs. passive mode and interference task between two tests.

Chapter 1 sets up the basic theoretical knowledge developed in the thesis. I review current and past knowledge of episodic memory, selective attention and negative priming, as well as the conflicting views on the role of action on memory.

In Chapter 2, I implemented a pilot study to investigate an innovative quantitative approach in order to measure episodic memory using a variant of the What-Where-When "episodic-like" task usually performed in non-humans. The pilot study includes two experiments that assess the impact of the behaviour of participants and look at various types of encoding conditions. In this study, I designed memory tests in which the encoding of various coloured objects (distractor and target) are presented behind 2D and 3D background images. The retrieval method used in these experiments was free recall. The reason why different types of background were included in the memory test was to study the impact of a richer environment (3D perspective) on memory recall at a later stage. Both experiments in this chapter provide initial results on the influence of the active mode that produces distractor suppression during immediate recall when measuring the total accuracy recall of the full episodic memory and its individual component; the effect was highly significant for both backgrounds, but target enhancement was observed during the delayed recall for the 2D background in all components.

Chapter 3 focuses on a stronger design and methodology in order to further investigate the effects observed in the previous pilot study. Chapter 3 includes two experiments with similar design, within which the background is plain white. In Experiment Three, I have included a recognition recall for the object identity component and cue recall for the spatial and temporal component of episodic memory. In Experiment Four, I researched the contribution of the type of recall on object identity and replaced the recognition recall for object identity with a cue recall. Overall, both experiments confirm strongly the preliminary results of distractor suppression observed previously for immediate recall and the removal of this effect after the interference task. The differences in accuracy recall on certain components of episodic memory are also discussed.

In Chapter 4, I replicated the last experiment inside the virtual environment *Second Life*. A key point relevant to my research is that virtual environments allow the study of cognitive functions under conditions which are extremely realistic, and specifically designed for the performance of formal experimentation within cognitive science. Again in this experiment, I designed an active mode where participants interact with the virtual environment during the encoding phase, and I also recorded participant actions for later use for the passive mode. In this experiment, the results were similar to those previously encountered for full episodic recall in Experiments Three and Four. However, when examining individual episodic components, I found strong distractor suppression for all components apart from spatial recall. I conclude that the object identity component is a reliable source of information, whilst the spatial and temporal (from the previous experiments) components are weaker. These issues will be addressed in a later experiment.

In Chapter 5, I was interested in investigating the influence of one person observing the actions of another, and what impact it could have on memory recall. The idea is based on the discovery of mirror neurons and of other mirroring mechanisms in the human brain, showing that the very same neural substrates are activated when these expressive acts are both executed and perceived. This experiment used the same 3D environment as the one in Chapter 4. In this experiment, both subjects (passive and active) are tested simultaneously and submitted to the same independent variables as during the previous tests. Overall this experiment was the weakest of all, with weak distractor suppression in most components, while the impact of social interaction was not strongly illustrated as expected.

Chapter 6 is a response to design issues encountered in Chapter 4 with the spatial and temporal component of episodic memory in the virtual environment. In this instance, I modified the virtual test to include a stronger encoding method for spatial location in order to avoid the random appearance of objects during the test. In doing so, I was interested in the possible influence of spatial encoding on full episodic recall. Moreover, I also addressed the possible design flaw of the temporal encoding task and only computed the extreme accuracy data of the temporal component. In this chapter, I also observed significant distractor suppression with all the components of episodic memory. Overall, I demonstrate a process of selective attention across all experiments and a significant effect depending on the mode of action as discussed in the literature review. A summary of all experiments is represented graphically in Figure 1.

I conclude with a chapter on the possible practical implications of the observed results, looking at the learning and memory field in more detail. I also present limitations of the experiments and propose different alternatives for future research.

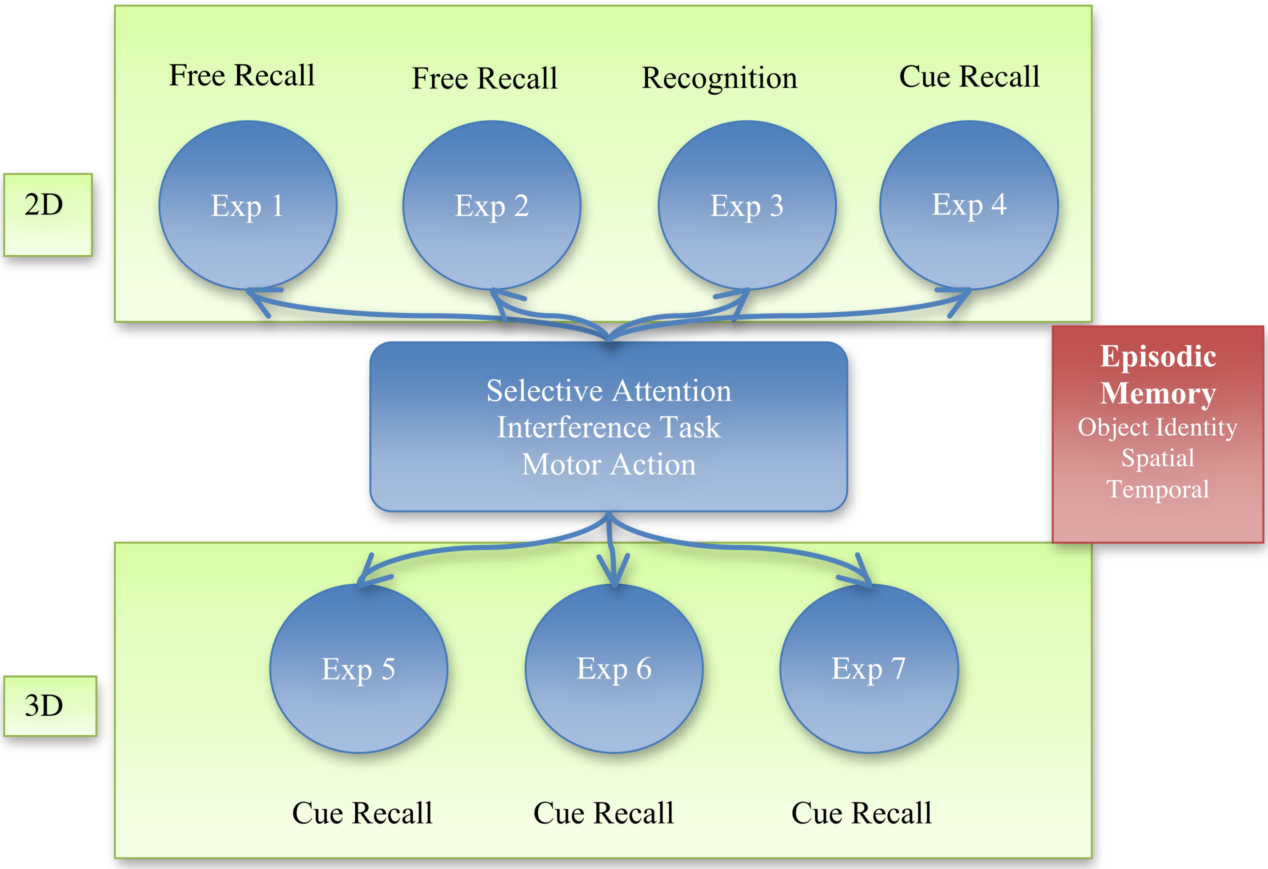

Figure 1. Summary of the experiments included in the thesis. On the top section of the graph are the experiments done with a 2D environment and with the different recall techniques and similar for the bottom section. The middle section represents the different variables affecting encoding during the task. Finally the red square represents the output of for each test, full episodic recall and independent recall components.

CHAPTER 1: FOUNDATIONS

Introduction

This chapter explores some of the key concepts at the root of the role of selective attention and action on episodic memory. This lays out some important foundations for developing the research methodology regarding the episodic memory tests to be used throughout the thesis.

To remember a past event means to be consciously aware of it. In the early history of memory study, there was no psychological study of memory that referred to conscious awareness (Tulving, 1985). Endel Tulving attempted to address this issue based on the growing debate on consciousness from some of the work of modern philosophers (e.g., Dennett, 1969; Chalmers, 1995) and other scientists. In his original definition of episodic memory, Tulving did not refer to consciousness, as his definition was very much about the recall of the “what,” “where” and “when” of an event. However, he later attempted to relate memory to consciousness with clinical observations and laboratory experiments.

In order to assess consciousness in episodic memory, one needs to perform some kind of qualitative measure, usually by means of verbal reports, which can also lead to subjective interpretation. One avenue explored in the thesis was the design of a quantitative approach to measure episodic memory; the design was influenced by recent research undertaken on animals and infants, which assessed whether or not they have episodic memory. Using a minimalist approach, researchers such as Russell and Davies (2012), Clayton and Russell (2009) and Clayton and Dickinson (1998) have explored the non-conceptual roots of spatiotemporal cognitive abilities described in Kant’s philosophy (1781) in the context of episodic memory which will be discussed in more depth in this chapter, in order to retain the consciousness aspect described in Tulving’s later definition.

Once equipped with an innovative approach for measuring episodic memory, studies on the role of action on memory recall and the effect of selective attention during encoding of an event could be undertaken. Therefore, the following sub-chapters will make an attempt to give a framework and foundation that led to each experiment and their particulars. The first sub-chapter will explain how a quantitative approach can measure episodic memory, keeping in line with memory and consciousness. The second section looks at the main key concepts and theories that define selective attention and how selection is achieved. Finally, a literature review will show supporting evidence for the impact of action on episodic memory with some conflicting views.

Episodic Memory

In 1972, Endel Tulving coined the term "episodic memory" with reference to the kind of memory that allows us to associate the many different types of information constituting an event into a spatio-temporal context, and to use the content of the event later in order to retrieve its context. Episodic memory is part of a set of major memory systems (Figure 2) and is closely associated with semantic memory (Squire & Zola, 1998). Semantic memory describes memory for general facts, whilst episodic memory describes memory for personally experienced events. Tulving later revised his definition to highlight the central importance of the phenomenological experience of remembering. He began to emphasize what he referred to as the "autonoetic" character of episodic memory, with the recollective experience being regarded as a sine qua non of episodic memory (Tulving, 1985). The central tenet of this theory is based on one's own experience and allows an individual to travel back in time. In this context, episodic memory's critical attributes are self, "autonoetic consciousness" (conscious awareness that characterizes remembering one's past) and subjectively sensed time. Tulving also defines the term "noetic awareness", which is the retrieval of information from semantic memory. The relation between noetic and autonetic, or semantic and episodic memory, has been derived from an experiment on a patient referred as to KC in the literature

(Tulving, 1993), from which the concept of remembering/knowing was introduced. As outlined above, episodic and semantic memory give rise to two different states of consciousness – “autonoetic and noetic” - which influence two kinds of subjective experience - remembering and knowing - respectively. “Autonoetic consciousness” refers to the ability to recover the episode in which an item originally occurred. In “noetic consciousness”, an item is familiar but the episode in which it was first encountered is absent and cannot be recollected. Remembering involves retrieval from episodic memory and knowing involves retrieval from semantic memory. Episodic memory has evolved from semantic memory, which develops early in childhood (Tulving, 2001). The existence of episodic memory is widely accepted by the majority of researchers (Squire, 2004, 2009), and neural bases of episodic memory are also here to prove its existence, indeed there is a large consensus that context-dependent memory for personally experienced events is supported by the hippocampus (Burgess, Maguire, O'Keefe, 2002; Squire & Zola-Morgan, 1991; Vargha-Khadem, Gaffan, Watkins, Connelly, Van Paesschen, & Mishkin, 1997).

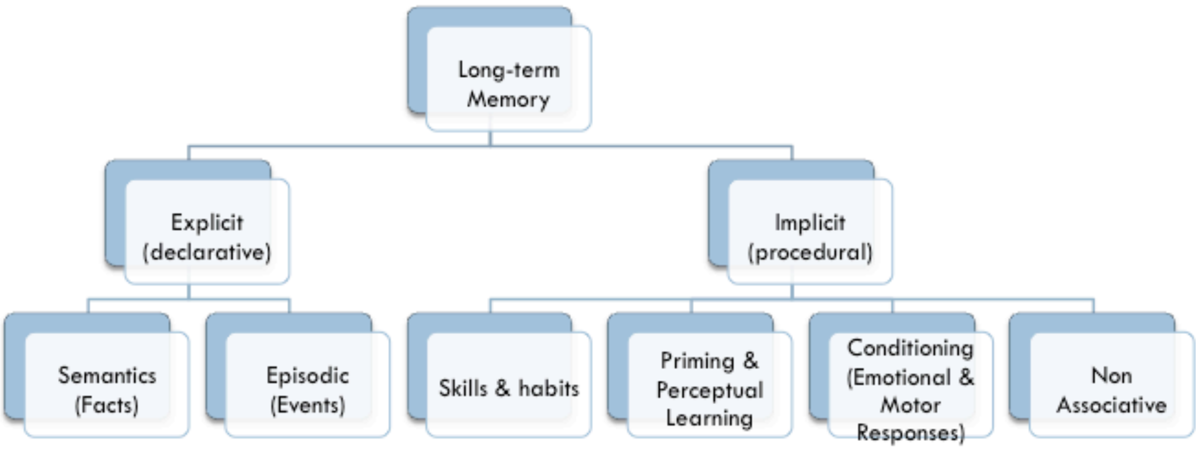

Figure 2. A taxonomy of mammalian long-term memory systems. The taxonomy lists the different memory systems thought to be especially important for each form of declarative and non-declarative memory, Squire (1987).

Measure of Episodic Memory

The famous German psychologist Hermann Ebbinghaus accomplished the first systematic and scientific approach to measure memory in 1885. His approach began with a focus on what memory allows us to do (process of memory formation), rather than on what memory allows us to experience (Moxon, 2000, p. 5). He defined an experimental approach to study memory composed of three components: a set of stimulus material, a procedure for presenting the material so that it can be remembered, and a way to measure memory. The memory tests were performed in a laboratory using verbal recall tests as, at that time, memory was viewed as a single unit. However, new information processing models in cognition in the late 50s and 60s (Neisser, 1967; see also Broadbent, 1958; Chomsky, 1967) produced a major shift in the understanding of how memory is constructed. Memory was then seen as consisting of multiple components, and so it became necessary to find different methods and tools to assess these different parts. The next paragraph will describe some of the common methods to assess episodic memory and how the results can be measured.

To measure episodic memory there are two traditional types of retrieval tasks - recall and recognition. Recall tasks generally include, but are not limited to, the following; free recall, serial recall, cued recall, as well as free choice recognition task (yes/no) (Magnussen & Helst, 2007). Free recall is probably the simplest recall measure in which a sequence of items, typically words, are presented and the subject is required to recall as many as possible in any order. When recall is immediate, the probability of a word being recalled correctly is typically dependent on its serial position during presentation, with the first one or two items enjoying a modest advantage (the primacy effect), the middle items showing a relatively flat function, and the final items showing the best recall (the recency effect). Serial recall is the recall of items in the order they have been encoded. Cued recall is also relevant in episodic memory - if asked what you had for dinner this evening; your answer would most likely reflect cued recall from episodic memory as the dinner and the time act as cues to retrieve the target event. Recognition recall is a type of extreme cued recall, as the target item itself is presented as a cue for retrieval (or recognition in this case). Finally a method that is closer to Tulving's concept is the Remembering/Knowing Paradigm (Tulving, 1982). Subjective reports of both states of awareness (episodic and semantic) are measured by Remember and Know responses, indicating at the time of memory retrieval which of the two mental states is experienced. In this paradigm, subjects have to give either ''Remember'' responses (R) if recognition is accompanied by the recollection of the learning context, or ''Know'' responses (K) if recognition is achieved without such access to information from the learning context.

Other types of tasks are available such as metamemory tasks defined as the capacity to make judgments and predictions about one's memory abilities (Metcalfe & Shimamura, 1994), judgment of source, which is the dissociation between item identity and episodic recollection (Schacter, Harbluk, & McLachlan, 1984) and recency judgements, which monitor the temporal dimension of events in the past (Milner et al., 1991). Others have proposed a field of view of memory where an observer can either have the perspective to seeing oneself "from the outside" or from one's own perspective (Nigro & Neisser, 1983; Robinson & Swanson, 1990).

Signal Detection Theory

There are various methods with which one can measure quantitatively the different types of recalls mentioned above. However, these methods can vary depending on what types of human memory models have been chosen. Dual process models assume that there is some probability that previously studied items will exceed a memory threshold. For example, the "Remembering and Knowing" paradigm described earlier, or the "Familiarity and Recollection" concept (Yonelinas 1994, 2001), are some examples of dual process models (Yonelinas, 2002). Single process models (e.g.,Dunn, 2004; see also McClelland & Chappell, 1998; Shiffrin & Steyvers, 1997), or more recently used in Berry, Shanks & Henson (2008), assume that we can place items on a familiarity continuum (see Figure 3), resulting in studied items registering at the high end of the continuum and new items registering at the low end. Single process models use only one single memory component and we can therefore use a single parameter (Yonelinas, 2001) to measure episodic memory. These models are well described by the Signal Detection Theory (SDT), which can describe dissociation between explicit and implicit memory. This model has also been successful in accounting for a wide range of data previously taken to support the dual-process models (Berry et al., 2008). Theoretical debate is ongoing to assess the value of each of these models (Diana & Reder, 2006).

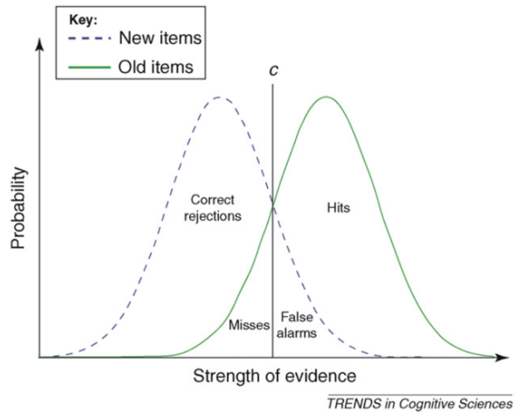

Figure 3. Signal detection sensory continuum. When a subject is presented with a signal (new and old items) at any particular time, the signal will fall along the sensory continuum according to the Signal + Noise distribution. The subject will base his judgement of detection of the signal according to some criterion (c) along the sensory continuum (Berry et al., 2008)

An example of the use of SDT is recognition memory judgment, which relies on the assessment of a single familiarity measure. In Yes/No recognition, a test trial consists of presenting a single item to which one of two responses is made (the response might be “Yes, I recognise this” or “No, I don’t recognise this,” or they might be “Old” or “New”). Yes/No recognition tests are easy to create, easy to explain, and easy to score. An old item is classified as a hit if judged old or a miss if judged new. A new item is classified as false alarm if judged old or a correct rejection if judged new. Measuring how well people can discriminate between old items and new items is done by comparing Hits with False Alarms or by computing a dprime value - a simplified computation would be Hits minus False alarms and other values could also be drawn from the measures for example, Accuracy would be the ratio of Hits over Hits plus Errors.

An Alternative View on Episodic Memory

The What-Where-When Task

Despite traditional memory tests having been tried and tested on humans for a long time, the subjective nature of Tulving's theory (subjective consciousness, which he later added to his 1972 original definition) makes it difficult for it to be assessed in the absence of verbal reports (for example, with young children or animals). In this context, a new approach has been introduced primarily to study whether non-humans or very young children do possess episodic memory. For example, what kind of memory do infants and young children exhibit? Although it is widely accepted that by 6 months of age, infants succeed on memory tasks that are thought to measure declarative or explicit memory, there is no clear evidence that they use memory skills, which are episodic (Hayne & Imuta, 2011). Researchers examined the original Tulving definition of episodic memory and developed the "what," "where" and "when" task, sometimes referred to as WWW. Within this simplest definition (often referred to as "episodic-like" as it does not evaluate the phenomenological aspects of episodic experience), episodic memory can be studied as a collection of the different characteristics of an event that occurred in the past (Hampton & Schwartz, 2004). The first researchers to work on this topic (Clayton & Dickson, 1998) studied Western Scrub Jays while caching food and, later, other researchers (Babb & Crystal, 2005; Hampton, Hampstead & Murray, 2005) looked at a variety of species. They established that some animals do possess "episodic-like" memory behaviour, but were unable to prove that they have a conscious recollection of their experiences. Further research (Clayton & Russell, 2009) is ongoing to investigate this possibility in animals or young children but Tulving (2001) argues that only human beings have the conscious aptitude. Recent research undertaken by Holland and Smulders (2011) and Hayne and Imuta (2011) has concluded that human beings use episodic memory to solve WWW tasks usually applied to animals, and that the tasks provide the mental time travel and autonoetic consciousness that are inherent in Tulving's definition (2005).

A Minimalistic View

The episodic-like memory model used in the WWW task is also referred as a minimalistic conception of episodic memory, which depends upon the idea that it is not the possession of certain concepts or conceptual abilities (past experience causing current knowledge) that marks the difference between episodic memory and other kinds of memory. The re-experiencing can be made possible by something non-conceptual[1]. The minimalistic conception is derived from the ideas of the German philosopher Immanuel Kant (1724 - 1804). In his 1781 landmark work *Critique of Pure Reason,* which has often been cited as the most significant volume of metaphysics and epistemology in modern philosophy, Kant set up a new theory of cognition and perception that has been used by modern scientists to consider episodic memory in a new light. Kant's world is complex and full of terminology, which it is necessary to understand in order to accurately grasp his ideas. Kant was concerned about the nature of the world and how we make sense of it; he generally opposed the views of empiricist philosophers such as Plato (ancient); Descartes, Spinoza, Leibniz (moderns) and rationalistic philosophers like Aristotle (ancient), Locke, Berkeley and Hume (moderns), and settled for a middle ground to concede the current thoughts.

[1] For a thorough definition of non-conceptualism and conceptual views see Hanna (2008) or Peacoke (2001).

One of his aims was to answer the fundamental question of metaphysic: ‘how is synthetic a priori knowledge possible?’ However, to begin to understand the meaning of this question, it is important to break it down into smaller parts and get to grips with Kant ideas.

In the first place, there is the dichotomy between synthetic (or intuitive knowledge) and analytic knowledge (or deductible knowledge). Analytic knowledge already contains the answer in the sentence - for example, “a tall man is a man” or “a bicycle has two wheels.” To Kant, this type of knowledge is not very useful, as it is a tautology and one of his main critiques of the empiricist philosophers who thought that all knowledge was deductible from experience (hence the title of the book *Critique of Pure Reason).*

Secondly, synthetic knowledge is about adding something on the basis of observation from the real world - for example, “an oak tree is a tree,” as it is a tree by analytic knowledge, but “a beautiful oak tree” is synthetic knowledge (it introduces the concept of beauty which is not contained in the definition of a tree). Kant believed we could make a priori (from the earlier) synthetic assumptions about the world.

Finally, an a priori knowledge refers to knowledge that can be known without reference to experiences or the world. For some empiricists such as John Locke (1632 - 1704), this kind of knowledge was impossible human were born “tabula rasa”, individuals are born without built-in mental content and that their knowledge comes from experience and perception. The most famous example of a priori knowledge is the sentence “Cogito ergo sum” or “I think therefore I am” (Descartes Principles of Philosophy (1644), Part 1, article 7) - I know I exist a priori; I don't need to check it. Now the meaning of the sentence makes more sense, as the development of an a priori idea is to add extra knowledge without reference to the real world, for example, to find out about the existence of other worlds (other parallel universes) that are not accessible to our sense of perception, analytic knowledge cannot help to the fact that there may be other worlds. Statements where you cannot derive the conclusion from the original proposition are not analytics but they are synthetics.

Kant's concepts are also better understood using the metaphor of a pair of spectacles. We have innate spectacles and we are reflecting on the nature of our own spectacles in order to arrive at a priori synthetic knowledge. Space and time are part of how we view reality, but they are not part of reality itself. In order to see reality, all we have to hand is the perceptual apparatus we are endowed with - the pair of spectacles - and, if they have pink lenses, we see the world as pink. Space and time are like the colours we take out there. The geometrical example that there is only one straight line between two points in our space can illustrate this concept, as it is the only thing we see because of our perceptual apparatus, and we therefore impose it onto reality. Therefore, we cannot really know how the world is; we can only know how we perceive it. The natures of God, other Worlds or Freewill are questions that cannot be answered by us, and Kant in his critique sets the limit of what can be understood. He does not deny that there is a reality out there, irrespective of us, but he claims that we are free to speculate about the questions that science cannot answer. To conclude, certain aspects of our knowledge of the world are not based on reality but are instead based on our experience of the world by the mind (Palmer, 2008).

If episodic memory is a form of re-experience as Tulving claims, then the minimalistic definition needs to inherit what is essential for something to be an experience at all. It must inherit two things from the original experience: the objects and actions within the original experience (the "what") and the spatiotemporal content (the "where" and the "when"). This needs to be synthesise to obtain an objective, non-egocentric spatiotemporal framework within episodic memory, with such an angle, this definition meets the transcendental conditions outlined in the work of Kant, meaning that they are a priori conditions rather than empirical characteristics that experiences do possess in fact (Russell & Hanna, 2012).

In *Critique of Pure Reason,* Kant dedicates a section to transcendental deduction to answer the fundamental question of metaphysic outlined before on a priori synthetic knowledge, and this helps to show that transcendental deduction is a useful system to help understand a minimalistic approach of episodic memory. The transcendental deduction contains two parts - the subjective and objective deduction – and, for this study, we will only refer to the former part. For a more in-depth discussion on objective deduction, see Hanna (1985).

Subjective deduction concentrates on the nature of the mind and, in particular, the nature of experience, belief and sensation. It is a basic theory of cognition that shows what is involved in a judgement. In simple terms, Kant tried to answer the following question: "Can I have knowledge of the world that is not just knowledge based on my own point of view?" (Objective knowledge) (Scruton, 2001, p. 34). To do so, he introduces the notion of understanding and sensibility, and we will consider the case of object recognition in order to explain these ideas.

Kant holds that the mental representation of some given external object is by no means a direct "copy" of the sensible impressions, a view held by the earlier empiricist philosophers. To the contrary, data received through the senses must be transformed into our cognition through the constructive work of two further mental capacities beyond the sensory. These he called the "imagination" and "understanding" respectively (see, e.g., pp. A78/B103; pp. A120-121; p. A126).

In Kant's theory, what he calls "the imagination" has the interpretive task of taking up received sensory material and arranging it in space and time. Taking space first, the given sensory material - visual, tactile, and so forth - has to be organised or arranged into specific three-dimensional shapes and located at a specific location or place within the one unique, continuous space that we consider all actual physical objects to occupy. Kant's technical term for the spatiotemporalised sensory materials, as produced by the imagination, is "intuition." Kant calls the "pure a priori forms" of space and time postulated in his theory "the pure forms of intuition."

We have seen that Kant argues that perception requires active reconstruction in space and in time, but it also requires concepts. The "understanding" is the home of concepts - for example, the concept "pen" is a special determination of the wider concept 'artefact' which is, in turn, a determination of "a material object", and so on until we can go no further, and each stage amplifies the concept of substance. By following this train of thought, Kant established 12 main categories, for example quantity (plurality, unity…) or relation (cause and effect), (Scruton, 2011, p. 37).

Kant emphasises that neither the intuition nor the understanding alone suffices; both are needed to have objective knowledge: "Thoughts without content are empty, intuitions without concepts are blind" (p. A51/B75). The reason Kant uses two different systems to represent objective knowledge is to help him suggest an explanation for the fact that there are two kind of synthetic a priori truth: mathematics and metaphysics. Mathematics is self-evident and obvious for all beings (a priori science of intuition) whilst metaphysics is a matter of debate and arguments.

This acknowledges the idea of a possible conscious experience that is not conceptually determined. For example, our knowledge of three-dimensional Euclidean space is not based on experience of objects; rather, in order to represent an object in the first place, the mind arranges given sensory material into the three spatial dimensions (using our spectacles). The purely spatial content of the experience can be illustrated with the two hands experience. When observing the reflection of one hand in a mirror, the real and the reflected hands are conceptually identical - they are the same hand, but they are topologically[2] different (Russell & Hanna, 2012). It would be impossible to describe the difference between the two hands to a person who has never experienced the concept of a reflection in a mirror.

For Kant, time like space is a form of sensibility. The temporal content Kant had in mind was not the dated nature of the experience, nor the way in which an experience fits into the broad temporal order of life events, but the fact that there will necessarily be "co-existence" (simultaneity) and "succession" (temporal order) in an experience, even one of minimal complexity (Clayton & Russell, 2009). The incoming sensory stream is always successive; this merely "subjective" succession may be reconstructed as views of an enduring thing (an object) or taken as a proper temporal sequence or ongoing event (an "objective" succession) (Palmer, 2008). Kant denies time and space of the a priori concepts; indeed, there is only the need for one space and one time in which all events are taken to occur, they are a priori but are not concepts because they do not accept instances as the categories do.

Using this approach, the issue of a full conceptual conception of episodic memory outlined by Tulving has been overcome. The "what" is conceptual while the "when" and "where" are non-conceptual but memory is necessarily characterised by its phenomenology content (see Figure 4). With this in mind, new episodic tests can be designed. Deferred imitation as a research tool for episodic minimalism affords a non-verbal test of WWW binding because one can use this technique to find out whether children can reproduce "what" actions they performed, "where" they performed them, and the order in which they performed them, "when" (Clayton & Russell, 2009; Russell & Davies, 2012).

[2] In the jargon of topology, they are enantiomorphs. There is then no conceptual difference at all between one hand and its so-called "incongruent counterpart"(Kant's term), (Clayton & Russell, 2009).

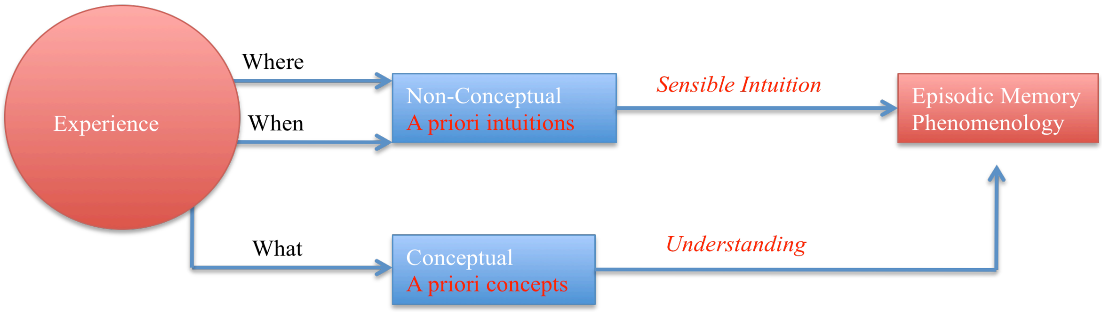

Figure 4. An illustration of minimalistic approach to episodic memory using Kantian terminology.

Selective Attention

Attention and Memory

American neuropsychiatrist and Nobel prize winner, Eric Richard Kandel acknowledges, in his landmark book *In Search of Memory* (2006), the fact that selective attention is a powerful factor in perception, action and memory in the unity of conscious experience (Kandel, 2006, p. 311). The brain has a certain capacity to process information and selective attention plays an important role in deciding what to exclude and keep in memory. Yet most of the memory studies do not explore the role of attentional selection in encoding while attention studies have ignored perceptual experience and past experience (Chun & Turk-Browne, 2007).

The treatment of attention begins with William James (1890) in his classical psychology text *The Principles of Psychology*. James captured the essence of attention in his famous definition:

> "Attention … is the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought. Focalization, concentration of consciousness are of its essence. It implies withdrawal from some things in order to deal effectively with others". (James, 1890, pp. 403-4)

Capacity theories of attention have suggested that we cannot process all stimuli that bombard our senses on a daily basis. In the early days of attention research, information processing was seen as a succession of stages; the pipeline model of selective attention proposed by Broadant (1958) is an example of an early selection view of attention, where humans process information with limited capacity and select information to be processed early. This model through evidence from neuroscience has been replaced and updated with a more flexible theory of attention (Posner, Sydner, & Davidson, 1980), suggesting that humans have much more flexibility in how they allocate processing. Attention can be seen as a spotlight that can focus brightly on a narrow area, or more broadly but shallowly on a wider range of inputs (Lieberman, 2012, p. 351). There is an important body of work on attention; for example, Chun, Golomb and Turk-Browne (2011) proposed a taxonomy model of attention in the same manner as it has been developed for memory. In this model, a taxonomy is proposed based on the types of information over which attention operates. It outlines that attention is both an internal and an external process; for example, humans can focus on external stimuli like target objects displayed on a computer screen or they can focus on thoughts that are retrieved from long term memory.

More comprehensive reviews can be found in Logan (2004) or Proctor and Read (2010). Topics discussed surround the debate on whether attention acts early or late in processing, or whether attention selects by enhancing relevant items, by inhibiting irrelevant items, or both. The question of inhibition is the most relevant to the thesis topic and therefore will be discussed in more depth.

In theories of visual attention stipulating the limited processing power of the brain as discussed above, some external stimuli need to be selected to the expense of others. In this context the emphasis has been on the amplification of target objects during selection for example the spotlight theory (Broadbent, 1982). Broadbent use the analogy of a "beam of light" that would highlight the relevant objects (targets) for selection to occur, hence enhance the target objects. However in the early 90s, the situation changed and the question to know if attention acts through the enhancement of relevant stimuli (targets) or the suppression of the irrelevant information (distractors) was again argued by information processing researchers (e.g. Tipper, 1995) which is also particularly relevant to this thesis. Many behavioural and neuro-imaging studies have supported the view that attention solves ambiguities during target analysis by suppressing irrelevant stimuli to prevent erroneous coding or binding (Mazza, Turatto, & Caramazza, 2009; see also Awh, Matsukura, & Serences, 2003). However these studies have used traditional attention tasks to observe distractor suppression. The approach in this thesis is much more oriented towards the study of memory.

Many factors (effortless or effortful) can influence which moments from our past are remembered best. As Brown and Kulik (1977) noted in their seminal paper on "flashbulb memories," events of emotional significance are more likely to be recalled vividly than mundane experiences, and neurobiological research has confirmed that the occurrence of affective responses can increase the likelihood that an event is stored in memory (LaBar & Cabeza, 2006). A flashbulb type of memory is an example of how the effect of attention could affect memory at the encoding stage. Another effortless factor influencing memory is arousal. According to various studies there may be two ways in which memory may be affected by emotion: by altering attention and perception during encoding (Christianson & Loftus, 1991) and by affecting memory retention (Kleinsmith & Kaplan, 1963). Various studies have indicated that following delay, arousal may affect memory; furthermore, other research indicates that neutral stimuli lead to memories diminishing over time and memories related to arousing stimuli remain the same or improve over time (Baddeley, 1982). This is particularly relevant in forensic psychology where emotional arousal is one variable that has been found to increase the accuracy of memory during significant and unexpected events and decrease the accuracy of memory when the level of stress is accompanied by the presence of a weapon (the weapon focus effect) (Loftus and Messo (1987)).

As described previously, the traditional model of a multiple memory system supports different type of memories. One distinction made is between the declarative and non-declarative types. Declarative memory refers to the type of memories that can be explicitly expressed, like facts (semantic) and events (episodic). Non-declarative memory describes memories that are expressed via behaviour, not accompanied with awareness and are usually acquired gradually across multiple trials such as skills, habits and priming (Squire, 1992).

In the model of multiple memory systems (Squire, 2004), episodic memory and priming are shown as two different systems. Priming refers to the increased ability to identify or detect a stimulus as a result of its recent presentation (Squire, Ramus, & Knowlton, 1992), for example in a picture naming task (Flores d'Arcais & Schreuder 1987), where participants are shown pictures of objects and asked to identify the item. If you prime the image of a "cello", it is easier to name it after presenting a semantically related prime "guitar" than after unrelated prime "chair" picture. Priming does not engage in the retrieval of a prior experience as episodic memory does, but under the traditional memory system the primary mechanism of priming, is argued to be the suppression of neural connections (Wiggs & Martin, 1998). It also fits with the idea of lack of awareness for such a phenomena, where priming has been designed primarily to improve the speed and efficiency of an organism to interact with its environment (Squire, 2009).

Traditional ways of measuring selective-attention tasks include the Stroop task (Stroop, 1935) and the Flanker task (Eriksen, 1974). In The Stroop task participants have to name the colour (e.g., red) used to write an incompatible colour word (e.g., green). Such types of task are usually harder for the participants and consequently diminish processing speed. The Flanker task, designed by Eriksen (1974), assesses the ability to inhibit a stimulus that is inappropriate during the task and also results in poor performance at retrieval time; the original test was designed with letter stimuli. Other tests include spatial localisation (Posner, Cohen & Rafal, 1982), lexical decision (Rubenstein, Garfield, & Milikan, 1970) and picture identification (Cave, 1997).

However, some researchers have observed episodic memory retrieval that can occur automatically and implicitly without the intention to remember (Logan, 1988; Homel, 1998) suggesting that episodic recollection and priming may be using the same underlying memory system and not as it is portrayed in the traditional separate model of memory explained as in Figure 2, making human memory model unnecessarily complex. In some cases, priming phenomena have been explained by appealing to an episodic trace. For example for non-remembering task such as switching cost recent empirical evidence supports the idea that costs associated with switching from one task to another may reflect the retrieval of bound episodic memory representations related to task-sets, that are retrieved by the current stimulus (Thomson, 2012). Others for example have attributed the priming found in negative priming to an episodic memory trace. Indeed episodic retrieval explanation of negative priming was observed by DeSchepper and Treisman (1996), who found that negative priming could be observed across 200 intervening items and up to delays of one month.

Negative Priming

In certain circumstances, repetition of a previously ignored item can impair or slow down subsequent responses to it (see Figure 5). Tipper (1985) named this effect negative priming and it was understood to reflect an inhibitory mechanism (Houghton & Tipper, 1994) that acted to reduce or revert the activation of the internal representation of the ignored item during its attentional de-selection. When the prime distractor item appeared again in a probe display as a target, its residual inhibition would result in increased latencies and errors.

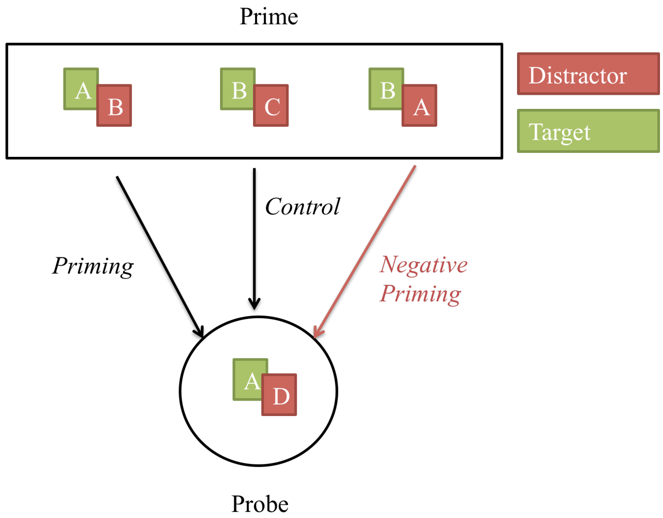

Figure 5. Example of priming and negative priming phenomena. Priming reflects the presentation of the same target item encountered in the probe (A green) when primed (A green). Negative priming will imply the presentation of a target item encountered in the probe (A green) when it was a distractor in the prime (A red).

The inhibitory model developed by Houghton and Tipper is one of the possible theoretical accounts that could explain negative priming. The model is based on a computational representation of an artificial neural network that presents an inhibitory rebound naturally emerging from the network connection between excitatory and inhibitory cells that can maintain internal equilibrium of a property unit (Houghton, Tipper, Weaver, & Shore, 1996).

Figure 6 represents the result of the computational model developed by Houghton and Tipper. At trial onset, stimuli are presented to a participant (e.g. target and distractor objects). At the start, both objects represented by the two curves are activated and follow the same pattern. At some stage, the two curves diverge because the distractor receives more inhibition (modelled by the neural network). At a certain threshold, the target is assumed to be selected. Once the external stimuli are set to off, the target activation will decay to zero but the distractor activation will go below resting level. This negative value is what causes negative priming for the next trial. Participants will be slower at responding to stimuli because of the negative value. A more formal specification of the model is described in length in Houghton and Tipper (1994) or Houghton, Tipper, Weaver and Shore (1996).

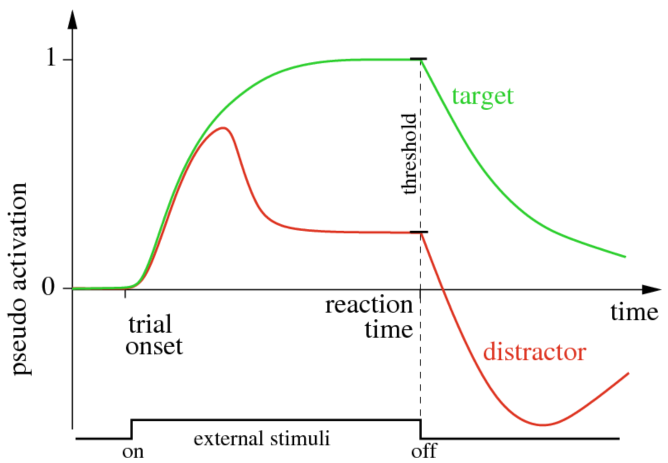

*Figure 6.*This schematic is a representation of the target and distractor activation during one trial from the distractor inhibition model (Houghton & Tipper, 1994). Diagram adapted from Degering (2009) thesis.

The negative priming model is not only a computational model but also has some neuropsychological interpretation (Houghton & Tipper, 1994) and is encountered in various tasks and items, such as picture naming, letter naming, letter matching, counting, target localization and lexical decision (Neill & Valdes, 1992). Moreover, the model strongly supports different effects - for example, it clearly explains the distractor saliency effect (Lavie & Fox, 2000). If distractors are more salient (e.g. brighter) they will produce a stronger inhibitory effect and therefore increase negative priming (Houghton & Tipper, 2004).

However, despite the Houghton–Tipper model, a revised version of 1985 Tipper model, the main challenges to the inhibitory theory came from the episodic memory account (Mayr & Buchner, 2007).

The episodic account of negative priming has its origins within the instance theory of automatisation. The theory relates automaticity to memorial aspect of attention (attention is essential for learning for example attention at encoding determines what is put into an instance, and attention at retrieval determines which instances are retrieved), rather than resource limitation (Logan, 1998), previously explained with Broadbent's filter model of attention. For Logan, humans start to learn how to perform a task (encode information through attention) by using a general algorithm to solve a certain problem. Once they have learned certain solutions to certain problems, they no longer need to rely on the algorithm, but will retrieve from memory an instance of the episode they have previously encoded, this links well to existing theory on episodic memory (Hintzman, 1976; see also Jacoby & Brooks, 1984). An example of automatisation is children learning how to count - they will first count using their fingers but, as their experience increases, they will rely on memory. The episodic retrieval model is based on the memory concept of specific instances (episodes) which is not directly associated to the idea of semantic network activation (Mayr, Buchner, 2007). It may not be as close as what Tulving meant but relevant to the discussion to link memory with inhibition.

Neill and Valdes (1992), for example, explained that when target and distractor appear during selection (prime), the distractor is tagged in episodic memory as “do not respond.” When the distractor appears again sometime after (probe time), its presence acts as a cue for retrieval of the previous episode where it was presented. Negative priming arises because of the conflict between tags in the current episode ("respond to X") and the previous one ("do not respond to X"), as a response has to be produced to an item tagged as "do not respond."

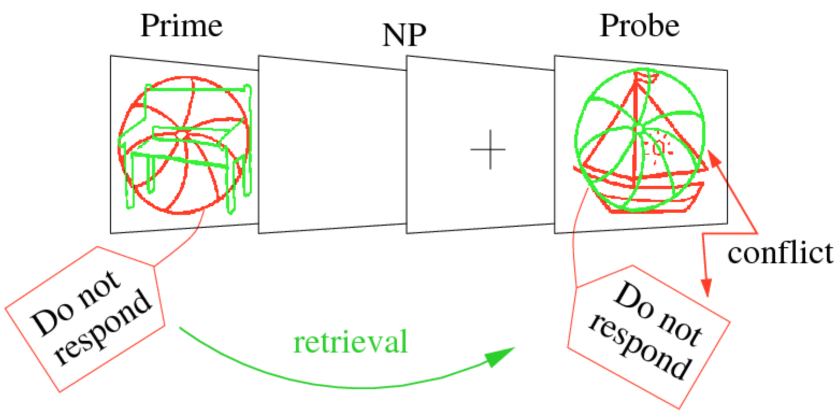

Figure 7. The episodic retrieval model of negative priming. Diagram adapted from Degering's (2009) thesis

In any case, a classic area of disparity between these two models is whether negative priming decreases over time. Whereas inhibition decays over time, episodic retrieval could last indefinitely, as episodic traces are expected to last in memory for a considerable amount of time (Tipper, 2001). Studies have commonly manipulated the Response-to-Stimulus Interval (RSI) to determine whether negative priming persists over time. This has been observed several times by Neill and Westberry (1987), and Neill and Valdes (1992) who found negative priming decreased over time (2020ms). However, there are some reports of negative priming persisting for relatively long intervals (6600ms), Tipper et al. (1991). However, it is possible that different results could correspond to differences in the designs. For example, Neill and Westberry (1987) manipulated RSIs within subject by randomly mixing different intervals within the same block of trials. However, Tipper et al. (1991) manipulated RSI using in-between subject variables. Predictability of the interval throughout several trials may induce different coding strategies for different intervals that may interfere with the results. Randomly mixing them in the same block would encourage a single strategy for all the trials, so certain differences in processing across these intervals would appear more clearly (Hasher, Stoltzfus, Zacks & Rypma, 1991).

In a more recent account, Tipper (2001) combined the inhibitory and episodic retrieval models to account for negative priming as an inhibitory selection mechanism. He emphasised that a better understanding of the encoding (inhibition accounts) and retrieval processes (episodic accounts) that mediate negative priming will have implications on cognitive functions that are memory and attention.

In context negative priming was used as analogy to explain inhibition of stimuli and selective attention (suppression of distractrors). If selective attention causes negative priming, then the same underlying mechanisms (inhibition of distractors) may also affect memory encoding. In the selective attention task, the nature of the movement rather than the visual spatial information determine the attentional relevance of stimuli and, therefore, the level of inhibition associated with the distracting stimuli (Tipper, Lortie, & Balys, 1992). For example, when attempting to reach for my coffee cup, an irrelevant cup, which is closer and ipsilateral[3] to the participant hand, could easily interfere with the participant action. The closer distractor object is shown to be associated with a greater inhibition as measured via negative priming than the distractors that were further away from the initial starting position of the reaching hand (Tipper, Meegan, & Howard, 2002).

Behavioral studies have demonstrated that attention influences the strength and content of memory (Chun and Turk-Browne, 2007). Generally speaking, selective attention becomes crucial when there is competition between stimuli in the environment and although it is more common to think about how attention improves memory, there is growing appreciation for how memory optimizes attention and perception.

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[3] Same side of the body

Conflicting Views on the Role of Action

Since episodic memory includes a spatio-temporal element, it is worth reviewing separately the different components that constitute this measure and the effect of an action on each of them in various environments (e.g. 2D and 3D environment).

Spatial component: Where

Research has found that active involvement in moving through a terrain does not enhance spatial memory. Using a driving simulation program Booth, Fisher, Page, Ware and Widen, (2000) studied spatial memory from the active driver and compared it with the passenger's one without showing any difference between the two. They suggested that the attentional limitations affecting the driver might have interfered with the learning in this virtual environment, possibly hiding a potential benefit of the action. This result has been replicated, and other studies have also failed to observe an effect of sensorimotor action on spatial memory (Wilson & Peruch, 2002; see also Gaunet, Vidal, Kemeny, & Berthoz, 2001 for similar results in virtual environments). Christou and Bulthoff (1999) had active explorers control their own movement through a virtual environment, whereas passive observers watched a playback of the active explorers' route inside a computer model of a house. In one of their experiment for scene recognition, they found no overall difference between the passive and active groups in scene recognition. The lack of overall memory improvement in the active group was attributed to the potential distraction experience in this group when training the task during the learning phase (increased mental load).

Contradicting these observations, separate sets of studies have found superior spatial memory during an active compared to a passive exploration of a virtual environment (Brooks Attree, Rose, Clifford, & Leadbette, 1999; see also Carassa, Geminiani, Morganti, & Varotto, 2002). For example, Attree, Brook, Rose and Andrews (1996), see also Tong, Marlin and Frost (1995) reported better memory of spatial layout (relative positioning of objects) for active explorers compared to passive ones. Another study from Péruch, Vercher and Gauthier

(1995) found an advantage for active subjects during training in a spatial localization task (topographical maps to orient in space) involving the use of a joystick as a motion control device. These differences in results may, therefore, reflect either task-specific differences between active and passive (observations of continuous visual sequences or selected snapshot) observers or simply different degrees of difficulty in the use of motion input devices.

When studying the influence of the action using different backgrounds results are also mixed. Tavanty and Lind (2001) revealed that 3D display improves spatial memory compared to 2D displays. However, in Cockburn and McKenzie (2002), the results indicate that, for relatively sparse information in retrieval tasks (up to 99 data items), 3D hinders retrieval tasks.

In conclusion, it is not clear whether action improves spatial memory, but any benefit seems to change depending of the type of environment or background used. It seems that an active mode adds cognitive load for the spatial component hence the superiority observed in some of the experiments mentioned above.

Object identity: What

Next we will look at object identity or the “what” component of episodic memory. A number of studies (Attree et al., 1996; James, Humphrey, Vilis, Corrie, Baddour, & Goodale, 2001; Harman, Humphrey & Goodale, 1999) using virtual or fully immersive environments, have either found that an active state during the encoding phase enhanced object recognition or that there was no real advantages over a passive state.

Conversely, Plancher et al. (2007), found no difference between participants for both recall and recognition of objects using a virtual environment (a 3D model of a town explored using a steering wheel and a pedal as navigation tool), finding benefits only on spatial memory. To make the matter worse, in another study from Plancher et al. (2012), the recall of details even substantially improved during passive compared to active exploration (see also

Christou & Bulthoff, 1999). In a study reported by Van Eynde and Spencer (1988), they found no difference for short memory retention active vs. passive (2 weeks), but observed that the active mode was superior to the passive mode for long-term recall of retention of study learning (13 weeks).

In conclusion similar to the Where component, there are mixed results on the role of the action for object identity recall.

Temporal component: When

Plancher, Nicolas and Piolino (2008a) observed no significant effect of sensorimotor involvement for temporal and spatial recall for navigation task in a virtual town, they attribute the lack of difference due to the fact that data were collecting from too few participants. Overall the role of the action in either a virtual environment or a real world type scenario did not seem to affect the temporal component. These results could be due to the fact that the most robust aspect of the episodic memory when performing a WWW task maybe the linking of the object identity (what) to the location (where) and not the addition of the temporal aspect of the task (When) (Holland & Smulders, 2011; Köhler, Keysers, Umilt, Fogassi, Gallese, & Rizzolatti, 2002). There is also a proposal on the working of an alternative definition of episodic memory by replacing “when” with “which” relying less on the temporal component of the task (Eacott, Easton & Zinkivskay, 2005).

Episodic memory

It is possible that different types of memory are stored differently to episodic memory per se, in a way that object information (What), for example, could rely on distinct encoding process (Köhler et al., 2002). Therefore, rather than analyzing separate components that may contribute towards episodic memory, an alternative approach is to study episodic memory as a whole using recognition tests for example. Plancher et al. (2008a), investigated episodic memory by testing its individual components with free recall tests as well as an overall recognition test and computed a total episodic score, they observed that active exploration of their virtual environment did not lead to significantly better episodic memory compared to solely the passive movement, a result also commonly found when studying separated components as mentioned earlier. They reported no difference between active and passive exploration, probably because a positive effect of active exploration on memory was counterweighted by a difference in attentional demands in their specific conditions (i.e., driving in a virtual town), which is similar to the study of Christou and Bulthoff (1999) discussed above for spatial locations. In an active condition, participants do not have the resources to pay attention to every detail, although they are more engaged in the task and may be more attentive (Plancher et al., 2012). This should enable them to encode information more strongly. However, the results suggest that it is probably not the attention per se that enables better encoding in this situation - in fact, for participants, the recall of details was improved after passive exploration. The results also suggest that the benefit of the active condition mainly relies on the implementation of procedural skills (action sequences) and self-involvement during encoding such as action planning, although little is known about how these components interact or bind together.

The capacity to retrieve an event can depend on the quality and strength of associations created between central information and contextual features. Motor activity and intentional encoding can reinforce the association between features of an event and therefore increase the capacity to retrieve the full event (Lekeu, Van Der Linden, Moonen & Salmonet, 2005). Kahneman, Treisman and Gibbs (1992) argue that identity and location information are bound together in a memory representation that they called "object-file". Taking this concept a step further, Hommel (2004) suggests that this episodic binding[4] described by Kahneman is not only restricted to perception, but also to attention, action planning and sensorimotor processing as well. Hommel subsequently replaced the term "object-events"

[4] to recollect events, the contextual features of these events need to be correctly connected to one another in memory by a process called binding (Plancher et al., 2010)

with “object-files” to take this into account. Plancher et al. (2012) also suggest that, following an active exploration, memory traces of the spatial environment are enhanced and, as a result, all related information is more likely to be retrieved. The binding of multiple features, such as object identity and location, through selective attention has been repeatedly reported (Tipper & Driver, 1991).

As reviewed above the role of the action may be varied for the spatial, temporal and object identity memory recall but how participants are engaging (via motor action for example) with the materials may also have an effect on the quality of memory recall. There is also an extensive literature review on how action can enhance memory or more directly, the perspective that our bodies have a significant influence on our minds. For a general overview one can refer to the work done by Madan and Singhal (2012a) who review the effects of enactment, gestures and exercise on human memory

In support of this other research can be cited, including studies that examine influences on how information is processed, for example, movement- related properties of objects (e.g., “affordances”, see Gibson, 1977) and words (Handy, Grafton, Shroff, Ketay & Gazzaniga, 2003). More recently research indicates that memory recall can be enhanced by the motoric properties of words used for objects (i.e word manipulability) and how these words are processed (Madan & Singhal, 2012b). This type of insight could help in the design of learning materials and how learners can engage with the content more efficiently.

Other research carried out by Chrastil and Warren (2012) focused on survey learning and the different types of information learners’ use during the encoding process. Inside a virtual environment participants learned the object locations in a virtual maze by choosing to walk, being pushed in a wheelchair in the virtual environment or watching a video at the same time choosing to make decisions about their route or accept guidance through the maze. The results of this research showed that, beyond vision alone, the primary contributor to active learning of metric survey knowledge is podokinetic information, i.e., moving as a response to the stimulus of light. Vestibular information and decision-making did not have any significant contribution towards survey learning.

Goal of the PhD

The latest reviewed literature suggests that there are no clear answers to the role of action and the influence of the type of environment when it comes to episodic recall.

The PhD has been very much an explanatory one, at least at the start, based on key literature reviews, such as Plancher et al. (2005), Holland and Smulders (2011), and Clayton and Russel (2009). It was decided upon to explore episodic memory building on the methods and results of these influential research papers, and to try to reunite conflicting views presented in the literature. Using very simple recognition tests, the first pilot study (Experiment 1) pointed towards promising results. Taking these results a step further, a long-term path for further tests formed the definitive goal of my research. The final outcomes presented in the thesis are consistent across most of the experiments carried out over a period of 3 years. Selective attention has never been studied in this way; indeed, the primary interest of the PhD was to assess the effect of the action (passive vs. active), and the environment (2D vs. 3D) on episodic memory and its components.

Some additional factors were also bolted on such as the type of retention (immediate vs. delay) or the type of objects to be recalled (target vs. distractor). Using an alternative approach to test episodic memory, distractor suppression effects have been observed during the retrieval of episodes. While traditional methods of selective attention have observed inhibitory processes, they have never been highlighted using episodic memory tests. On these grounds, the work achieved in this thesis is original and results could lead to practical applications, for example, in a learning context. The results observed using an episodic memory task are novel but recent research done by Ritcher and Yeung (2012) has focused on cognitive control (using task switching tasks) and long-term memory and also provided an insight on how memory and cognitive control are intertwined, which could indicate that the results presented in the thesis are not specific to one type of task.

The experimental chapters of this PhD have not been published. However, at least one published paper will be extracted from this thesis and is in preparation to be shortly submitted to the *Journal of Trends in Cognitive Sciences*. Across all experiments, the same analysis has been carried out, and there may be some crossover or repetition in the method. However, they will all address the same questions on selective attention as discussed in the literature review. At the end of each experiment, I will present a results summary, and explain how the results may have led me to implement a different approach in the next experiment.

CHAPTER 2: EXPLORATION PHASE: 2D VS 3D BACKGROUND

Experiments 1 & 2

Introduction

All studies reported in this thesis take a quantitative approach to measuring episodic memory and use a variation of the What-Where-When "episodic-like" task usually performed in non-humans. The task assesses the impact of the behaviour of participants using standard computer tests and looks at various types of recall and recognition task. The purpose of this present study is to look at the various parameters that could influence episodic memory, and also investigate how the WWW task allows us to quantify the results using signal detection theory. Factors such as passive (watching) and active (clicking) modes, short-term and long-term retention, and target vs. distractor objects, with intentional encoding are introduced.

Since most of the studies on sensory motor interaction and different components of episodic retrieval have been designed on 3D interactive platforms, it was decided to implement a study using a 2D interface and, in later research, to develop a similar study in a 3D world in order to investigate the differences. To research the influence of active vs. passive encoding of information, the experiment comprised of two groups who were told to encode the objects presented on a computer screen (not using a virtual environment): a group assigned to click on target objects (active mode), and a group who just watched the objects (passive mode). This first experiment was designed as a pilot study, where participants were asked to recall the objects using free/cued recall activities against different types of background - a 2D map and a map with richer features such as 3D perspectives. Simple yes/no recognition tests to measure memory for both recognition and cued recall were used.

This research study is intended to assess the impact of the various factors mentioned above on recall accuracy of episodic memory that includes object identity, and spatial and temporal recall, since only very few studies have considered the three components separately.

Method

Participants

In this preliminary study, 42 participants participated, 20 for the passive mode and 22 for the active mode. Participants were chosen from a pool of friends and work colleagues. They all voluntarily participated in the study without receiving any form of material compensation. The participants ranged in age from 21 to 50 (M = 34.31; SD = 10.11). The participants did not have any medical conditions associated with memory deficit or other cognitive functions.

Apparatus & Stimuli

The test was conducted using Microsoft *PowerPoint*. The stimuli consisted of 2D objects chosen from the image library www.thinkstockphotos.com (Figure 8). They were selected with the illustration vector only images option. The pool of target and distractor objects consisted of 32 items; a list of all stimuli can be seen in Appendix C.

Figure 8. Example of stimulus target and distractor objects

The images making up the stimuli were presented at different locations (office or home) on a Mac book pro 15inch laptop screen. The screen was divided into a 2x2 matrix; 16 targets and 16 distractors. For this study, we used two backgrounds: a 2D map of Bangor university campus and 3D view in *Second Life*. The 3D view is not an exact representation of the 2D map and neither truly represents the campus. It is a snapshot of Bangor University Island[5]. The test was conducted from about 50-60 cm and, on average; the visual angle for each object was 2.2 degrees.

Figure 9. Stimuli presented to participant in PowerPoint. First image represents stimulus with a 3D background, the second image is for a 2D background

Procedure

Table 1. Groups of participants

Mode	2D Background	3D Background
Active (within subjects)	Immediate Recall Delayed Recall	Immediate Recall Delayed Recall
Passive (within subjects)	Immediate Recall Delayed Recall	Immediate Recall Delayed Recall

In the 2D and 3D tests, subjects were instructed to remember any objects on the map but also were told to pay more attention to target objects (objects with a name on the test slide). To distract the user while they performed the tests, distractor objects were used. In both modes, displays were identical, and the only difference was the task that participants had to perform (Table 1). In the passive mode, the target object flashes on the map to direct the

5 http://maps.secondlife.com/secondlife/Bangor%20University/146/77/27

gaze, and the name of the target object is written at the top of the slide. The participants had 5 seconds to concentrate on this before the next slide appeared. In the active mode, participants had to click on the target object (also with the name of the object at the top of the slide) in order to move to the next slide (Figure 10). There was a sequence of 8 slides with a break slide in the middle designed to help temporal recall (see Figure 11). In this design the timing for passive and active participants may not be identical. Passive participants had to wait 5s for the slide to move while active participants could move to the next slide anytime between 1s-to 5s (usually took 3-4s).

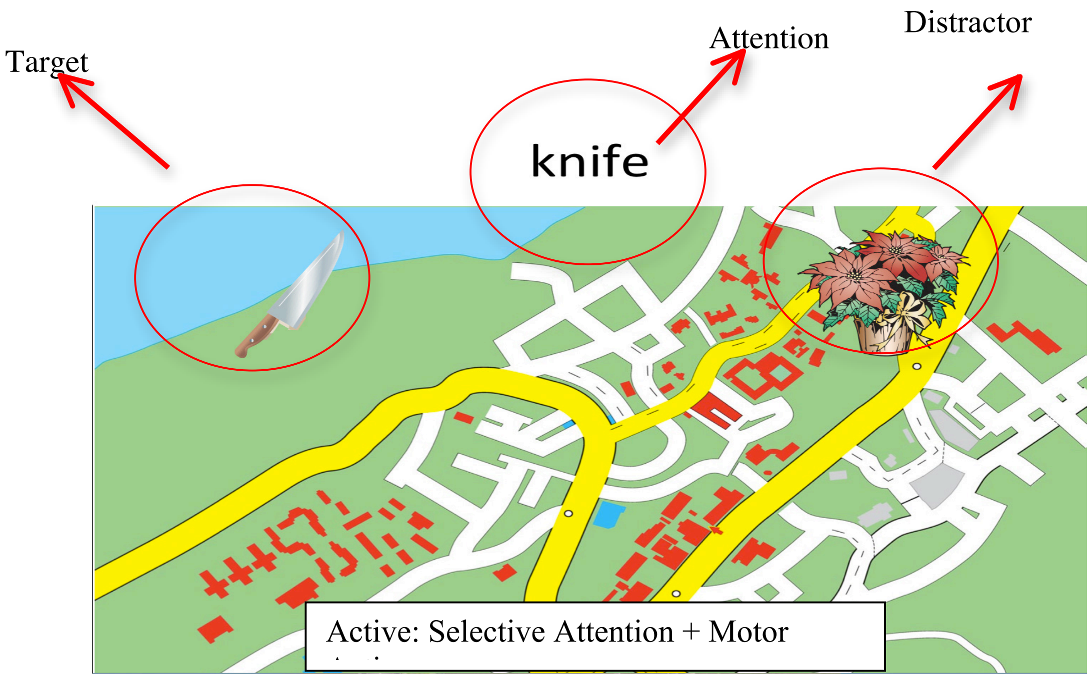

Figure 10. Encoding slide with 2D background

To ensure that tests were independent of settings, order and subject, a permutation for participants was designed using the Orthogonal Latin Squares Balanced Block Mixer (Edwards, 1951). The advantage of such a technique is that specific episodic effects associated with the use of certain objects in a specific environment are not experienced. If an effect is found, it should be exclusively due to the 3D/2D scenes, but not to the specific object set, or the combination object/scene. Without permuting them, object set and scenes will be confounded. More details can be found in Appendix E.

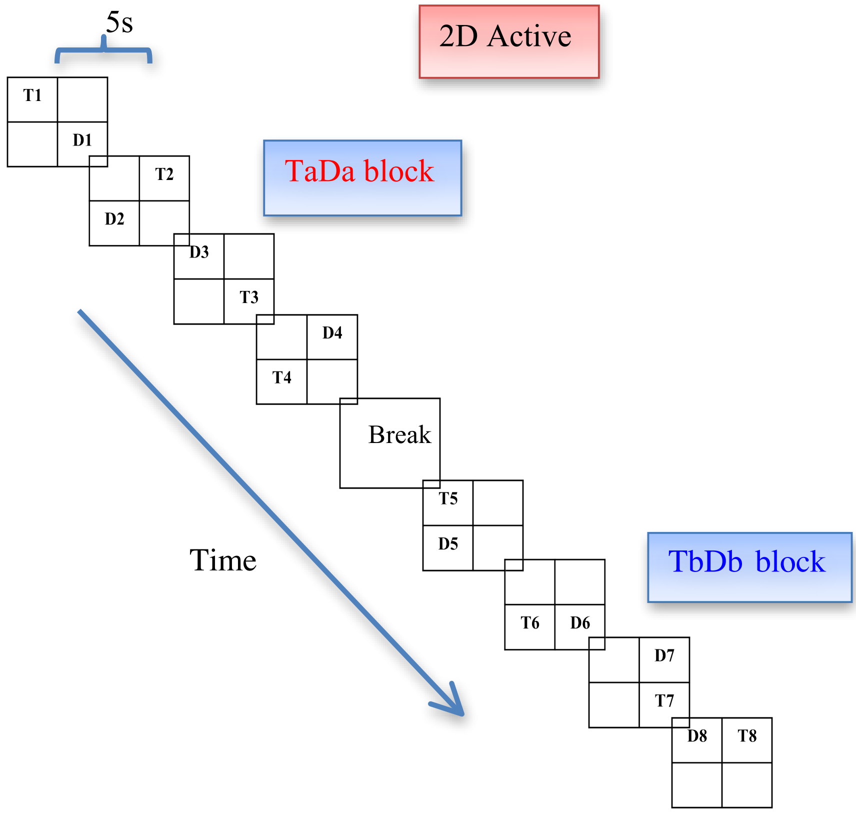

Figure 11. Sequence of slides for participants, the break section (self-timed of 5s) was used as a clue for participants to remember the TaDa block to be recalled for the delay condition

Responses were collected through a questionnaire that was printed on paper and hand written by each participant. The demographic data (such as age, sex, time of the test, name and whether participants where familiar with video games or not) was collected at the end of the test. The questionnaire comprised of the following questions:

- Recall the objects you saw (free recall);
- In which part of the screen did the objects appear? (A 2x2 matrix choice was given to help participants place the objects in the right quadrant)
- When did the object appear? (Before or after the break?)

Bangor University's School of Psychology's internal ethics committee approved the study. Before the experiment, all participants were told that their memory was going to be tested (intentional encoding). They received a verbal explanation of the procedure, and were shown a few trial screens. They also signed a consent form, and were told that they could stop the experiment at any time. At the end of the test, participants were offered an explanation of the research and asked how they had found the test. The duration of the test, including the recall phase, was an average of 20 to 30 minutes.

In this specific design since it was a within-subject design, participants (passive and active) were both exposed to different type of background. All participants undertook the memory test at two different times: the first took place immediately after the first stimuli 2D background was presented, and the second after a delay where participants were asked to perform a 2 minute task of their choice, usually checking their emails, surfing the web or having an informal conversation with the experimenter. This task was not used for the delay recall test but to remove any interference from the previous test (2D) before proceeding to the 3D background, the interference task for each background was in fact the test on the TbDb block in this instance, see Figure 12.

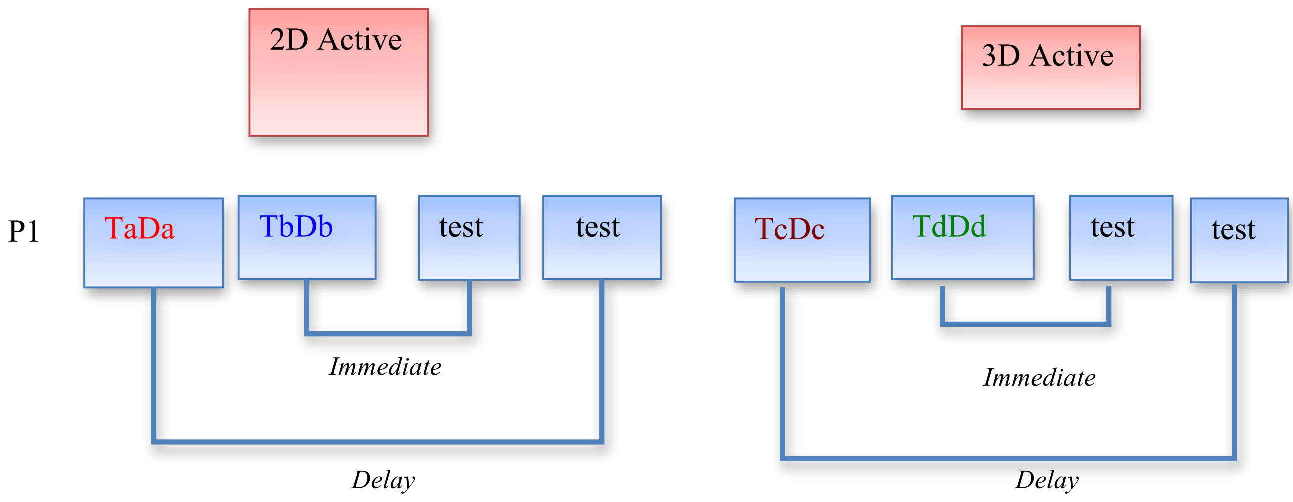

Figure 12. Object permutations for the active tests, therefore tests are independent of settings, order and subject (within subjects). In the first part for the 2D background, participants are tested immediately with the TbDb block, than they are tested with the TaDa block for the delay conditon (the immediate test is used as a interfrence task). Similar condition is set for the 3D background memory test.

Notes on data analysis

The following analysis is valid for all experiments throughout the thesis. A conservative approach was used in which episodic retrieval of a particular object was inferred only in those cases where the three memory components (what, where and when) were correct. However, partially recalled objects were computed for object identity (what), spatial location (where) and temporal (when). The spatial and temporal location measures are however a binding with the "what" component. Indeed to know if a participant recalled correctly the "where" or the "when" one needed to know the "what" that matches. Measures reported in all experiments of the "where" and "when" are in fact "what-where" binding and "what-when" binding.

Elements of signal detection theory were applied to report all results. During recall a hit referred to an old object (object present at testing) recalled correctly, an error was scored when a participant failed to remember an old object, and finally false alarms were recorded when a participant thought they saw an object when it fact it was a new object presented during probing.

The accuracy values reported throughout this experiment and all others were computed as hit/(hit + error) proportions for all analyses. Since the focus of attention in this thesis is about the difference between distractor and target objects, only the detailed impact of false alarms are reported for the free recall experiments (Experiment 1-2) but not for the other experiments (cue, recognition); false alarms data cannot be extracted and only a combined value for the active and passive mode are presented (if a new object is presented at probe time, it can neither be a target or distractor object); see Appendix F.

Most of the results are reported in % for better comparison across all experiments. It makes it easier to compare across the changing number of trials per condition. However analysis using binomial data could also have been used if all experiments had been pre-designed with a defined structure.

The results section includes an analysis of full episodic recall and also recall of the individual components of episodic memory. The final analysis looks specifically at the influence of each component over full recall. The same data that was removed from the episodic memory analysis was also not included in individual components of the analysis.

All significant interactions and main effects are reported in the appendices (see Appendix H). For each analysis significant interactions are reported. However if an interaction is not present T-Tests are still used to follow the descriptive data and observe trends for each experiment.

For each analysis description for the different components when suppression or enhancement for an object are described, it should be explained as object identity for the "what" component, object location for the "where" component, and object temporal properties for the "when" component. However to keep the descriptive analysis shorter generic terms have been used (target or distractor).

Finally a summary table in Appendix A summarises the difference between all experiments designed in this thesis.

Analysis

In this experiment means of overall accuracy rates per participant (42) and per condition were analysed through a 2 (Objects: Target, Distractor) x 2 (Temporal delays: Immediate, Delayed) x 2 (Modes: Passive, Active) mixed Factorial ANOVA where Objects and Temporal delays were manipulated within subject and the Mode was manipulated between groups.

Results (2D background)

Note on confabulation

Before starting the main results analysis, and due to the specificity of the design of the test, using free recall it is expected to have confabulations made by participants, that is objects not present at probe time but being recalled later during the free recall activity. A look at the data suggested that the number of confabulations for both the 2D and 3D only reached 0.09% of the total recall; therefore they did not impair the results presented below.

Results for episodic memory recalls

The analysis showed that memory was significantly higher during immediate recall (10%) than during delayed recall (6%), [$F(1,40)=6.75$, $p=.013$, $\eta^2_p=.144$] .

It was found that memory was greater for target objects (7.3%) than for distractor objects (1.3%) [$F(1,40)=4.13$, $p=.05$, $\eta^2_p=.094$].

It was also found that memory of targets was influenced by the type of mode [$F(1,40) = 18.96$, $p<.001$, $\eta^2_p= .322$]. Distractors were recalled significantly more in the passive mode (6.8%, $t(40)=2.57$, $p<.014$) than in the active mode, while targets were recalled more in the active mode (8.7%, $t(40)=2.63$, $p<.012$) than in the passive mode.

Despite the lack of three way interaction, it can be observed that in the active mode, distractor recall performance (reduced memory for distractors compared to targets) was observed during both the immediate recall (9.3%, $t(19)=2.5$, $p=.018$), and delayed recall (9.4%, $t(19)=3.1$, $p=.005$): but it was not present for either during the immediate or delayed recall in the passive mode. Indeed, in this mode there was even a trend for distractors to be recalled even better than targets (3.9%) when tested immediately after encoding ($t(21)=1.9$, $p=.065$).

Additionally, it was also found that memory for distractors during immediate recall was significantly reduced in the active mode (6.8%, $t(40)=2.09$, $p=.04$) compared to the passive mode, while the trend for target memory seems to be not enhanced in the active mode (6.4%, $t(40)=1.8$, $p=.076$) compared to the passive mode. After a delayed recall, however, there was some evidence that targets benefited from the active mode compared to the passive one (10.8%, $t(40)=3.95$, $p<.001$).

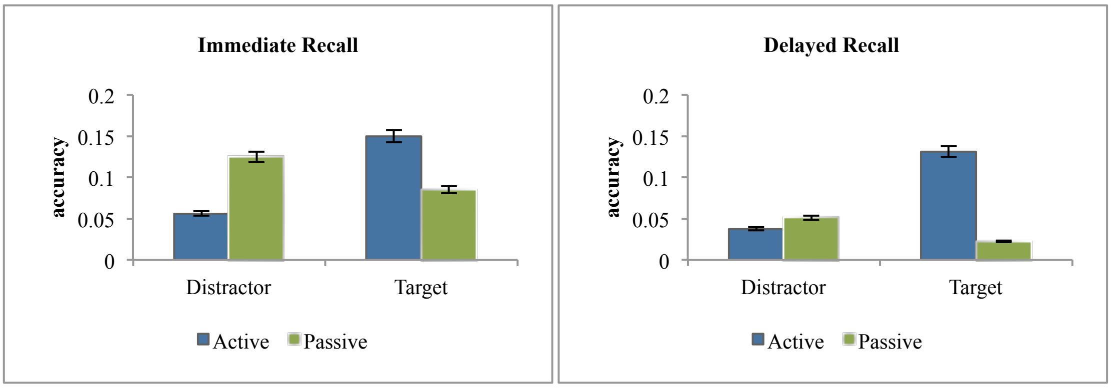

Figure 13. Exp 1: Mean accuracy recall for full episodic memory during immediate and delayed recall. Note error bars denote one standard error around the mean.

Results for object identity recall (what)

Following the pattern found with full episodic memory results, the analysis showed memory to be significantly higher during immediate recall (19.5%) than for delayed recall (12%), [$F(1,40)=15.75, p<.001, \eta^2_p=.28$].

The type of delay and the mode influenced memory recall [$F(1,40) = 8.84, p<.005, \eta^2_p= .181$]. During immediate recall, there was a trend for memory in the passive mode to be slightly better than in the active mode ($t(40)=1.89, p<.066$). This was reversed during delayed recall where memory in the active mode was much better ($t(40)=2.34, p<.024$).

Interestingly, memory of targets was influenced by the type of mode [$F(1,40)=12.5$, $p < .001, \eta^2_p=.238$]. Targets in the active mode were better remembered than distractors

(7.5%, $t(40)=2.63$, $p=.012$). Distractors were however better remembered in the passive mode (6.8%, $t(40)=2.57$, $p=.014$) than in the active mode.

There was no significant three-way interaction between mode, object and temporal variables ($p=.86$). However it was observed that during the immediate recall task target were better selected (16.2%, $t(19)=4.3$, $p<.001$) for the active mode, which was not replicated for the passive mode (2.1%, $p=.6$). During delayed recall, target objects were significantly better recall for the active mode (15%, $t(21)=5.33$, $p=.002$) but not for the passive mode (0%, $p=1$).

Additionally, it was also found that memory from distractor during immediate recall was significantly reduced in the active mode (8.7%, $t(40)=2.99$, $p=.005$), while target memory was not enhanced in the active mode (1.7%, $p=.66$), supporting the view that the difference between target and distractor memory in the active mode for immediate recall is due to distractor suppression and not target enhancement. After a delayed recall, however, there was some evidence that targets benefited from the active mode compared to the passive one (13.4%, $t(40)=3.49$, $p=.001$) in the same manner observed for full episodic recall.

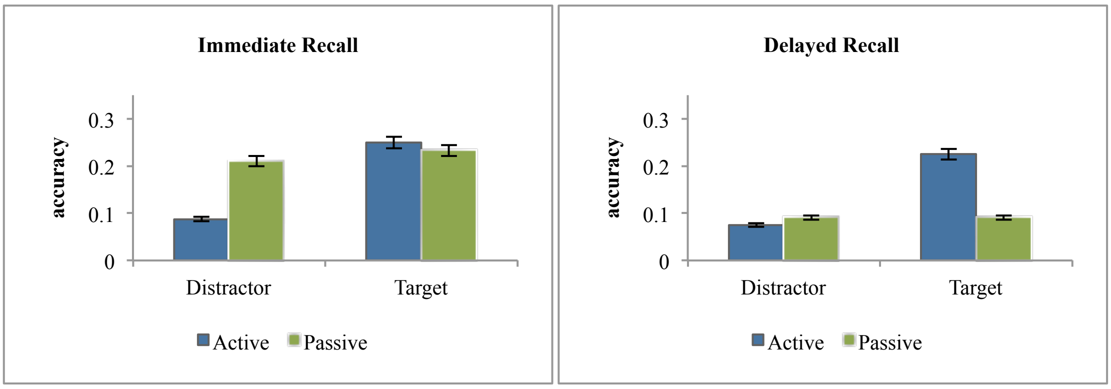

Figure 14 .Exp 1: Mean accuracy recall for object identity during immediate and delayed recall. Note error bars denote one standard error around the mean.

Results for spatial recall (where)

The pattern of results for the location of objects was very similar to the one observed for object identity. Again, memory was better during immediate recall (14%) compared to after delayed recall (6.8%), [$F(1,40)=15.62$, $p<.001$, $\eta^2_p=.281$], recall of target object locations (13.2%) was higher than distractor object locations (5.1%), [$F(1,40)=10.06$, $p=.003$, $\eta^2_p=.201$].

Of most interest to the current experiment, there was an object-mode interaction [$F(1,40)=14.93$, $p<.001$, $\eta^2_p=.272$]. Distractors were recalled significantly more in the passive mode (5.4%, $t(40)=2.42$, $p<.02$), while targets were recalled more in the active mode (7.2%, $t(40)=2.83$, $p<.007$). Additionally, the mode influenced how memory was impaired after delayed recall [$F(1,40)=6.2$, $p=.017$, $\eta^2_p=.135$], as there was a memory decay in the passive mode (12.5%, $t(21)=5.14$, $p<.001$), but not in the active one (2.75%, $p=.37$).

There was still no three-way interaction but the pattern of the data closely resembled the one seen in the analysis of memory for object identity (see Figure 14). As before, it was confirmed that during the active immediate recall task, a strong selection of targets (better performance) was present (12.5%, $t(19)=3.6$, $p=.002$) which was not replicated in the passive mode (1.1%, $p=.754$). During delayed recall, distractors were also less recalled than targets in the active mode (10.6%, $t(19)=3.49$, $p=.002$) but in the passive mode there was a trend for targets to be less well remembered than distractors (3.4%, $p=.06$).

As before, evidence for distractor suppression in the active immediate mode was found because memory for distractors in the active mode was significantly less than for the passive one (9.6%, $t(40)=2.46$, $p=.018$) while no difference was found for targets. In addition, after a delay, there was no evidence of distractor suppression as found in immediate recall, but target enhancement due to the active mode (15%, $t(40)=4.6$, $p<.001$).

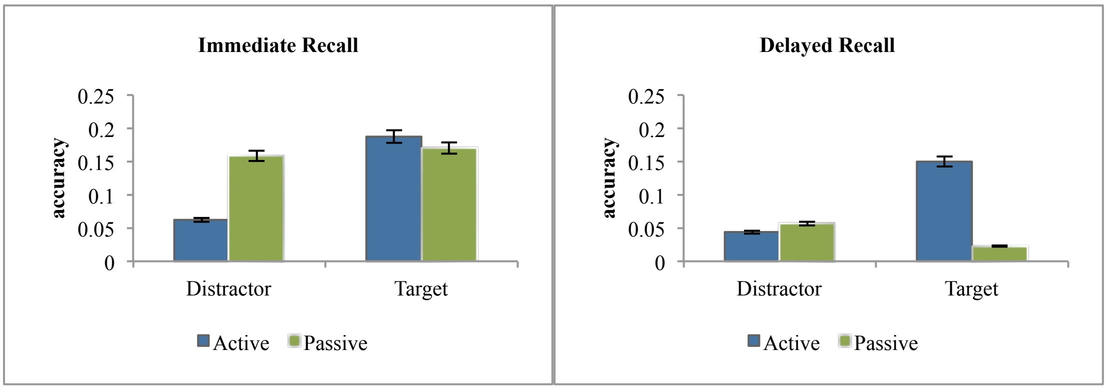

Figure 15. Exp 1: Mean accuracy recall for the spatial component during immediate and delayed recall. Note error bars denote one standard error around the mean.

Results for temporal recall (when)

Results demonstrated higher accuracy of recall when targets appeared (12.8%) than for distractors (9.4%), [$F(1,40)=3.96$, $p=.05$, $\eta^2_p=.09$]. Additionally, there was a significant object by mode interaction [$F(1,40)=14.4$, $p<.001$, $\eta^2_p=.265$]. The moment in which targets appeared were recalled better than for distractors in the active mode (11%, $t(40)=3.52$, $p<.001$).

Again, the three-way interaction was not significant, but the pattern replicated the one seen previously. During the short delay there was a target selection (9.3%, $t(19)=2.3$, $p=.032$) for the active mode, however in the passive mode better recall performance of distractors was observed (5.11%, $t(21)=2.1$, $p=.05$). During delayed recall, distractor objects were significantly a strong section of target objects for the active mode (12.5%, $t(19)=5.33$, $p=.007$) compared to distractors but not for the passive mode (1.7%, $p=.4$).

As before, evidence for distractor suppression during immediate recall in the active mode was found because memory for distractors in the active mode was significantly less than for the passive one (7.1%, $t(40)=1.85$, $p=.07$), while in this case there was a significant difference with the targets (7.3%, $t(40)=2.1$, $p=.04$). In addition, after a delay, there was still no evidence of distractor suppression as in immediate recall, but targets enhancement due to the active mode (12.5%, $t(40)=3.3$, $p=.002$).

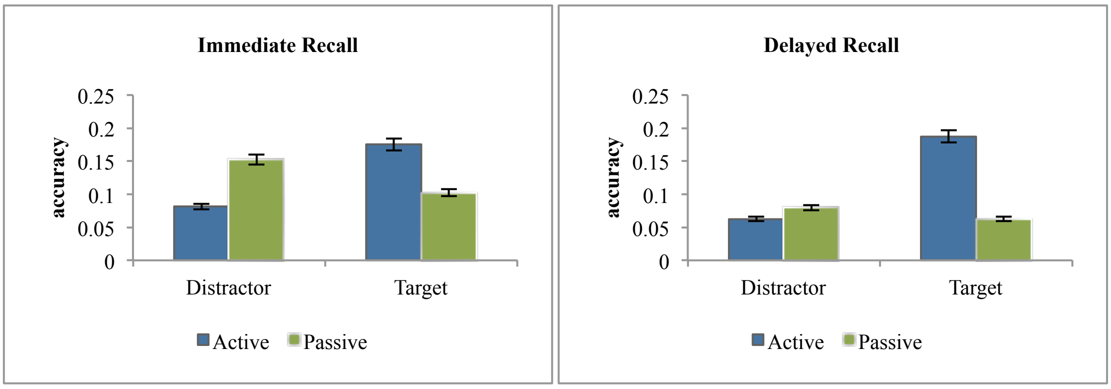

Figure 16. Exp 1: Mean accuracy recall for the temporal component during immediate and delayed recall. Note error bars denote one standard error around the mean.

Results (3D background)

Results for the full episodic recall

Overall, results did not show a significant reduction in full episodic memory after the delay [$F<1$]. The mode was significant [$F(1,40)=8.6$ $p=.006$, $\eta^2_p=.177$], passive participants remembered more object temporal properties (8.1%) than active participants (4.2%). Moreover targets were overall recalled better (8.4%) than distractors (3.8%), [$F(1,40)=14.3$, $p<.001$, $\eta^2_p=.263$].

More interestingly for the purpose of this research study, despite the lack of three-way interaction or two-way interactions [$F<.1$], it can be noted looking at the descriptive trends that during immediate recall there was a strong target selection (8.12 %, $t(19)=3.57$, $p=.002$) in the active mode, which was not replicated in the passive mode between the objects (1%, $p=.1$). For delayed recall, in the active mode better performance of recall for target objects was also observed (5%, $t(19)=2.37$, $p=.02$) but not for the passive mode (4%, $p=.1$).

Additionally, as found in the 2D object identity analyses, memory for distractor during immediate recall was significantly reduced in the active mode (7.7%, $t(40)=4.4$, $p<.001$), while target memory was not enhanced in the active mode ($t(40)=1.2$, $p=.23$), supporting the view that the difference between target and distractor memory in the active mode for immediate recall is due to distractor suppression and not target enhancement. After a delayed recall, targets did not benefit from the active mode compared to the passive one (3.9%, $p=.21$). Memory from distractors after delayed recall was not significantly reduced in the active mode (4.3%, $p=.8$).

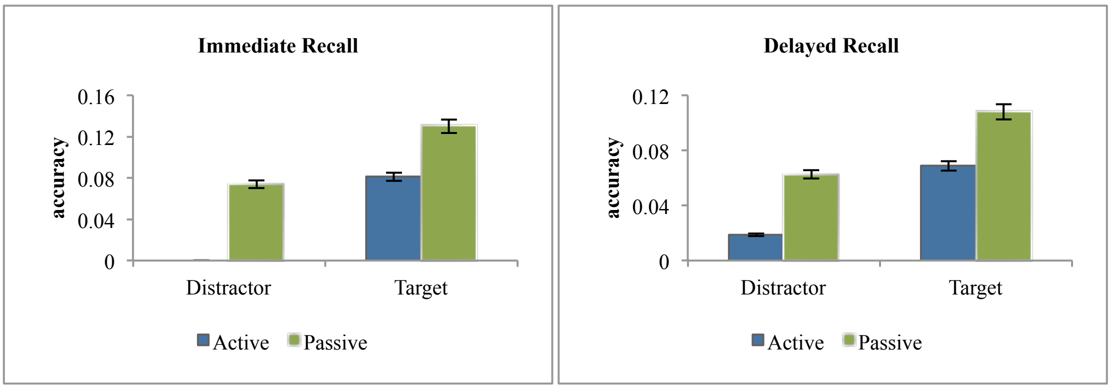

Figure 17. Exp 2: Mean accuracy recall for full episodic memory during immediate and delayed recall. Note error bars denote one standard error around the mean

Results for object identity recall (what)

The analysis showed that memory was significantly higher during immediate recall (18.6%) than for delayed recall (12.7%), [$F(1,40)=12.9$, $p<.001$, $\eta^2_p=.24$]: recall accuracy of targets (23.6%) was higher than for distractors (7.3%), [$F(1,40)=51.7$, $p<.001$, $\eta^2_p=.56$]. Finally the mode was significant; recall accuracy in the passive mode (18%) was better than in the active mode (13.1%), [$F(1,40)=7.78$, $p=.008$, $\eta^2_p=.16$].

Interestingly, memory of targets and distractors did change depending on the delay [$F(1,40)=13.43$, $p<.001$, $\eta^2_p=.25$]. When tested immediately, targets were better remembered than distractors (20.3%, $t(41)=7$, $p<.001$). The same happened for targets after delayed recall (11.2%, $t(41)=4.7$, $p<.001$) .

Moreover a significant three-way interaction between mode, object and temporal variables [$F(1,40)=3.84$, $p=.06$, $\eta^2_p=.08$] was present. As in the previous results for the full episodic recall analysis, this interaction demonstrated that during immediate recall there was a strong target selection (27.5%, $t(19)=7.3$, $p<.001$) in the active mode; however it was also replicated in the passive mode to a lesser extent (14%, $t(21)=3.6$, $p=.002$). During delayed recall, target selection was present in the active mode (12.5%, $t(19)=3.6$, $p=.002$) but also was present in the passive mode (10.2%, $t(21)=3.1$, $p=.005$).

Additionally, it was also found that memory for distractors during immediate recall was significantly reduced in the active mode (7.3%, $t(40)=4.4$, $p<.001$), while target memory was not enhanced in the active mode compared to the passive mode. In this case the difference between target and distractor memory in the active mode during immediate recall was due to distractor suppression and not target enhancement. After delayed recall, however, there was no evidence that targets benefited from the active mode compared to the passive one (3.8%, $p=.21$).

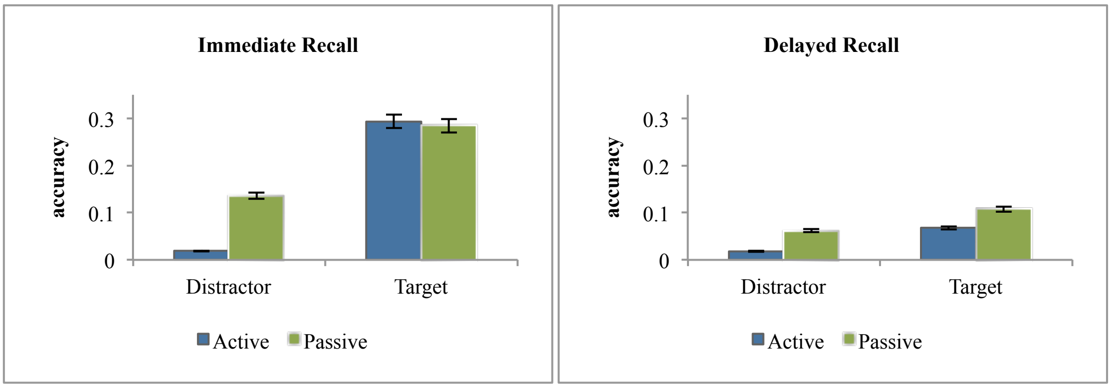

Figure 18. Exp 2: Mean accuracy recall for the object identity during immediate and delayed recall. Note error bars denote one standard error around the mean

Results for spatial recall (where)

Memory accuracy during immediate recall was better (12%) than during delayed recall (8.5%), [$F(1,40)=4.7$, $p=.036$, $\eta^2_p=.105$]. Recall for targets was higher (12%) than for distractor objects (8.6%), [$F(1,40)=5.2$, $p=.028$, $\eta^2_p=.115$].

Interestingly, memory of target and distractor locations did change depending on the delay [$F(1,40)=23.72$, $p<.001$, $\eta^2_p=.372$] regardless of the mode. When tested immediately, targets were better remembered than distractor locations (12.8%, $t(41)=4.7$, $p<.001$) . To a lesser extend target locations after delayed recall (6.25%, $t(41)=2.7$, $p=.01$) were also significantly better remembered than distractor locations.

Despite the lack of three-way interaction, spatial recall followed a similar pattern to that exposed for object identity and full episodic recall. It demonstrated that during immediate recall there was a strong target selection (18.7%, $t(19)=4.7$, $p<.001$) in the active mode However it was also replicated in the passive mode to a lesser extent (7.3%, $t(21) = 2.2$, $p=.04$). During delayed recall, target selection was significant in the active mode (7.5%, $t(19)=2.34$, $p=.03$) but not in the passive mode (5.1%, $p=.14$).

Additionally, it was also found that memory for distractors during immediate recall was significantly reduced in the active mode (7.1%, $t(40)=2.8$, $p=.006$) compared to the passive mode on the other hand memory for distractors was not during delayed recall ($t(40)=1.45$, $p=.15$).

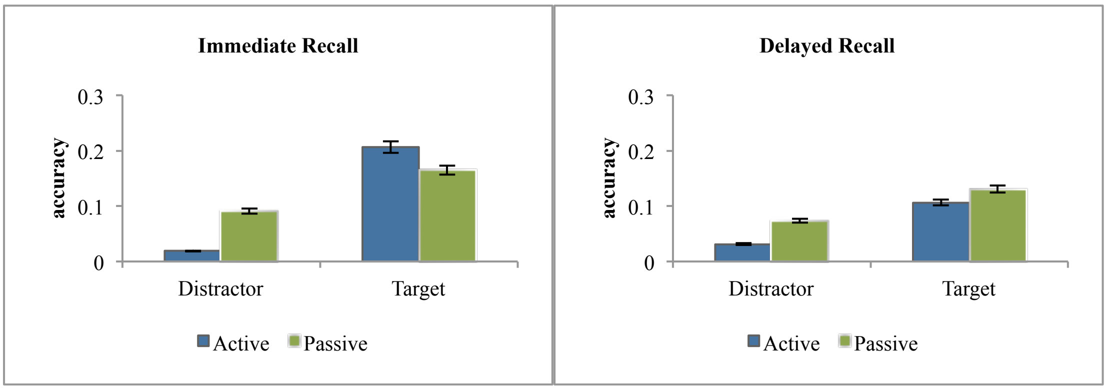

Figure 19. Exp 2: Mean accuracy recall for the spatial component during immediate and delayed recall. Note error bars denote one standard error around the mean.

Results for temporal recall (when)

Recall accuracy of targets (14.4%) was higher than for distractor objects (5.2%), [$F(1,40)=25.8$, $p<.001$, $\eta^2_p=0.39$] and accuracy in the passive mode (13.2%) was higher than for the active one (6.6%), [$F(1,40)=14.1$, $p<.001$, $\eta^2_p=.26$]. No other interactions and effects were reported.

However, despite the lack of two-way or three-way interaction, a strong target selection during immediate recall can be observed in the active mode (11.8%, $t(19) = 4.49$, $p<.001$) and the passive mode (9.6%, $t(21)=2.3$, $p=.031$). Target selection survived the interference task for both the active mode (7.5%, $t(19)=3.2$, $p=.004$) and the passive mode (8%, $t(21)=2.53$, $p=.019$).

Evidence for distractor suppression during immediate recall in the active mode was found because memory for distractors in the active mode was significantly less than in the passive one (7.1%, $t(40)=2.87$, $p=.006$).

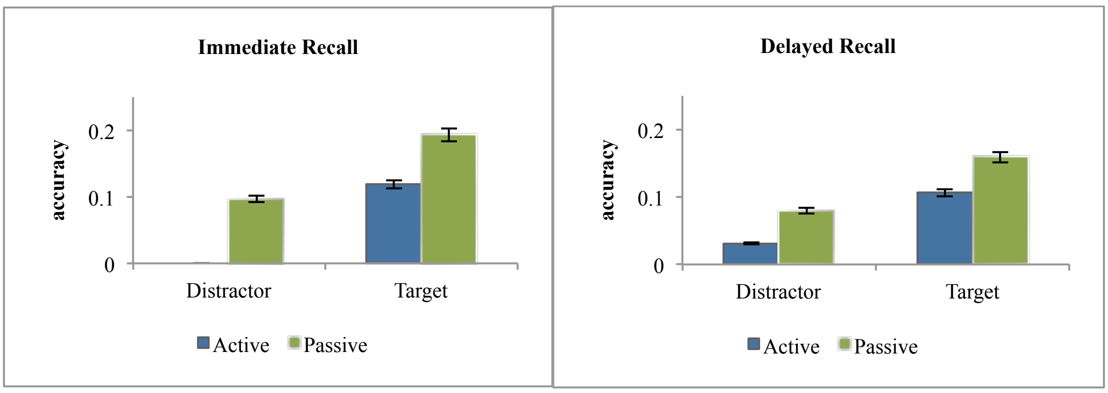

Figure 20. Exp 2: Mean accuracy recall for the temporal component during immediate and delayed recall. Note error bars denote one standard error around the mean.

Discussion

The two-presented experiments attempted to address whether a more complex background would interfere with episodic memory during free recall activity however because of the interesting results observed the role of action and selective attention will be the main focus of this discussion. The rationale behind using the different types of background was to prepare future memory experiments inside a virtual world where the environment would be richer and more cognitively challenging. Initially, the experiments were set up to expose the same participants to 2D and 3D backgrounds during encoding in a passive mode. In contrast, another set of participants were exposed to the same 2D and 3D backgrounds during encoding, but were subject to an active mode. However, results have been presented differently. Results in Experiment 1 analysed the impact of the type of mode with the 2D background, whilst results analysed in Experiment 2 investigated the impact of the 3D background with a similar set up.

Firstly, results taken with a 2D background were consistent overall for the full episodic memory and its individual components, and followed the same patterns. The results showed that distractors were suppressed immediately but did not survive the delayed recall activities (although this might be due to a floor effect). Indeed, a free recall technique is used in this experiment, and memory is in general very poor. Participants can let their mind wander during the retrieving task but despite the low number of accurate recalls, significant effects are still observed.

Targets seemed to be encoded more strongly in the active condition. Although the numbers of targets recalled during the immediate recall test were not enhanced, it is clear that they survived the interference task more successfully than distractor objects. However both targets and distractors survived the delay and are still encoded regardless the type of mode.

The pattern during immediate recall strongly supports both the suppression of distractors and the benefit on target encoding during the active mode. Selective attention effects are therefore observed, which are usually measured with priming techniques relying on speed when measuring implicit memory of participants who have no need to be aware of what they are encoding. However, in this set-up, and across the following experiments, an explicit test is performed and similar results are observed as in attention tasks, meaning that selective attention is used for memory encoding and not simply for action control.

The influence of the mode is not very pronounced on all components of both experiments, for objects and temporal delay combined (see Table 6). However, results tend to suggest that, when participants are active, they recall less information; they are more selective and only encode target objects. Whilst passive, participants are able to encode more information (target + distractor), which could link the improved encoding to the processing of some irrelevant information. This selective attention test seems to be linked to responses that people make; the passive condition contains a selective component in the absence of motor output (the green star attached to the object), and the real passive measure is the distractor object.

Secondly, the results with the 3D background replicate to a similar extent the results observed in immediate recall with the 2D background for distractor suppression with episodic recall and its individual components. However, it is also worth noting that for the passive mode during immediate recall, for object identity, spatial and temporal components, a significant suppression of distractor was observed.

This time, the results during the delayed recall tasks suggest that there are no significant target enhancements in all episodic components, as observed in delayed recall for the 2D background. The effect of target enhancement would have to be replicated throughout other experiments, in order to eliminate the risk that this effect is solely caused by the particulars of the first experiment. However, distractor suppression survived the interference task in the active mode for Experiment 2 (episodic and spatial).

To conclude when discussing the impact of the type of background, there are two notable differences in the experiments: target enhancement after the interference task for the 2D background, and distractor suppression due to the action during immediate recall for the three separate components with the 3D background.

Chapter Summary

This chapter presents evidence for a possible account for distractor suppression observed during episodic retrieval while participants are active. The type of background did not seem to have affected the results during immediate recall for distractor suppression due to the mode (a more formal approach to compare the impact of the background could be done with the background as another (within-subject) factor). The experiment also highlighted the interesting possibility of target enhancement when participants are active after an interference task for the 2D image background (see Table 3). These later results would need to be confirmed in the next set of experiments, in order to offer a valid explanation of such a phenomenon.

The following experiments in this research will look at a similar type of pattern as shown in Figure 21. Despite the fact that fewer distractors are remembered in the active mode (Table 7) or better selection of targets, this still does not tell us anything about the effect of the action on memory. However, the fact is that distractors are better recalled in the passive mode than in the active one, whilst (and this is very important) targets are not better remembered in the active than in the passive mode. This effect could be called suppression or simply filtering; it is both the action that makes target memory the same and distractor memory worse, and it is the distractor that is affected negatively by the action, not the target.

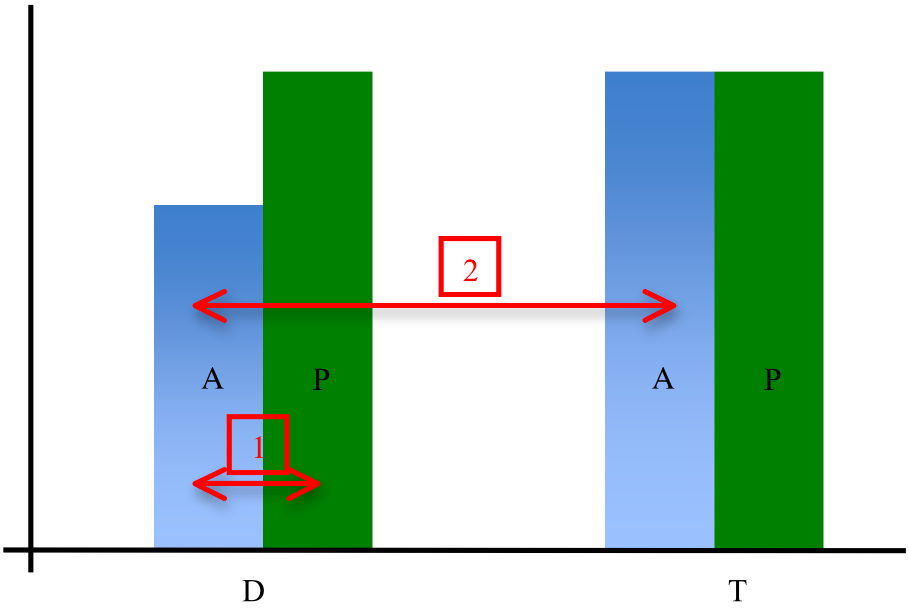

Figure 21. Summary of results relevant to Table 3

Figure 21 explains the results found in Appendix A (Table 3). Section 1 of the table (or number 1) compares the effect of the mode for each type of object (role of the action on target or distractor objects), while Section 2 of the table (number 2) observes the difference in the type of objects for each mode. On the basis of Table 3, it is possible to provide a descriptive summary for each experiment. For the following statistical descriptions of all experiments, whenever there are three-way interactions they will be described and followed by a) description of interaction number 2 (recall of objects for each mode), then interaction number 1 (the impact of the types of mode upon the types of object). If there were no significant three-way interactions, interactions 1 and 2 were still described for the purpose of the research.

Following the promising results observed in the first two experiments, it was decided to build a more thorough experiment to investigate selective attention and action on episodic memory in the following chapters.

CHAPTER 3: THE IMPACT OF SELECTIVE ATTENTION ON MEMORY: SETTING THE WWW TASK IN A 2D ENVIRONMENT

Experiment 3

Introduction

In this experiment, the focus was on selective attention (distractor and target objects) as well as action (passive and active), and not so much the interference due the type of background involved during the two previous experiments. Therefore a white background only was used during the encoding phase since the type of background did not seem to influence the results strongly (only target enhancement during delayed recall for 2D background). Another major change in this experiment was the type of recall – free recall was replaced by a recognition recall for object identity and cue recall for the spatial and temporal component of episodic memory was consolidated. Finally, the orthogonal Latin squares balanced block mixer was not used in the procedure to test participants, therefore immediate and delay recalls were not counterbalanced. A new interference task was introduced requiring a stronger cognitive load, but all other conditions remained unchanged (Mode, Delay and Object).

Method

Participants

In this study, a total of 61 participants took part. 39 participants took part in the active mode and 22 participants in the passive mode. Most of the participants were students from Bangor University, recruited internally via a web-based advertisement system, and work colleagues and friends. All participants voluntarily took part in the study and students received course credits. They ranged in age from 18 to 56 years (M = 22.8; SD =10.9). None of the participants reported having any memory deficit or other cognitive dysfunction.

Apparatus & Stimuli

The objects used in these experiments were all drawn from a string of standard pictures from the Snodgrass and Vanderwart database (Snodgrass & Vanderwart, 1980). From the 256 objects in the database, 32 with the highest percentage of name agreement from 95% to 100% were chosen. Coloured objects were also used, rather than black and white, in order to facilitate object recognition (Rossion & Pourtois, 2004). An initial set of 16 target/distractor objects was presented to participants during encoding ("old" objects). An additional 16 new random objects were mixed with the previous ones as fillers during the recall/recognition phase ("new" objects). The stimuli for this test were created using a laptop computer, 15" monitor running at a resolution of 1024 X 768 pixels for viewing from about 60cm and, on average, the visual angle for each object was 2.2 degrees. The stimulus (see Figure 22) was a static screen with a white background divided into 4 squares with 2 objects appearing in different blocks and in random positions each time.

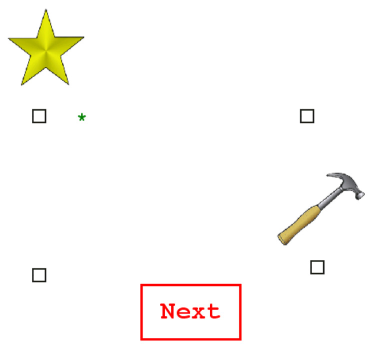

Figure 22. Eprime screen for stimulus

The presentation of the stimuli, sequence of events and response recording were programmed electronically using the E-Prime 1.2 software.

Procedure

There were two groups of participants randomly assigned to each of the two modes: Passive and Active. Both mode displays were identical, and the only difference was the task that participants had to perform. In the passive mode, the target was the object with a green star next to it, which participants needed to focus on during the 5 seconds before the next slide appeared automatically. In the active mode, participants had to click on the target object (also with the green star) in order to move to the next slide. The active participants could click on the objects before the compulsory 5 seconds allocated in the passive mode between each slides. Before each test participants where instructed to pay attention to the overall scene but where more importantly they were told to focus on the target objects during encoding.

For the recall/recognition phase, the participants were presented with a screen showing the objects (distractor, target and random) at the top with a tick box next to it (see Figure 24). From the "what" recognition task, participants were asked if they remembered the object and, if they did not, they were asked to click on the next button to move onto the next slide. However, if they believed that they remembered the object, they were asked to click the tick box, and were consequently obliged to answer the "where" and "when" question (forced choice). The "where" cue-recall task simply required the participants to indicate in which section of the screen they saw the object prompted by a schematic representation of the four quadrants. The "when" cue-recall task was prompted by a "begin" and "end" tick box, where the participants would tick "begin" if they thought that they had seen the object at the beginning of the sequence of slides (first 4 slides), and "end" if they thought they had seen the object during the last section of the sequence (last 4 slides).

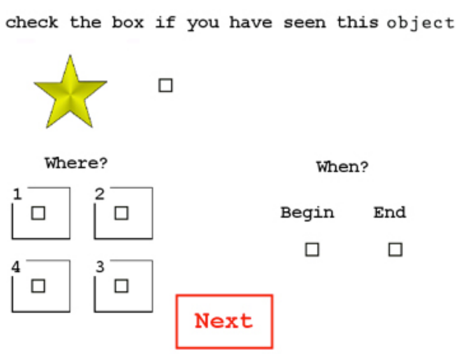

Figure 23. Eprime screen for the recognition/cue probe

All participants undertook the memory test at two different times: the first took place immediately after the stimuli were presented (immediate recall), and the second (delayed recall) after a two to three minute delay during which participants were asked to perform the same interference arithmetic task, however the time it took to complete the interference task varied due to the ability of participants to perform the arithmetic test. Overall the duration of the total test, including the recall phase, was an average of 30 minutes.

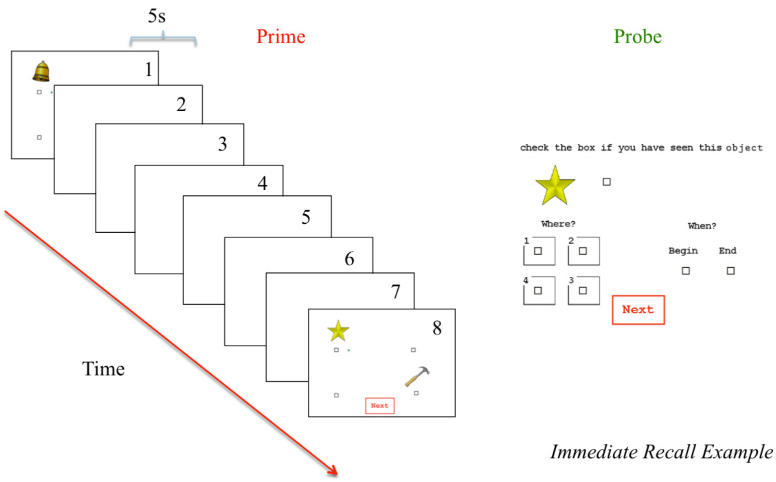

Figure 24. Sequence of stimuli

A conservative approach was used in which episodic retrieval of a particular object was inferred only in those cases where the three memory components (what, where and when) were correct for the full episodic recall. Data from objects that were not remembered was discarded as well as false alarms. However, partial recalled objects were computed for object identity (what), spatial location (where) and temporal (when). The accuracy values were computed as hit/(hit + error) proportions for all analysis.

Analysis

Means of overall accuracy rates from 49 participants were analysed through a 2 (Objects: Target, Distractor) x 2 (Temporal delays: Immediate, Delayed) x 2 (Modes: Passive, Active) mixed Factorial ANOVA where Objects and Temporal delays were manipulated within subject and the Mode was manipulated between groups

Results

Data from one participant was removed in the active mode due to testing error.

Full episodic recall

It can be noted that episodic memory after a short delay was in general better (42.7%) than later after an interference task (15%) [$F(1,47)=90.7$, $p<.001$, $\eta^2_p=.659$].

As expected, distractor objects were remembered less (22%) than target objects (35%) [$F(1,47)=33.5$, $p<.001$, $\eta^2_p=.42$]. But this difference was greater for the active mode [$F(1,47)=11.7$, $p<.001$, $\eta^2_p=.20$]. Indeed, targets were remembered an overall of 29 % better than distractors in the passive mode while the target superiority was up to 35.6% in the active mode ($t(26)=7.02$, $p<.001$) compared to distractors.

More importantly, there was a reliable three-way interaction [$F(1,47)=7.47$, $p<.009$, $\eta^2_p=.136$]. This interaction demonstrated that during the immediate recall there was strong distractor suppression (24.5%, $t(26)=5.7$, $p<.001$) in the active mode, but this was not replicated in the passive mode (0%, $p=1$). For delayed recall, both in active and passive modes the distractors were significantly suppressed (13%, ($t(26)=4.4$, $p<.001$) and (9.7%, $t(26)=2.5$, $p=.02$).

Additionally, we also found that memory from distractors during immediate recall was significantly reduced in the active mode (21.2%, $t(47)=2.81$, $p=.007$), while the target memory was not enhanced in the active mode compared to the passive mode, in this case the difference between target and distractor memory in the active mode during immediate recall is due to distractor suppression and not target enhancement. After a delayed recall, however, there is no evidence that targets benefited from the active mode compared to the passive one (0%, $p=.9$) and the distractor suppression did not survive the interference (2.9%, $p=.3$)

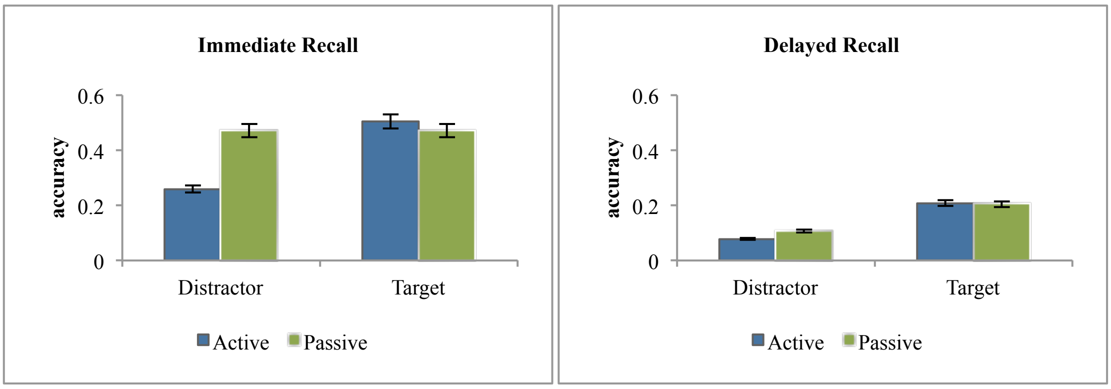

Figure 25. Exp 3: Mean accuracy recall for full episodic memory during immediate and delayed recall. Note error bars denote one standard error around the mean.

Results for object identity recall (what)

Memory for recall for distractor objects were less (74.4%) than for target objects (86.3%), [$F(1,47)=21.7$, $p<.001$, $\eta^2_p=.32$] and recall of objects was stronger in the passive mode (86%) than in the active mode (75%), [$F(1,47)=8.42$, $p=.006$, $\eta^2_p=.152$].

However in the interest of the research and despite the lack of other interactions, some patterns can be explored based on the descriptive results. It is difficult to access if distractors are suppressed during immediate delay as it happens in both modes. It could be that either distractors are suppressed or targets are enhanced. However we can describe the results in term of selection of target or better recall performance (we are not looking at the role of the action), In the immediate recall there was a better recall of targets (15%, $t(26)=2.4$, $p=.02$) in the active mode, however it was also replicated in the passive mode (9%, $t(21)=3.07$, $p=.006$). For the delayed recall, targets were selected in the active mode (19%, ($t(26)=3.5$, $p<.001$) but not in passive mode (6%, $p=.11$).

It was also found that memory for distractors during immediate recall was significantly reduced in the active mode (16%, $t(47)=2.35$, $p=.02$), while the target memory was also suppressed in the active mode, (10%, $t(47)=2.39$, $p=.02$). After a delayed recall, there is no evidence that targets benefited from the active mode compared to the passive one

(3%, p=.57) but the distractor suppression did survive the interference (15%, $t(47)=2.62$ p=.03).

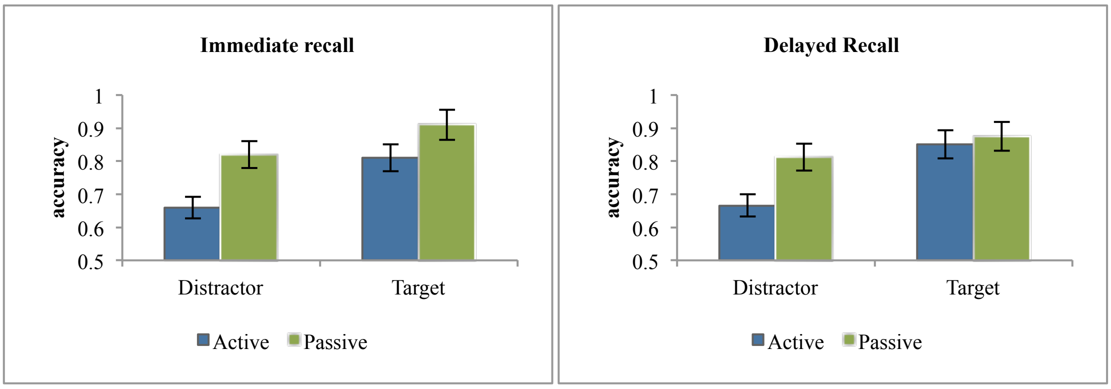

Figure 26. Exp 3: Mean accuracy recall for object identity during immediate and delayed recall. Note error bars denote one standard error around the mean

Results for the spatial recall (where)

In this analysis more object locations were recalled after the immediate recall (60.3%), than after delayed recall (23.2%), [$F(1,47)=134$, $p<.001$, $\eta^2_p=.74$]. Besides distractor object locations were remembered less (35.5%) than target object location (47.9%), [$F(1,47)=22.6$, $p<.001$, $\eta^2_p=.32$]. No other significant interaction can be reported.

As previously during the immediate recall there was a better performance for targets (16.6%, $t(26)=2.9$, p=.007) in the active mode, however this was also the case in the passive mode (10%, $t(21)=2.73$, p=.01). During the delayed recall, similar results were observed in the active mode (10%, $t(26)=2.78$, p=.01) and in the passive mode (12.5%, $t(21)=2.6$, p=.01).

There was no distractor suppression due to active or passive modes both, during immediate and delayed recalls (p>.05).

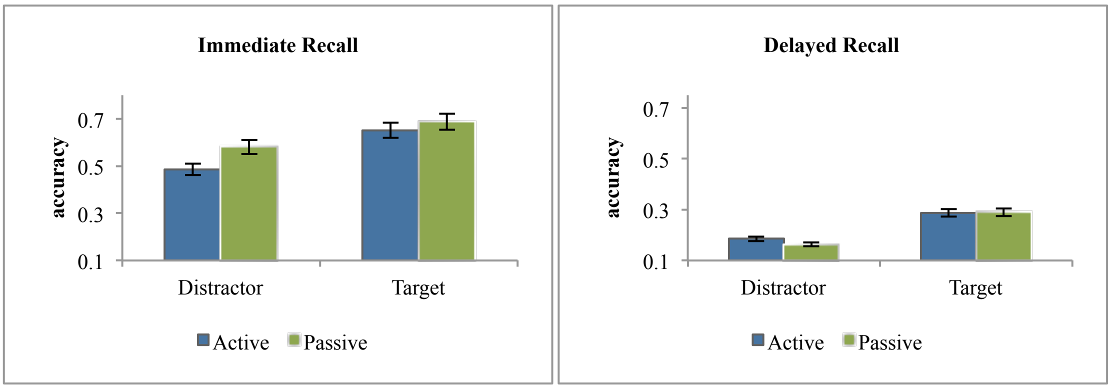

Figure 27. Exp 3: Mean accuracy recall for the spatial component during immediate and delayed recall. Note error bars denote one standard error around the mean.

Results for temporal recall (when)

More object temporal properties were recalled after immediate recall (60.3%), than after delayed recall (52.7%), [F(1,47)=10, p=.003, η^2_p=.175]. Distractor objects were remembered less (52.4%) than target objects (60.6%), [F(1,47)=10.56, p=.002, η^2_p=.18]. No other interactions can be reported.

Like for the spatial component analyse there was no distractor suppression due to active or passive modes, both during immediate and delayed recalls (p>.05).

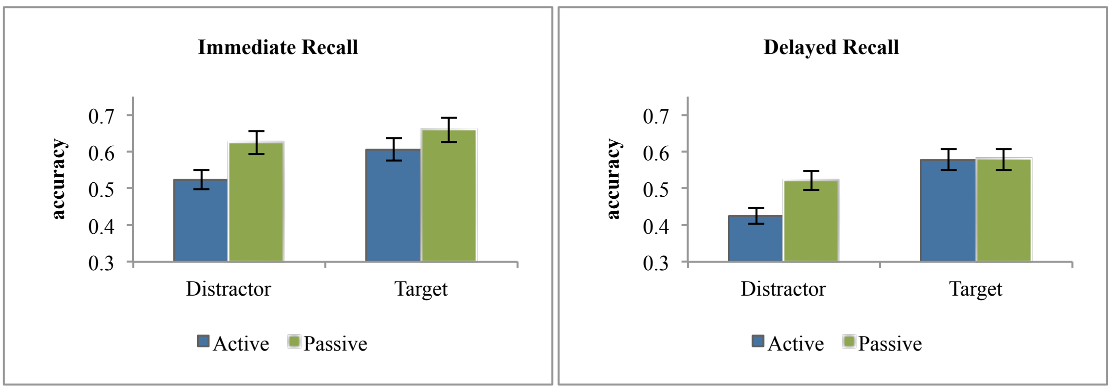

Figure 28. Exp 3: Mean accuracy recall for the temporal component during immediate and delayed recall. Note error bars denote one standard error around the mean.

Discussion

The present experiment aimed to reinforce the results observed in Experiments 1 and 2 with a difference in experimental design where a plain background was used instead of background images as well as the use of a different retrieval technique. This time recognition was used for the object identity and cue recall for the spatial and temporal component of episodic memory. Since this experiment used stronger retrieval techniques recall accuracy was expected to be higher and floor effects should not be present.

The findings of Experiment 3 produce similar reliable effects during immediate recall for distractor suppression for episodic memory. However other components in this experiment, such as the temporal component did not show any significant results during immediate recall. This may be highlighting the fact that the temporal component is the most difficult aspect of episodic memory to test or it may underline that in this particular experiment the design for the temporal cue may not be strong enough to produce reliable results. Indeed participants were asked to recall objects with a “begin” and an “end” cue from the testing sequence: it is therefore difficult for participants to be able to divide the sequence into two sections during the encoding phase (no middle slide). Another significant result observed is for object identity; where in the active and passive mode the distractor is suppressed suggesting there is no advantage in the type of mode. Moreover for the full episodic recall the suppression did not survive the interference task. It worth mentioning that passive participants were always exposed for 5sec to the stimuli whereas active participants could have clicked through themselves and be exposed less time to stimuli and that might make a difference, especially on the distractor objects recall.

In general, these results still strongly show that the superiority of memory under passive encoding could mostly involve the incidental encoding of distractor, not relevant information. There is no evidence that the memory of target information is impaired under the more active mode. Instead, it is the distractor information that is suppressed and filtered out, at least during a short delay. In this new experiment target enhancement was not observed.

Nevertheless, to replicate and further consolidate this pattern of results, further tests in a second experiment were conducted in which cue recall was used instead of recognition to test object identity memory.

Experiment 4

Introduction

This study is a duplicate of Experiment 3. However, in this particular instance, a cue recall replaced the recognition test for the recall of object identity task. Other factors throughout this experiment remained unchanged.

Method

Participants

In this study a total of 46 participants took part – 25 participants in the active mode and 21 participants in the passive mode. Most of the participants were students from Bangor University recruited internally via a web-based advertisement system. All participants voluntarily took part in the study and received course credits. They ranged in age from 18 to 44 years (M = 22; SD = 6.1). None of the participants reported having any memory deficit or other cognitive dysfunction.

Apparatus & Stimuli

The apparatus & stimuli of the experiment were identical to that of Experiment 3.

Procedure

For the cue recall phase the participants were presented with a screen showing the name of the objects (distractor, target and random) at the top with a tick box next to it (see Figure 29). From the "what" recognition task, participants were asked if they remembered the object by presenting the name of the object as a cue and, if they did not, they were then asked to click on the next button to move onto the next slide. However, if they believed that they remembered the object, they were asked to click the tick box, and were subsequently obliged to answer the "where" and "when" question (forced choice) in the same way as Experiment 2.

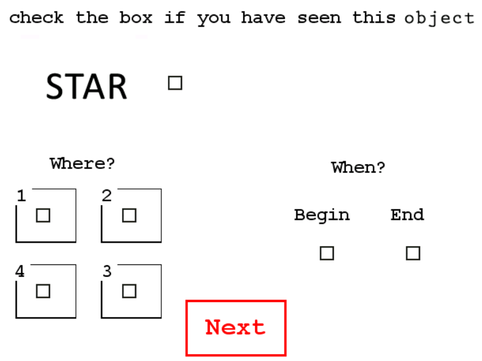

Figure 29. Eprime screen for the cue probe (what, when and where)

The same design was applied as for Experiment 3. The duration of the test, including the recall phase, was an average of 30 minutes. In the same way as Experiment 3, the accuracy values were computed as *hit/(hit + error)* proportions. Partial and full recalls were computed for the full episodic recall and the episodic memory components.

Analysis

Means of overall accuracy rates were analysed through a 2 (Objects: Target, Distractor) x 2 (Temporal delays: Immediate, Delayed) x 2 (Modes: Passive, Active) mixed Factorial ANOVA where Objects and Temporal delays were manipulated within subject and the Mode was manipulated between groups.

Results

Data from 1 participant in the passive mode was removed, as its accuracy level for recalls fell in the area of 1.5 times more than the interquartile range (IQR), (Appendix H).

Full episodic recall

Memory after a short delay was in general better (39.5%) than later after an interference task (12.9%) [$F(1,43) = 107.6$, $p < .001$, $\eta^2_p = .69$].

As expected, distractor objects were less well remembered (23.2%) than target objects (28.6%) [$F(1,43) = 6.56$, $p = .014$, $\eta^2_p = .13$]. There were no other significant interactions to be reported.

However it is worth looking at distractor suppression during immediate and delayed recall for the purpose of the study despite no two-way or three-way interactions. There was a significant suppression during the immediate recall of distractor objects in the active mode (10.4%. $t(23)=2.0$, $p=.05$) but there was no suppression in the passive mode (0%, $p=1$) . During delayed recall there was a distractor suppression in the passive mode (5.9%, $t(20)=2.35$, $p=.03$).

Target objects did not benefit from enhancement depending on the mode for both immediate and delayed recall. There was no significant evidence of distractor suppression according to the type of mode during immediate and delayed recall (p>.05).

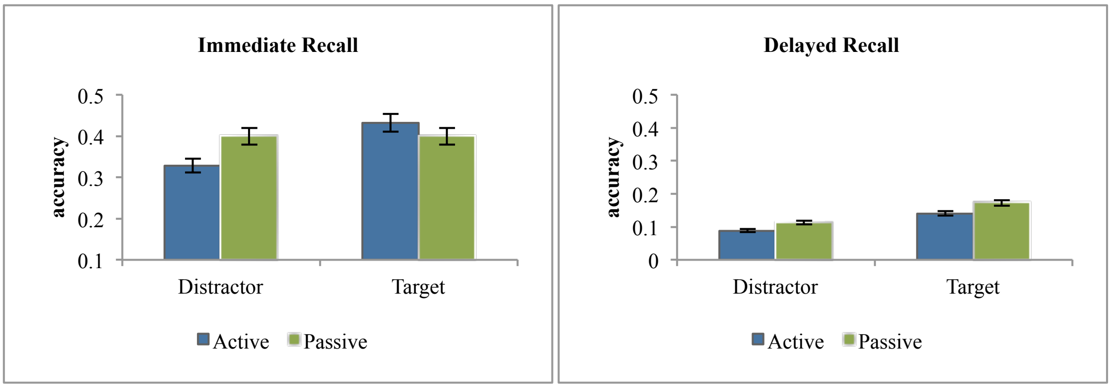

Figure 30. Exp 4: Mean accuracy recall for full episodic memory during immediate and delayed recall. Note error bars denote one standard error around the mean.

Results for object identity recall (what)

More objects were recalled in the passive mode (77.8%) than in the active mode (65.2%), [$F(1,43)=7.7$, $p=.008$, $\eta^2_p=.153$]. Moreover more target objects (77.4%) were recalled than distractor objects (65.7%), [$F(1,43)=19.53$, $p<.001$, $\eta^2_p=.312$].

There was an object – mode interaction [$F(1,43)=8.75$, $p=.005$, $\eta^2_p=.169$] . Distractors were recalled significantly more in the passive mode (20.4%, $t(43)=3.5$, $p<.001$), this was not the case for target objects (4%, $p=.3$). There was also an object – temporal delay interaction [$F(1,43)=6.56$, $p=.014$, $\eta^2_p=.132$]. There was no significant difference of recall between target and distractor objects during immediate recall (6.4%, $p=.11$), however there were more target objects recalled during delayed recall (18.1%, $t(44)=5.26$, $p<.001$).

During immediate recall there was a strong distractor suppression (15.6%, $t(23)=2.5$, $p=.019$) in the active mode, which was not replicated in the passive mode (4.2%, $p=.24$). During delayed recall, distractor objects were equally significantly suppressed in the active mode (23.4%, $t(23)=4.04$, $p<.001$) and in the passive mode (11.9%, $t(20)=4.26$, $p<.001$).

Additionally, we also found that memory from distractors during immediate recall was significantly reduced in the active mode (27.6%, $t(43)=3.89$, $p<.001$), while the target memory was not enhanced in the active mode, thus supporting the view that the difference between target and distractor memory in the active mode during immediate recall was due to distractor suppression and not target enhancement. After a delayed recall, distractors were not significantly reduced according to the modes.

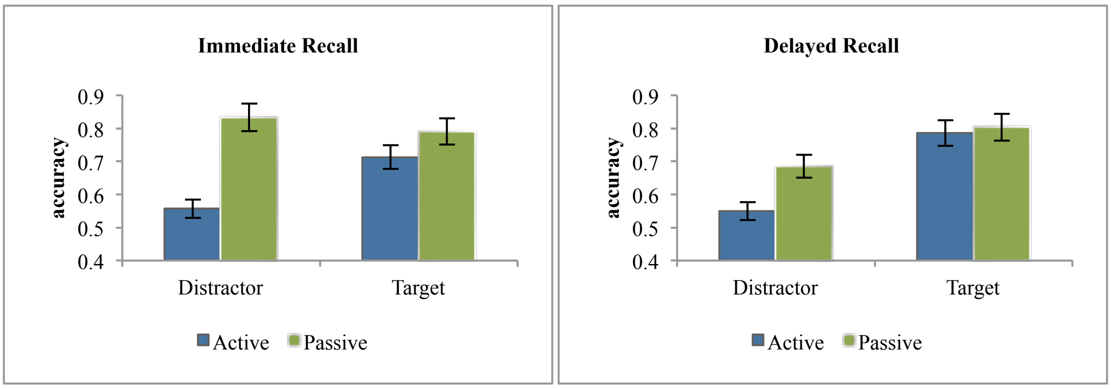

Figure 31. Exp 4: Mean accuracy recall for the object identity during immediate and delayed recall. Note error bars denote one standard error around the mean.

Results for spatial recall (where)

Better recall was observed during immediate recall (51.1%) than during delayed recall (23.2%) [F(1,43)=88.23, p<.001, η^2_p=.672]. Moreover more target objects (41%) were recalled than distractor objects (33%), [F(1,43)=13.47, p<.001, η^2_p=.239].

More importantly there was a three-way interaction between object – temporal delay – mode variables, [F(1,43)=5.1, p=.029, η^2_p=.106]. This helped to demonstrate the following interactions.

During immediate recall there was a stronger target selection (18.2%, t(23)=3.49, p=.002) in the active mode, which was not replicated in the passive mode (0.6%, p=.88). During delayed recall, a better performance of recall for target objects was observed in the passive mode (7.7%, t(20)=4.04, p=.034) but not in the active mode (5.7%, p=.185).

Additionally, it was also found that memory for distractors during immediate recall was significantly reduced in the active mode (15.6%, t(43)=2.05, p=.046). There were no other suppressions or enhancements to be reported.

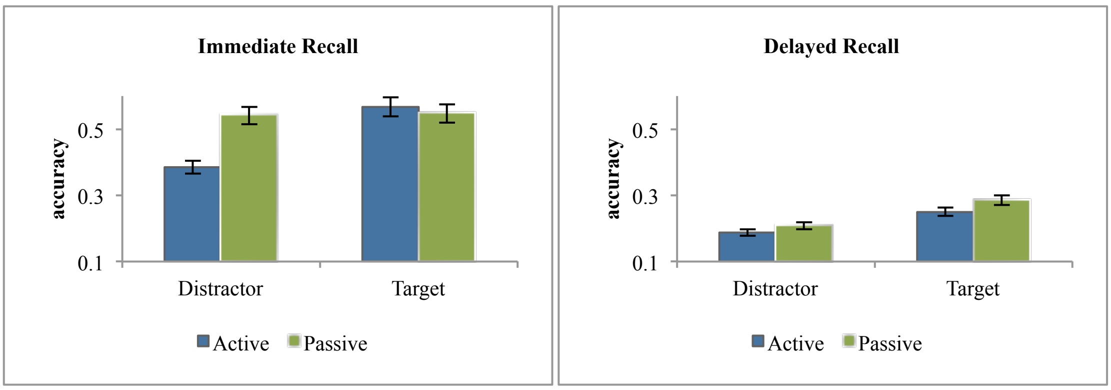

Figure 32. Exp 4: Mean accuracy recall for the spatial component during immediate and delayed recall. Note error bars denote one standard error around the mean.

Results for temporal recall (when)

Overall more target objects (54%) were recalled than distractor objects (45%), [$F(1,43)=10.25$, $p=.003$, $\eta^2_p=.193$]. No other significant interactions are to be reported for distractor suppression or target enhancement (p>.5).

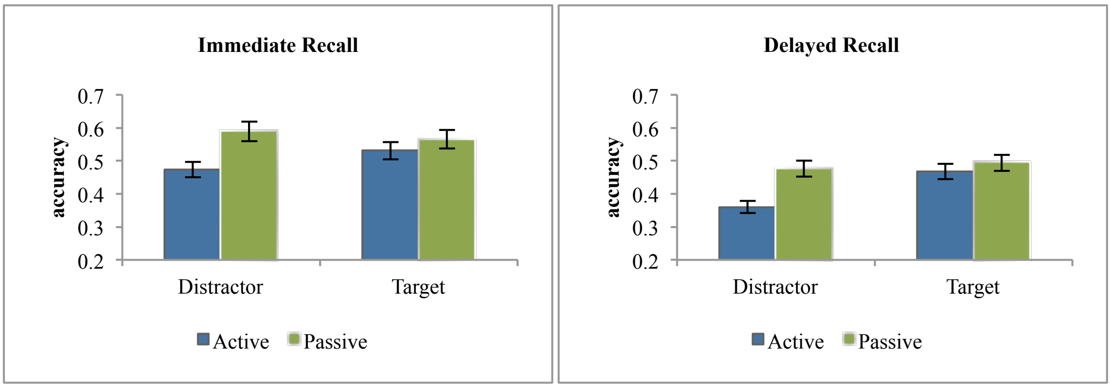

Figure 33. Exp 4: Mean accuracy recall for the temporal component during immediate and delayed recall. Note error bars denote one standard error around the mean.

Comparison between Experiments 3 and 4 for the object identity component (Passive mode only)

Means of overall accuracy rates from Experiment 3 and 4 with in total 93 participants were analysed through a 2 (Objects: Target, Distractor) x 2 (Temporal delay: Immediate, Delayed) x 2 (Exp: Exp3, Exp4) mixed Factorial ANOVA where the type of object and the temporal delay were manipulated within subject and the different experiments (Exp3 and Exp4) was manipulated between groups.

Both modes were analysed separately and only for the passive mode a 3-way significance between Objet-Delay-Experiment was observed [$F(1,41)=7.43$, $p=.009$, $\eta^2_p=.154$] , see Appendix H for more details.

During the immediate recall there was a stronger target selection (12.4%, $t(41)=3.68$, $p=.001$) for Experiment 3 (Recognition). There were no other suppressions or enhancements to be reported. This would imply that there was no target enhancement during cue recall.

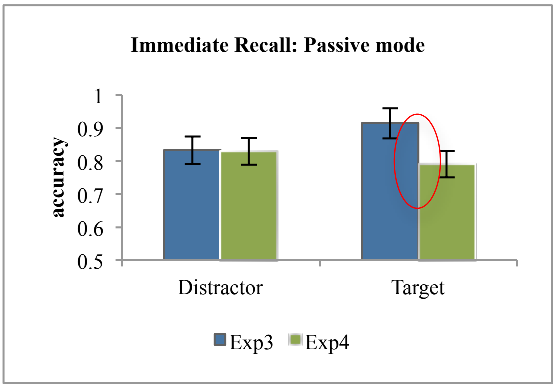

Figure 34. Object identity recall during immediate recall for recognition (Exp3) and cue recall (Exp4), Passive mode only.

Discussion

The results from Experiment 4 are clear: in the active mode distractor objects were less recalled than target objects for all components apart from the temporal component. Distractor suppression due to the action during the immediate recall task happened for the object identity and the spatial component, but this suppression was not present during the temporal recall. The temporal component as tested in Experiment 3 did not have a significant impact. This was not the case in the first two experiments. This could be due to the new retrieval setting (cue recall for object identity), despite the fact that the temporal cue in Experiment 1 and 2 was similar (begin and end cue) but it was set in a different context (free recall for object identity) moreover there was no time marker (diving slide) to help for the temporal recall.

During delayed recall, suppression of distractors due to the action did not survive the interference task while it was the case for recognition with object identity in Experiment 3. In a holistic approach of episodic memory all its elements should be remembered including the spatiotemporal context. However the current sets of experiments have shown so far a fragmented view of episodic recall. It has been demonstrated so far that temporal information was a very poor cue whilst object identity was the best cue (it needs to be remembered that we have already a binding in our results with a what-where and a what-when). It could be that there are different processes involved in different types of retrieval depending on cue specificity. This has been highlighted by comparing the two experiments however the impact of the type of cue at retrieval was only shown in the passive mode, this still supports the idea that implicit recognition memory can be used when memory is retrieved with a stronger cue (images) rather than using words. This will be discussed further in the general conclusion.

Chapter Summary

The aim was to produce a new measure of episodic memory that would not depend on free recall. Instead a condition was created that participants should be accurate about three pieces of information key for episodic encoding: Object identity (what), space location (where) and temporal position (when).

In Experiment 3 for object identity a recognition task was used. There was no advantage found in the type of mode for object identity during immediate recall (suppression was present for distractor and target objects). This task is believed to be sensitive to both explicit (for which episodic memory would be part of) and implicit memory (Voss, Lucas & Paller, 2012). One could argue that the short-term trace associated with object information could be boosted by the use of this technique, more sensitive to recency and primacy effects, as they are part of implicit memory. Note that this influence would account for only a small part of the effect in full episodic recall, as participants also had to remember the position and time of the distractor, making it very unlikely for the effects to be due exclusively to implicit encoding. In Experiment 4, these results were challenged by modifying recognition to a cue recall for object identity, the impact was significant, suppression due to the active mode was still present for the full episodic recall but this time the object identity only demonstrated suppression during the active mode, highlighting the importance of the type of cue during memory retrieval (Figure 34).

Overall, in both experiments, distractor suppression was observed for the full episodic memory and the suppression did not survive the interference task. The temporal component of episodic memory was the least reliable component of all, maybe because of the type of cue recall to which participants were submitted.

CHAPTER 4: THE IMPACT OF SELECTIVE ATTENTION ON MEMORY: SETTING THE WWW TASK IN A VIRTUAL WORLD

Virtual Worlds

In this chapter, I will discuss the particulars of the virtual world - *Second Life* or *SL* - that has been used throughout my experiments (5 to 7). In order to be clear about what constitutes a virtual world, I will define terminology such as virtual worlds and 3D. I will also discuss the notion of virtual embodiment and will present an overview of different virtual platforms available on the market as per 2012. To conclude, I will give an example of scientific application of virtual worlds closely related to the area of cognitive science.

Definitions

Virtual world

Many scholars have attempted to give a formal definition to virtual worlds (Bartle, 2004; Castronova, 2004; Koster, 2004). However, I will use the following definition for the purpose of this thesis:

> A virtual world is a computing environment composed of a 3D graphic interface and a database of objects that generate a space shared by different users, which attempts to recreate reality in an imaginary universe (Bourassa & Edwards, 2007).

I have chosen this definition because it highlights two elements that characterise *Second Life*. Firstly a simple technical description of what is a virtual world: “a 3D graphic interface and a database of objects”, that will be explained in the next paragraphs, and secondly a more qualitative view that presents the social and imaginary facet of *Second Life,* though in the following experiments these latter characteristics will not be considered.

What is 3D (Dimensional) in computer graphics?

Research into visual perception highlighted the fact that people judge 3D according to different types of visual cues (Kourtzi, Welchman, Deubelius, Conrad, & Bu, 2005). A picture that appears to have height, width and depth is three-dimensional (or 3D); a picture that has height and width but no depth is two-dimensional (or 2D). For example, you can perceive 3D features such as depth from a 2D image depending on the nature of the cues. It is important to highlight the difference between perceiving a 3D image qualitatively (optical illusion using depth cues, for example) and measuring the three dimensions quantitatively.

The basic start for most of computer graphic modeling study is learning how to describe 3D objects on the computer screen using the wire frame model. Without dwelling on the technicality of computer graphics, I will discuss measures that help researchers describe the perceived 3D structure of surfaces. Three-dimensional relationships in our environment seem to be constant, which means that, for an object to be accurately encoded and retrieved from memory, the object needs to be recognised from any viewpoint. The object consistency is widely discussed in the literature with varying theoretical standpoints (Biederman, 1987; Marr, 1982).

To obtain an accurate measure of a 3D object, one should seek an independent viewpoint frame of reference, and not one that changes depending on the observer position. A common measure of 3D is depth, which is defined as the set of coordinates (x, y, z) for every visible region on an object or surface (Tittle, Woods, & Roesler, 2001). To gain a qualitative measure using our own perception, an image with numerous depth cues[6] will give a better sensation of perceived 3D to the observer (Wexler & Van Boxtel, 2005). However, depth cues are viewpoint dependent and, depending on the observer location, depth cues may

[6] Reichelt, Häussler, Fütterer, Leister, Link, Ralf, and Gerald, (2010), give an overview of the various cues for depth perception. Depth cues are classified according to visual depth cues and oculomotor depth cues.

change and degrade the perception of the object (see Figure 35), with different amount of depth cues in an object making the difference between 2D and 3D.

Another cue is local orientation. The unit vector perpendicular to the tangent plane on a surface is called the *surface normal*, and provides a measure of orientation (see Figure 34). This measure works well if the *surface normal* remains constant when we translate the object but, if we rotate it, it does not. Again, this is not viewpoint dependent (Tittle et al., 2001). A *surface normal* is a calculation of a vector that is perpendicular to the surface. It is used to calculate light, reflection, refraction, etc. and it will effectively give the illusion of 3D. This is also referred in the area of computer vision as the shading problem (Kimmel, 2003, p. 3).

Some objects named “Geon” have invariant properties; regardless of illumination direction and surface marking or texture, these objects can be distinguished from the others from almost any viewpoint. This is drawn from the Recognition-by-Components theory (Biederman, 1987), which helps observers recognise objects regardless of viewing angle. This is known as viewpoint invariance.

Finally, another quantitative measure is the curvature, characterised as the rate at which orientation changes in a particular direction along an object’s surface (Tittle et al., 2001). This measure has been applied in computer science, in areas ranging from object recognition, scene analysis to feature extraction (Angelopoulou & Wolff, 1998). In this case, the curvature does not change with the viewpoint (translation, rotation and zooming), as you measure the curvature locally (see Figure 39). For a more thorough mathematical description of the invariance properties of curvature one can refer to the analysis of numerical geometry of images (Kimmel, 2003, p. 33).

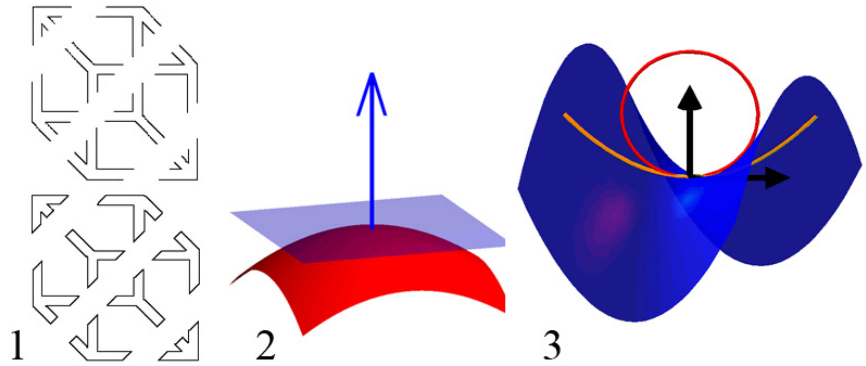

Figure 35. Different types of measure to define 3D: depth (1), local orientation (2) and curvature (3).

Another important and noteworthy measure to assess 3D is occlusion (Wickens & Hollands, 2000), which is simply defined as "closer object blocks farther object…" Occlusion is already a phenomenon encountered during the selective attention literature review and plays a significant role in how the selection of a virtual environment is achieved.

In order to perceive a 3D structure using a set of quantitative measures described above, different types of information need to be taken into account. The curvature definition presented by Tittle et al. (2001) implies a rate of change, and how a function f(x) changes as its input x changes with time. Time is an element, which must be taken into account when 3D is involved. If you have one static image of 3D, you can perceive 3D, but it could also be an optical illusion.

A more convincing 3D measure is a change in object featured over time or using a snapshot – for example, if you walk in a virtual environment or manipulate an object, you will see different snapshots and understand the entire experience as 3D. I approached 3D more with computer graphics, since the set of experiments in this chapter and following ones would involve object recognition in a 3D environment with user interaction.

What is virtual embodiment?

A recurrent theme in virtual worlds is to discover whether we can experience ourselves in avatar[7]-based virtual worlds through embodied presence. Notions of virtual embodiment date as far back as the late 1960s, it first appeared in the Winograd's SHRDLU system[8], which is a program for understanding natural language using Artificial Intelligence (AI). AI has been the basis of embedded cognition on robots in the real world since its beginning. Virtual worlds, however, provide a different type of embodiment from physical or material bodies; 3D offers a greater embodiment than the traditional online environment such as the web, chat boxes or forums.

The *Embodied Research Group* (Egoyan, 2007) has laid the foundations of the notion of embodiment in a virtual world. There are two types of embodiment in a virtual world: cognitive and social. The cognitive definition of embodiment is: "the impact our ability to act within our surroundings has on our cognitive and emotive processes". The social definition is: "an existential condition in which the body is the subjective source or inter-subjective ground of experience". These two performative definitions suit well a tool like *Second Life* (with a poor user interaction compared to other virtual reality tools or games) and reinforce the idea that embodiment is less about physicality but more on how we act, how we experience and the consequences of those actions.

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[7] The term avatar is a Sanskrit word originally referring to the incarnation of a Hindu god, more particularly the god Vishnu. A more adapted definition of an avatar in the virtual context is given by Bell (2008) "An avatar is any digital representation (graphical or textual), beyond a simple label or name, that has agency (an ability to perform actions) and is controlled by a human agent in real time".

[8] Http://hci.stanford.edu/~winograd/shrdlu/

As identified by Denise Doyle (2009), a virtual world experience depends upon the interaction of a number of elements. She argues that Spinoza's theory of imagination[9] as a form of bodily awareness can help us understand the phenomenon of bodily experience in virtual worlds.

> Virtual world experience consists of the interplay of a number of elements: of ourselves experiencing telepresence; of our imagined presence in virtual space; and of ourselves switching to the disembodied perspective of Idhe's 'image-body'. This double experience relies on a complex set of relationships between the body and the mind. At the centre of this is the imagination (Doyle, 2009, p. 139).

By using this virtual technology, we can give ourselves immaterial bodies where imagination is the only limit. However, these immaterial bodies are subject to the same barriers encountered in the real world. For example, it is noticeable that prejudices around men and women still hold in virtual worlds. A female avatar will have ten percent less benefit compared to its male counterpart during a financial transaction (Sussan, 2009, p. 59). Avatars represents our sense of identity, and we trust what resembles us most, this has been demonstrated with an experiment by the Virtual Human Interaction Lab. [10] In this research, participants were shown random faces morphed with, firstly, their own faces, and then with those of politicians. Significant results showed that participants preferred the faces, which were morphed with their own image.

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[9] The imagination cited by Doyle is different from the concept we saw previously with Kantian terminology. Imagination is borrowed from the Spinoza idea, which helps to emphasize the relationship between the body and the mind.

[10] Http://vhil.stanford.edu/projects/

This also goes some way to explaining why an avatar of indeterminate sex does not inspire confidence, as we attempt to reproduce worlds closer to reality because they demand less adaptation (Sussan, 2009). However, there are a number of virtual users who embody themselves with fantasy creatures such as dragons, vampires or werewolves.

Jaron Lanier (2006), a pioneer in virtual reality, explains that our capacity to invent new bodies and new worlds could be a means as powerful as language or music with which to express ourselves in a different way. He calls this post symbolic communication. Whether users would prefer to transform themselves into strange creatures rather than a beautiful re-incarnation of themselves to help to achieve this new means of expression remains to be seen in the virtual world.

Similarly, Douglas Engelbart, who invented the computer mouse, argues that gaming or virtual worlds are flexible enough to experiment with technology, interface or unrealistic environments, and allow us to think and consider of things in a different way (Sussan, 2009, p. 92). Engelbart (1962) in his important paper on the augmentation of intelligence with the interaction between man and machine, founded his reasoning on the Neo-Whorfian hypothesis [11] and advances that effective intellectual activity is directly affected by the manipulation of symbols, which integrated at the time the new capabilities of a digital computer into the intellectual activity of humans.

[11] The Whorfian hypothesis states that the worldview of a culture is limited by the structure of the language which that culture uses.

Figure 36. Example of different types of avatars: on the left, fantasy and sophisticated looking avatars; on the right, an out-of-the-box avatar used for this research.

I have touched upon virtual embodiment, as it is relevant to the body of work in this thesis, but there are other forms of embodiment using different types of technologies that compete with the virtual ones. These include robotics, virtual reality and the use of haptic interfaces and devices, or other interfaces connecting virtual worlds that have grown rapidly, such as *Wii* technology. More traditional virtual worlds such as *Second Life* have not fully caught up yet with competing technology mentioned above.

Virtual platforms available

There are many closed-source commercial or open source worlds available, each with their own purpose and technical specificity. The most popular have been *Second Life* and *World of Warcraft* (WoW) (Blizzard Entertainment 2001) in the commercial category. Others have came to light, such as *There* (Makena Technologies 2011), *Active Worlds* (ActiveWorlds 2001) and *Metaplace* (Playdom 2013). Linden Lab, the makers of *Second Life*, have started to work with the community to establish standards for interoperability with new clients and servers. It is also worth mentioning a few past and present open source projects: *Metaverse* (www.metaverse.sourceforge.net, not active anymore), The O*penSimulator* project (www.opensimulator.org) and *The OpenViewer* project (www.openviewer.org). All have their advantages and disadvantages, but I will not review each platform in detail – for a good discussion and some application of different virtual worlds I recommend the online journal of Virtual Worlds Research (www.jvwresearch.org).

Instead, in the following section, I will endeavour to describe in more detail the *Second Life* platform and why I chose it as a platform to conduct the next set of experiments for this thesis.

Second Life

Historical Perspectives

Created in 2003 by Linden Lab*, Second Life* is a virtual world, or online community, with millions of users, although only a certain number are active, making statistics difficult to estimate (for more detail, one could refer to http://gridsurvey.com/index.php, where there are monthly statistics available).

Second Life, was originally conceived as a simple gaming and social networking environment, but is now a space open for creativity, research, marketing and teaching. In *Second Life*, users use simple tools to create content in real-time, and there is no separation between a modelling stage (usually using external 3D modelling tools like *3D Studio Max*) and a rendering stage (the content created is instantly presented in the world). *Second Life* viewer, released as open source software, already includes the necessary building and programming tools. The power of this virtual world lies in its huge user database mixed with the opportunity for collaborative work – for example, building a 3D object.

Linden Lab operates the *Second Life* platform exclusively as a 3D content hosting provider. Persistent objects, created from graphic primitives ("prims"), are stored on central servers co-located by Linden Lab on several facilities; the actual scenes where objects and avatars are deployed run from individual simulators, each running a section of a visually contiguous imaginary world; together, all regions are known as a grid (Fishwick, 2009). *Linden Lab* charges a monthly fee (known as “tier”) depending on the size of the virtual space required for hosting all its content. Long-term projects have to budget for several months, or even years, of recurring monthly costs; there is no “off-world” building ability or any backup facility, and educational projects are charged the same fees as commercial ones.

The economy and popularity of *Second Life* has varied since its creation in 2003. It was at its peak during the 2005-2008 period, when it was arguably ahead of its time, and arrived at the very beginning of a social media revolution with the global breakthrough, of *Facebook*. Academics and businesses noticed this dynamic 3D revolution, and invested in what was, at the time, a niche market and the domain of regular visitors or keen gamers. *Second Life* became a potential world for collaboration (virtual meeting), learning, virtual commerce or animation (Machinima) (McArthur, Teather, & Stuerzlinger, 2010). However, by 2009 *Second Life's* star had begun to fade with the general economic downturn[12].

In 2012, the new CEO of Linden Lab, Rod Humble began refocusing the objectives of the company, introducing original and innovative ideas rather than one monolithic product. The company is now expanding its portfolio to include new digital entertainment products, including *Patterns*, a new 3D universe for users to shape; *Creatorverse,* a tablet and mobile game that allows users to set their creativity in motion; *Dio*, a new shared creative space on the web; and *Versu*, an interactive fiction experience that makes the reader a part of a living story (http://lindenlab.com/about). *Second life* is also working with Oculus VR, a company that design a headset for immersive virtual reality applications to bridge the gap mentioned earlier with other virtual platforms on the market. There is also some development work to link *Unity 3D* and *Second Life*, while *Unity 3D* is a very good tool for creating 3D

[12] www.nwn.blogs.com/nwn/2013/03/second-life-performance.html

environment it lacks some of the user interaction that *Second Life* offers (Yardley, 2013). These changes may help *Second life* to be seen as an innovative company once more.

The technical side of Second Life

Computers connect to the *Second Life* server, which is similar to a web server hosting web pages. In order to access the *Second Life* world, the client program needs to be downloaded onto the client machine, which in turn starts a login process, which allows exploration of the *Second Life* world with an avatar.

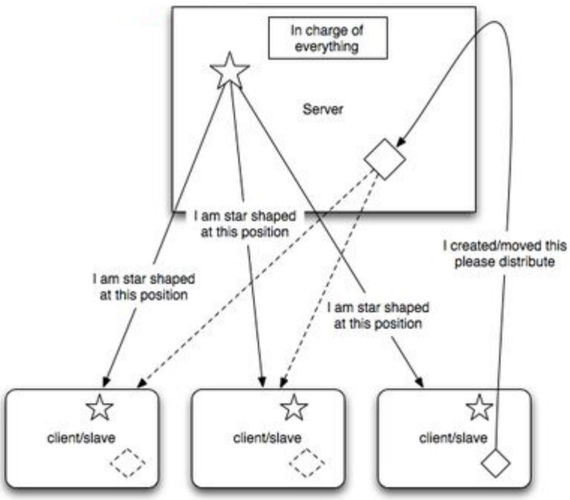


Figure 37. Example of *Second Life* set-up (Hughes, 2010)

Primitives are the basic blocks for object building in *Second Life*. As mentioned earlier, it is not necessary to be an expert in 3D design to be able to build things, and there is always the opportunity for advanced users to use different tools to bring in 3D content. But for these users who want more flexibility in creating content inside *SL* and are used to work with 3D tools like *Maya* or *3D Max,* the lack of integration can become a barrier for users.

In *Second Life*, virtual physical objects such as cars, houses, jewellery, and even less obvious things like hair and clothing are made out of one or more prims. Objects made from prims are usually created in the world using the built-in object-editing tool. This tool serves the same purpose as *3D Max*, *Maya*, or *Blender*, but is customised for *Second Life* with simpler interface and limited options.

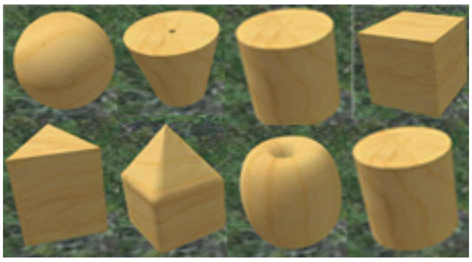


Figure 38. Second Life offers eight primitive shape types ("Building Block Type")

Each prim (Figure 39) is represented by a set of parameters, including shape/type, position, scale/size, rotation, cut, hollow, twist, shear, etc. These parameters are sent from a server to the viewer to run on their desktop, where the local video card is used to render the visual appearance of everything. A very high percentage of content in *SL* (98%) is made out of primitives (Bar-Zeev, 2008).

The advantage of using primitives is their simplicity. *SL* is web-based, and everything the user sees needs to be rendered on their machine, which is similar to a website. For example, if an object moves to somewhere else in the *SL* world, the server needs to redistribute the objects in the new position to the clients (see Figure 37). Primitives are made out of two-dimensional shapes extended to a third one by extruding the third dimension along a vertical path. The most basic example is a cylinder, which starts out as a 2D circle and extrudes along a linear path with no modifications to make a cylinder (Figure 39).

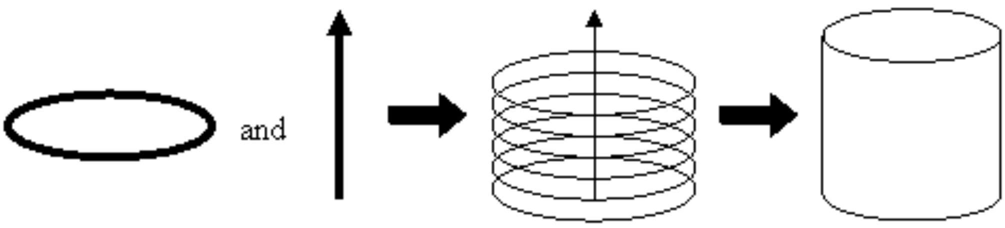


Figure 39. From 2D to 3D (Bar-Zeev, 2008)

Bar-Zeev (2008) describes the mathematical process of convolution to explain the conversion of a two-dimensional shape to a three-dimensional one. The term convolution comes from signal theory where one waveform is essentially multiplied at every point along another. This is basically the multiplication of two vectors together. There are two curves in space – 2D or 3D – multiplied perpendicularly that will produce a 3D volume. One input is called the Profile and one is called the Path. All primitives in the *Second Life* system are essentially built in the same manner. Once the basic block is chosen by the user in the basic primitive block, it can be modified and made into a Sculpted Prim – a prim whose shape is determined by an array of x, y, z coordinates stored as Red, Green and Blue (RGB) values in an image file. These sculpted prims can be used to create more complex, organic shapes that were not previously possible within the *Second Life* prim system. If done well, they can represent shapes that are made of one prim only.

For the novice user, there are only a few limited tools in *Second Life* to manipulate the basic prims. An advanced user will be able to work with more complex tools like *3Dmax* or *Blender* to import better-defined primitives. However, as mentioned earlier, there are technical difficulties when importing prims made with other 3D tools.

The drawback of using single prims is that they provide a low-resolution level of 3D objects. The use of polygons/triangles/quads is highly suitable for efficient low-level 3D objects, as they are easy and fast to render and do not require a great deal of shading. However, in order to have dynamic levels of detail, such as zooming in and out, one must lose quality (Bar-Zeev, 2012), similar to comparing an object (image) made of pixels and one (graphic) made of vectors. One is made of a bitmap, whilst the other is a mathematical function that does not require interpolation between two points.

In order to be able to add interactivity in the virtual world, users have the opportunity of using a Scripting Language unique to *SL*. Its structure is based on Java and C. They are a set of instructions that can be placed inside any object in the world, or any object worn by an avatar, but not inside an avatar. They are written with a built-in editor/compiler.

Virtual Environments as a Simulation Tool for Scientific Research

The recent development of virtual environments has empowered researchers to explore these worlds in order to conduct various experiments. For example, *Second Life* has been used to conduct formal experiments in social psychology or cognitive science, as researchers are able to construct facilities comparable to a real-world laboratory and recruit research subjects (Kraeme, 2013; Toro-Troconis & Kamel Boulos, 2009). *World of Warcraft* has also been tested for non-intrusive statistical methodologies examining social networks and economic systems, and extract data (Bainbridge, 2007). In another context, virtual environments can offer new possibilities in various fields such as economy and finance training[13], astronomy (Hut, 2008) or for data visualisation (Bourke, 2008). Indeed, virtual worlds can provide a good compromise between the complexity of data size in scientific information and how the human intuition comprehends this data. The emergence of data visualisation has offered novel insights in social sciences for example. Indeed concepts, ideas or data are more likely to be remembered when pictures are added to words compared to when just text is used; images are supported by many subsystems of memory, whereas words are represented by only one system (Zimmer et al., 2007). *Second life* is an example of tool where the exploration and manipulation of data could be done.

In the foundation chapter related to the conflicting view on the role of action, an overview of related work on memory and virtual worlds has been provided, but I will give one example of cutting edge research using virtual worlds. As mentioned in the introduction of this thesis, my research started with an interest in Artificial Intelligence and virtual worlds and, so, it seems logical to cover the topic in more depth.

[13] http://www.omega-performance.com/SimuStar

For many years, the phrase Artificial Intelligence (AI) has been associated mostly with intelligent software that has the potential to outperform humans in specific tasks embedded in our everyday life such as a chess program, the Google search engine or a programme to drive a car. This is called Narrow AI or weak AI (Searle 1980). There is also another type of AI, called Artificial General Intelligence, defined by Goertzel (2006, p. 195), which refers to the pursuit of software that can display a wide variety of intelligent functionality such as the ability to communicate richly in language. The idea is to recreate and ultimately move beyond human-level intelligence. Other terms used in the literature include "human level intelligence", "strong AI" or just "AI".

The term "AGI" compared to other terminology stresses the general nature of the research goal and cognitive scope found in humans without committing too much to any theory or technique (Wang & Goertzel, 2006). The term "General" in AGI also relates to a loose relationship with the notion of "g-factor" in psychology (Wang & Goertzel, 2006), which is an attempt to measure general intelligence, i.e. intelligence across various domains.

One landmark paper on gaming published by Laird and Lent (2001) provided an appealing way to give AI systems an environment requiring perception, action, language, emotion and socialisation, but without the engineering difficulties associated with robotics. Despite the emergence of a conference series devoted to the synergy of AI and gaming (the AIIDE series), there has not followed a great amount of work developing the promise outlined in the Laird and van Lent paper.

Back in 2006 -2008, when virtual worlds were at their height, various groups of researchers worked on virtual worlds and Artificial Intelligence as an alternative to robotics – for example, the application originated via the collaboration between Novamente LLC and The Electric Sheep Company to make AI virtual dogs in *Second Life.* They created a virtual dog controlled with Novamente LLC cognitive architecture (*OpenCog*) that could learn new tricks via imitative and reinforcement learning (Jeriaska, 2008). Other work moving in a similar direction was presented by the Rensselaer AI & Reasoning Lab. Using their own cognitive architecture, they have shown that an autonomous virtual agent endowed with some of the capability of a four-year old child in *Second Life* can possess genuine mental states (e.g. reason about his own beliefs), resulting from a formal theory of mind. They developed a cognitive test inside *SL* (Figure 40) where in a typical real-life version of this test, a child witnesses a series of events in which Person 1 places an object (teddy bear) in a certain location (box A). Person 1 then leaves the area, and during his absence Person 2 moves the object to a new location (box B). The child is then asked to predict where person 1 will look for the object when he gets back. The right answer, of course, is box A, but children aged four and under will generally say box B because they have not yet formed a 'theory of the mind' of others. The Rensselaer AI & Reasoning laboratory was not interested in doing cognitive science and developing a computational theory to recreate human behaviour (like Goertzel), *i.e.* an agent advancing through learning stages (Bringsjord et al., 2008). They were more focused on the gaming industry, to enable artificial agents to reason and trick the players in the game. It may be that, in time, their work will provide some valuable knowledge about human common-sense psychology states. At the moment, however the development in *Second Life* has not progressed since 2009 but ongoing work is happening in the area of serious gaming.

Figure 40. The test of false belief in *Second Life* reproduced with Rensselaer AI & Reasoning Lab permission.

However, Jon Laird (quoted in Biever, 2008) claims that this type of work has already been done in robotics by Dr Cynthia Breazeal of the Massachusetts Institute of Technology's Media Laboratory. Dr Breazeal programmed the "theory of the mind" ability into a physical robot called Leonardo, where the Robot starts with basic learning abilities like the Novamente LLC cognitive architecture. There is plenty of scope for researchers to improve the cognitive development of virtual agents – for instance, as Goertzel (Goertzel, personal communication, 24 October, 2007) argues, one could take the Piagetian cognitive development theory and its more modern descendants and create a series of virtual environments designed to help AI systems learn to pass through the Piagetian stages, and subsequently test whether the AI systems have indeed acquired the cognitive abilities associated with them.

Unfortunately, these various projects were never commercially launched due to a downturn in the virtual worlds' market. However, Novamente LLC has not dismissed the idea and, alongside pursuing AI with robotics, they are now working with the M-Lab[14], which was recently awarded a grant by the Hong Kong government's Innovation and

[14] http://opencog.org/2010/10/opencog-based-game-characters-at-hong-kong-poly-u/

Technology Fund (ITF) to work on a software toolkit for creating intelligent non-player characters in video games. The focus of their project is the creation of generally intelligent humanoid game characters, powered by the *OpenCog* cognitive architecture and the M-Lab's *Lucid* game engine, with the capability for simple English conversation and realistic human-like emotional dynamics. One of the tasks includes the design and development of a technical demonstration of the Open Cognition Framework in a game-like format. This includes integrating and expanding the *Unity3D* game engine (Unity Technologies) to include *OpenCog* functionality with C#, C++, Java, and Python. Their goal is to release an *OpenCog* version used for controlling an animated agent in a *Unity3D* based game world at the end of 2013.

Whatever the simulation world chosen, there are several open questions, such as how important it is to realistically simulate real-world physics in the simulator, as opposed to surrealistic video-game-style physics; and how important it is to have extremely rich data shaping the simulation world, e.g. data obtained from scanning real physical environments as opposed to highly simplified simulation environments.

For Goertzel, if simulated worlds are created with better physics (possessing a large variety of patterns of a large variety of types on a large variety of different scales) and real world data, then it is likely that the cognitive requirement will be met. This may be why he chose to use a game engine like *Unity3D* to pursue his ideas rather than a simpler tool like Second Life where the world physics is weaker than a game engine. There is also a debate surrounding which senses could provide the best embodiment: vision (Friedlander & Franklin, 2008); touch (Goertzel, 2006, p .257); smell, hearing, taste or all senses at once.

As discussed, virtual worlds are possible routes to researching AGI, and will be useful in helping to simulate the development of an infant brain into adult, which can help us in our challenging complex environment. However, development will not occur without bugs and improvement (Hall, 2008) and, before we have a fully general AGI system, we are going to have one that is almost as good, in the same way that chimpanzees are almost human, and gibbons are almost chimpanzees (Brooks, 2007). AGI systems will have to be carefully crafted by scientists to counter the pessimistic view of our occidental culture and its fear of machines which, interestingly, is not the case in Japanese culture[15] where robots are loved (Heudin 2008, p. 425). Virtual worlds are still too immature to develop full AGI, but both AI research and simulated worlds are developing at a fast pace and, as stated by Sibley Verbeck, the CEO of Electric Sheep company in the AGI conference in Memphis 2008 (Verbeck, personal communication, 2008), current technology is advanced enough to develop intelligent tasks but, the more users we acquire, the more developers will be able to put back into the richness of virtual worlds.

Finally, I would like to comment on the choice of *Second Life* for this thesis. When I began my PhD, this virtual world was the main virtual platform available in the market, and my employer, Bangor University, bought land to build a virtual campus. It was also a platform I had experienced previously during a project that looked at reconstructing real world models (Roberts, Gittins & Thomas, 2010). I was interested in the work conducted in AGI, and closely followed the development of *SL* with Novamente LLC. At the time, my intention was to focus more on virtual environments but, when I changed to Psychology, I decided to concentrate more on cognitive science rather than the specificity of a virtual environment. I therefore decided to use *Second Life* as another means of exploring episodic memory and selective attention. During my work with virtual worlds, I discovered some *Second Life* limitations, but these will be addressed at a later chapter in this thesis.

[15] Shintoism religion also plays a role in the acceptance of robots in the Japanese society. Shintoism is infused with animism: it does not make clear distinctions between inanimate things and organic beings, (Levy, 2008, p. 140).

Experiment 5

Introduction

In Experiment 1-2 different types of backgrounds were used (2D and a 3D). The 3D background was a first attempt to explore what it could be like to use a 3D environment like *Second Life* for memory recall. Thanks to the previous experiments, a consistent set of significant results have been observed, and it seemed an appropriate time to set up a similar set of episodic memory tests inside *Second Life*.

Method

Participants

In this study, 61 participants took part – 36 participants in the active mode and 25 participants in the passive mode. Most of the participants were students from Bangor University recruited internally via a web-based advertisement system, or friends and work colleagues. All participants voluntarily took part in the study and students received course credits. The participants ranged in age from 11 to 56 years (M = 22; SD = 7.7). None of the participants reported having any memory deficit or other cognitive dysfunction.

Apparatus & Stimuli

All 3D objects have either been created using the 3D interface in *Second Life* (Figure 41), chosen from a pre-existing gallery inside *Second Life,* or have been bought online in various online shops which can be found in virtual worlds. No other external tools have been used to enhance the look and feel of the objects, no shading or texture added to the prims with *SL* tools. Objects were made of one prim only or a sculpted prim. The experiments ran inside Bangor University Island in a free development space (a sandbox). The only visual details apart from the objects were blue sky, and a partial view of the sea and the floor where the avatar was moving around the scene. This floor was divided into a square of 4 colours (red, green, blue, yellow), above which a set of objects would later materialise. This was used as a strategy for participants to encode the spatial location (see Figure 42).

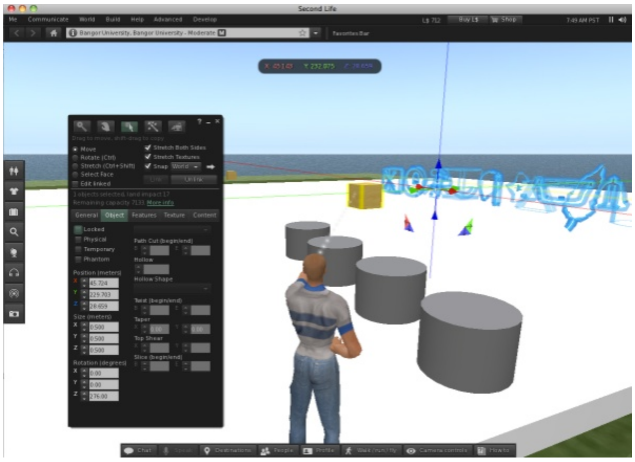


Figure 41. Content creation and set up of the experiment in *Second Life*

The stimuli were presented using second life on a Mac Book Pro laptop with a 15’’ monitor. Viewing distance was approximately 60cm; the visual angle for each object was 2.2 degrees. Manipulation of the avatar in *Second Life* was operated using a standard QWERTY keyboard (track pad to point at objects + arrow keys to move the avatar in the virtual environment).

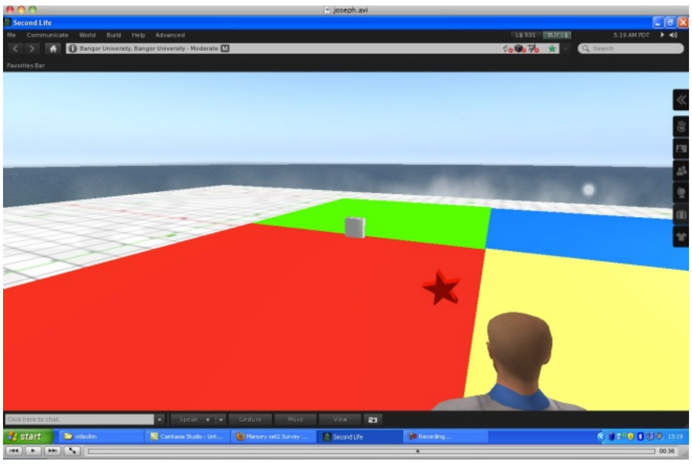


Figure 42. Second Life as seen by participants

Procedure

This procedure replicates as closely as possible the other experiment procedures. Similarly, there were two groups of participants randomly assigned to each of the two modes: Passive and Active. Both mode displays were identical, and the only difference was the task that participants had to perform. Before each test participants were instructed to pay attention to the overall scene but where more importantly they were told to focus on the target objects. In the active mode, participants had to navigate the avatar in *Second Life* and start the test by clicking on a square box. A pair of objects would then appear at random locations above the floor (one distractor in white and one flashing target in black). The avatar had to point to the flashing target object in order to move to the next pair of objects. Should the participant not click on the target object immediately, after 10 seconds a new pair of objects would appear. In the passive mode, participants were subjected to the same stimuli as the active participants (each passive participant watched a different video). The stimuli were recorded as a movie using *Camtasia* (TechSmith Corporation) during the active mode while active participants were doing their own tests. At the end of the sequence, the square box came back to its original position.

The avatar was always represented in the 3rd person perspective; this however can be easily changed in *SL* setting.

Some scripting had to be done to enable the functionality of objects appearing at random locations, and the SL script can be found in the Appendix A. The script was attached to the square box containing all target and distractor objects see (Figure 43).

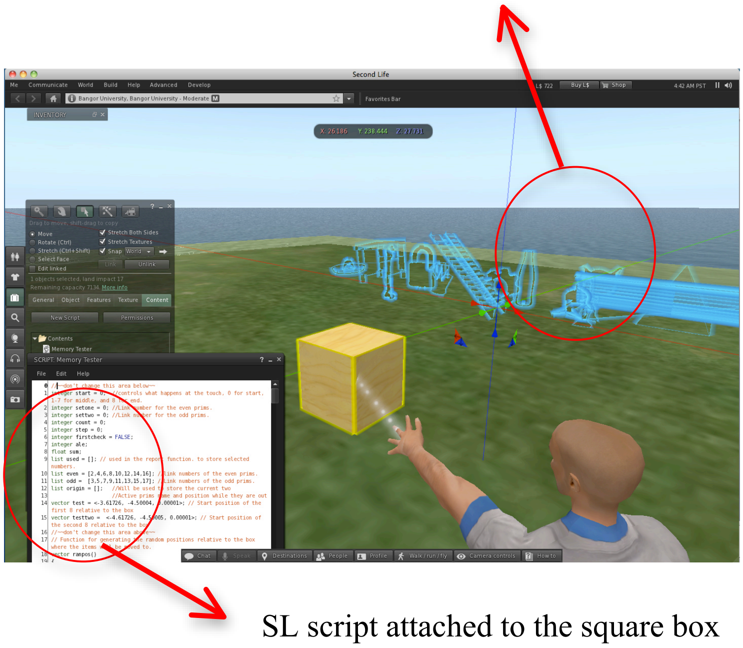


Figure 43. Scripting in *SL*

As in the other experiments, there was a set of 16 “old” objects to remember (8 distractors and 8 targets) for the immediate recall, and 16 new objects for delayed recall. The same arithmetic interference task was used, and the total time of the experiment lasted on average 40 minutes.

Active participants were first introduced to *Second Life* and had a practice run before the real test.

For the recall/recognition test, the participants were directed to a *SurveyMonkey* web page (http://www.surveymonkey.com/s/set1a and …/s/set2a), where they completed an online questionnaire for both immediate and delay tests. The questionnaire included the “what” cue task indicating the objects’ names. Included in the questionnaire were random objects (false alarms) for the recall tests. Participants were asked if they remembered the object and, if they did not, they were then asked to click on the next button to move onto the next set of question. However, if they believed that they remembered the object, they were asked to click the tick box, and were consequently obliged to answer the “where” and “when” question (forced choice). The “where” cue-recall task simply required the participants to indicate above which colour they had seen the object. In order to help them, they were also provided with a piece of paper with the four colours set up in quadrants similar to the *Second Life* floor set up. The “when” cue-recall task was prompted by a “begin” and “end” tick box, where the participants would tick “begin” if they thought that they had seen the object at the beginning of the sequence, and “end” if they thought they had seen the object during the last section of the sequence. The participants were told verbally before the start of the test that the beginning of the sequence was the first four pairs of objects and the end of the sequence was the last four pairs (there was no real separator in the presentation like in Experiment 1 and 2). Before the start of the test, the full procedure was explained in detail, in order to avoid participants devising a strategy during encoding.

Since objects appeared at random (location and time sequence) during tests, there was no easy way in *Second Life* that I was aware of to record the correct sequence specific to the test. To be able to compare participant answers from *SurveyMonkey* with the correct data at test time, right answers had to be added manually with the help of the video recording. In this way, the spatial location of the objects was adequately monitored and the sequence of objects could either be checked that way or at the end of each test. *Second Life* threw a message inside the instant messenger box with the correct sequence of objects for the current test (16 objects) see Figure 44. Following this, the results were manipulated within an excel spreadsheet, and design pivot tables were used to retrieve the full episodic score and other data.

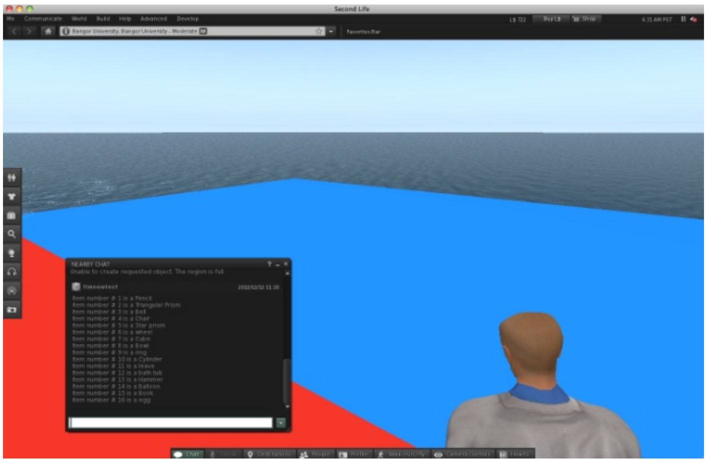


Figure 44. Instant messenger box that shows the sequence of objects at the end of a test, (The nearby chat is usually used to communicate with other avatars).

The same approach was used as for the other experiment, in which episodic retrieval of a particular object was inferred only on those cases where the three memory components (what, where and when) were correct. However, partial recalled objects were computed for object identity (what), spatial location (where) and temporal (when). The accuracy values were computed as hit/(hit + error) proportions for all analysis.

Analysis

Means of overall accuracy rates from 46 participants were analysed through a 2 (Objects: Target, Distractor) x 2 (Temporal delays: Immediate, Delayed) x 2 (Modes: Passive, Active) mixed Factorial ANOVA where Objects and Temporal delays were manipulated within subject and the Mode was manipulated between groups

Results

Data from 9 participants (6 from the active mode and 3 from the passive one) were removed due to technical errors while testing. In this experiment and for all *Second Life* experiments there is yoked design, with one passive participant for every active participant watching exactly the same experience. Therefore the mode should be set as a within subject variable. However the results presented in this experiment are presented with the mode set as between groups. Unfortunately the matching of participants (passive and active) has been lost over the course of the research. The matching was of course available at the time of scoring the passive participants in order to be able to analyse the data. To keep in line with all experiments in *SL* the mode will be set as between group, however an example for the mode set as a within subject variable will be discussed in a later experiment (Experiment 7) where the matching was possible[16].

Full episodic recall

Overall, data showed a significant reduction in full episodic memory (27.1%) during the delay with the interference task (20.7%), [$F(1,50)=6.38$, $p=.015$, $\eta^2_p=.112$] but there was no significant interaction with the type of mode ($F<1$). There was also an effect of the mode [$F(1,50)=5.3$, $p=.024$, $\eta^2_p= .09$] . More objects in the passive mode (27.5%) were recalled than in the active mode (20.3%). Moreover targets were overall recalled better (26%) than distractors (21.3%), [$F(1,50)=8.1$, $p=.006$, $\eta^2_p=.139$].

Despite the lack of other interactions it is worth investigating distractor suppression for this analysis. During immediate recall there was a better performance of targets recall (7%, $t(29)=2.0$, $p=.05$), in the active mode, which was not replicated in the passive mode

[16] This will also helps me to remember in the future, what could be the impact on analysis with these changes.

(0.8%, p=.10). During delayed recall, distractor objects were not suppressed in the active (0.8%, p=.84) or in the passive mode (5.6%, p=.24).

Additionally, we also found that memory from distractors during immediate recall was significantly reduced in the active mode (10.6%, $t(50)$=2.67, p=.01), while the target memory was not enhanced in the active mode, supporting the view that the difference between target and distractor memory in the active mode during immediate recall is due to distractor suppression and not target enhancement. After a delayed recall, there was no evidence that targets benefited from the active mode compared to the passive one (6.4%, p=.15).

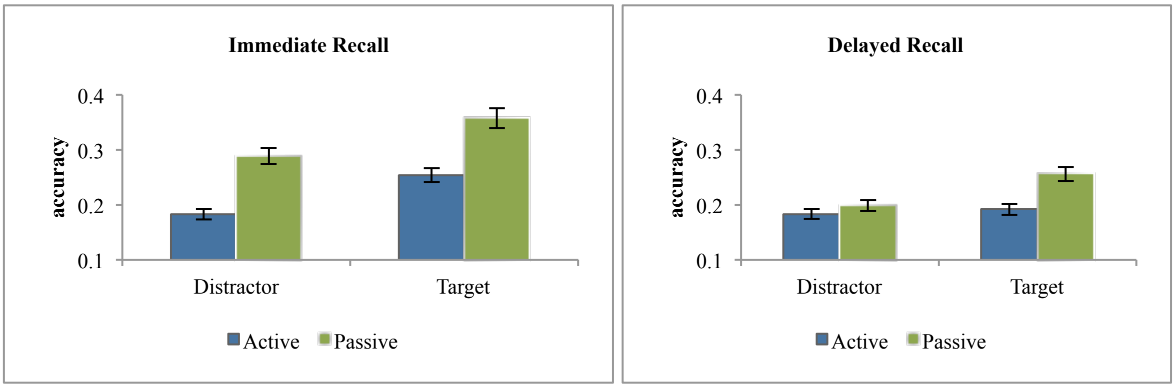


Figure 45. Exp 5: Mean accuracy recall for full episodic memory during immediate and delayed recall. Note error bars denote one standard error around the mean.

Results for object identity (what)

More objects were recalled during immediate recall (72.5%) than after delayed recall (67.8%), [$F(1,50)$=4.7, p=.034, η^2_p=.087]. Target objects (73.7%) were also better recalled that distractor objects (66.6%), [$F(1,50)$=9.13, p=.004, η^2_p=.154]. Finally objects were better recalled in the passive mode (75.2%) than in the active mode (65.1%), [$F(1,50)$=10.62, p=.002, η^2_p=.175].

There was an object – temporal interaction [$F(1,50)=7.32$, $p=.009$, $\eta^2_p=.128$] demonstrating that more target objects (15.1%, $t(51)=4.32$, $p<.001$) were recalled than distractor objects during immediate recall. There was no significant difference during delayed recall (0%, $p=1$).

More importantly, a significant a three-way interaction between mode, object and temporal variables [$F(1,50)=4.1$, $p=.05$, $\eta^2_p=.076$] was present. This interaction demonstrated that during immediate recall there was a solid target selection (22%, $t(29)=4.44$, $p<.001$) in the active mode, which was not replicated in the passive mode (5.7%, $p=.56$). For delayed recall, no better performance for target objects was observed in the active mode (1.6%, $p=.75$) or in the passive mode (2.2%, $p=.56$).

Additionally, we also found that memory from distractors during immediate recall was significantly reduced in the active mode (17.7%, $t(50)=3.43$, $p<.001$), while the target memory was not enhanced in the active mode, supporting the view that the difference between target and distractor memory in the active mode for immediate recall is due to distractor suppression and not target enhancement. After a delayed recall, however, there was some evidence that targets benefited from the passive mode (12.7%, $t(50)=2.46$, $p=.017$) compared to the active mode.

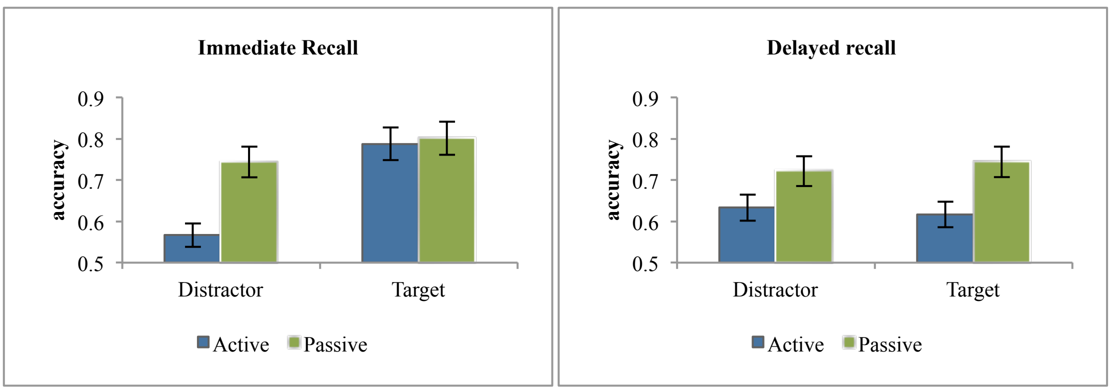


Figure 46. Exp 5: Mean accuracy recall for object identity during immediate and delayed recall. Note error bars denote one standard error around the mean.

Results for the spatial recall (where)

The accuracy analysis of spatial recall showed that more objects were recalled during immediate recall (38.7%) than during delayed recall (32%), [$F(1,50)=4.7$, $p=.035$, $\eta^2_p=.08$]. Target objects (38.8%) were also better recalled that distractor objects (32%), [$F(1,50)=10.9$, $p=.002$, $\eta^2_p=.18$]. Finally objects were better recalled in the passive mode (40.7%) than in the active mode (30%), [$F(1,50)=6.76$, $p=.012$, $\eta^2_p=.12$]. No other significant interactions can be reported.

Despite the lack of other interactions, it is worth investigating distractor suppression for this analysis. During immediate recall there was no better target selection in the active mode (1.25%, $p=.85$) or in the passive mode (0.5%, $p=.91$). During delayed recall, a better performance for targets was present in the passive mode (11.9 %, $t(21)=2.47$, $p=.02$) but not in the active mode (2%, $p=.64$).

We also found that memory from distractors during immediate recall was significantly reduced in the active mode (10.6%, $t(50)=2.8$, $p=.007$), while the target memory was also suppressed in the active mode (13.5%, $t(50)=1.97$, $p=.05$. After a delayed recall, there was evidence that targets benefited from the passive mode (12.9%, $t(50)=2.06$, $p=.04$).

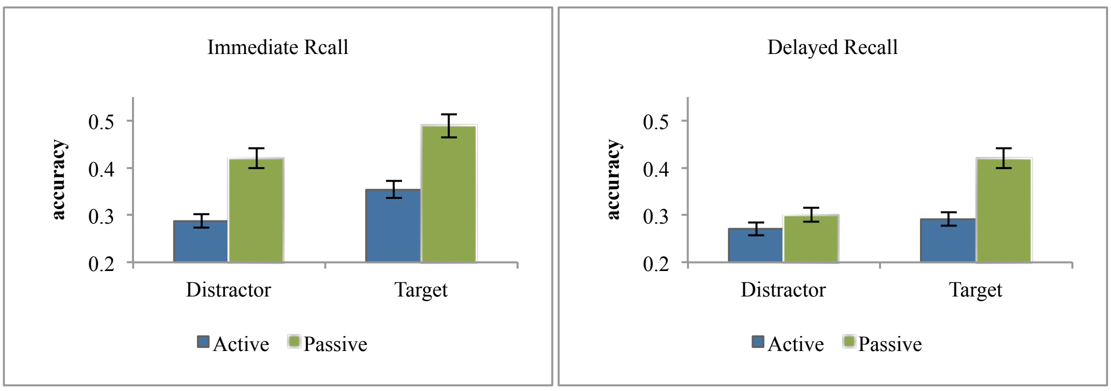


Figure 47. Exp 5: Mean accuracy recall for the spatial component during immediate and delayed recall. Note error bars denote one standard error around the mean.

Results for temporal recall (when)

More objects were recalled during immediate recall (48.5%) than during delayed recall (39%), [$F(1,50)=14.17$, $p<.001$, $\eta^2_p=.22$]. Target objects (47.5%) were also better remembered than distractor objects (40%), [$F(1,50)=9.12$, $p=.004$, $\eta^2_p=.15$]. Finally object timings were better recalled in the passive mode (48.1%) than in the active mode (39%), [$F(1,50)=7.72$, $p=.008$, $\eta^2_p=.13$]. No other significant interactions can be reported.

For immediate recall there was a better performance of recall for targets in the active mode (14.1%, $t(29)=2.89$, $p=.007$). Additionally, we also found that memory from distractors during immediate recall was significantly reduced in the active mode (12.7%, $t(50)=2.46$, $p=.017$), while the target memory was not enhanced in the active mode (6.6%, $p=.25$), supporting the view that the difference between target and distractor memory in the active mode for immediate recall is due to distractor suppression and not target enhancement. After a delayed recall, there was no significance evidence of distractor suppression or target enhancement.

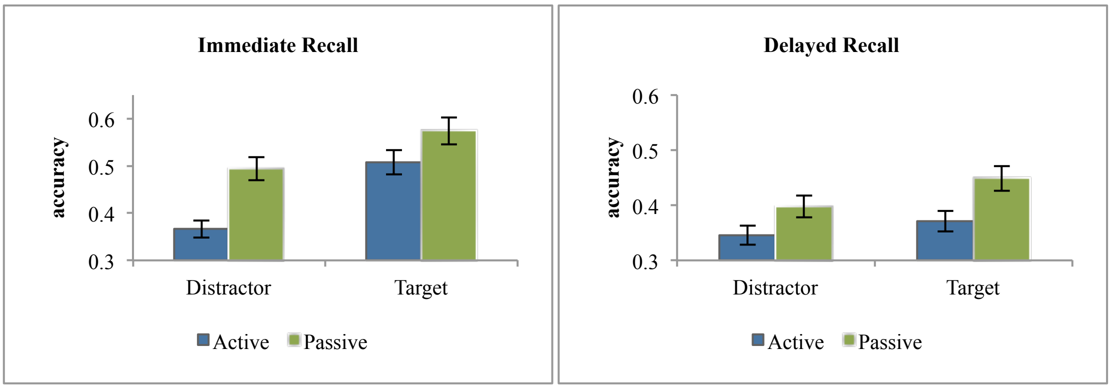


Figure 48. Exp 5: Mean accuracy recall for the temporal component during immediate and delayed recall. Note error bars denote one standard error around the mean.

Discussion

The present chapter has provided an interesting and innovative step to test participants in a virtual world. As described in the literature review, researchers have used virtual worlds to conduct different memory tasks that lead to various findings, however none have used *Second Life* as a tool to study memory - maybe because technologically it is not as flexible as other standard 3D environments or that for cognitive scientists the learning curve to design experiments in a 3D environment is more time consuming than with standard 2D interfaces traditionally used in the field of psychology. Moreover, *Second Life* was primarily intended to be used as a 3D social network and collaborative world to create, socialize, share and have fun (http://lindenlab.com/about), in my work none of these features have been used and a 3D standalone tool would have suffice. Despite these facts, based on my personal knowledge and experience of the software, the enthusiasm in the academia world at the time, I took on the challenge to build an environment that would allow me to replicate the cognitive tests designed in a 2D interface like in *Eprime.*

The testing phase was more challenging than before because of the learning curve for some participants had to go through. They all had an initial training period but sometimes it was not long enough to be familiar with the navigation, while other participants had gaming experience and had no problem to manipulate the avatar with the keyboard. Other problems were encountered such as loss of network connection during testing (*Second Life* is not a standalone tool, internet connection is necessary) or a slow connection, which made some of the test inconclusive. Finally the coding of participant results was not presented in a user friendly manner due to the complexity of coding the experiment itself and the main aim was to do a memory test without spending a huge amount of programming time.

In spite of some of these issues results demonstrated a similar pattern to those found in previous experiments. Indeed during the immediate recall fewer distractors were remembered and most importantly the suppression of distractor objects due to the action while target objects did not get affected by the type of mode in the episodic recall, as well as in object identity and temporal component, in this case a strong binding of almost all components was observed. However it is worth noting that in the spatial component the targets were significantly affected by the type of mode, targets were suppressed during the active mode. This unexpected result may be due to the difficulty for participants to recall the spatial location of objects in the current experiment (the floor made of square of colours).

Finally distractor suppression did not survive the interference task for all components, but targets were still suppressed due to the active mode. Results due to the interference task are like in other experiments more random in regards of what component get significantly affected by the selective attention process. A more detailed impact of the delayed recall will also be discussed in the final conclusion when explaining cross experiment results.

Chapter Summary

The method developed to test episodic memory proved to produce consistent results across various set up and retrieval memory tasks. The results observed in a 3D environment closely resemble the last four experiments done with a 2D interface.

Finally no floor effects were observed due to the more challenging manipulation and navigation of the avatar during the encoding task. The results are promising and allowed me to be more explorative in the design of the next set of experiments; therefore Experiment 6 explores the idea of emulating the social interaction when someone watches someone else performing an action based on the recent discovery of mirror neurons.

CHAPTER 5: ON OBSERVING ANOTHER PERSON’ S ACTION IN A VIRTUAL ENVIRONMENT

About Mirror Neurons

The design of this experiment has been motivated by a talk given by the Neuroscientist Vilayanur Ramachandran, who outlined the fascinating functions of mirror neurons during his speech at a TED conference (TED, 2009). The recent discovery of mirror neurons in premotor and parietal cortices of the macaque monkey (Di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992) has opened a new door into interesting research in interactions of action and perception. These neurons have been so named because they ‘‘mirror’’ actions of other individuals by re-enacting them on the observer’s motor repertoire. The neurons fire not only when the monkey performs an object-directed action such as grasping, tearing, manipulating or holding, but also when it passively observes the same action. There is now substantial evidence that these mirror neurons exist and have been observed in humans using different techniques such as behavioural with stimulus-response compatibility paradigms (e.g., Brass, Bekkering, Wohlschläger, & Prinz, 2000; Stürmer, Aschersleben, & Prinz, 2000) or using functional magnetic resonance imaging (Iacoboni, Molnar-Szakacs, Gallese, Buccino, Mazziotta, & Rizzolatti, 2005).

However, prior to the discovery of mirror neurons, the psychologist Albert Bandura, who has often been considered the bridge between behaviourism and cognitive psychology, claimed that we learn by observation. Bandura saw learning as the acquisition of behaviours. In his eyes, we see others and model our behaviour on this observation. Learning by watching involves the observation of a model, which is then duplicated. This may involve no teaching at all. For Bandura (1977), observational learning is influenced by:

1. Attention (necessary when learning)
2. The coding, storing and retaining of the patterns, so that they can be retrieved
3. Motor reproduction (kinaesthetic and neuromuscular patterns are practiced until the model's behaviour is learned)
4. Motivation and reinforcement (needed to push the learner to practice and retain knowledge and skills)

His work has seen a revival from the discovery of "mirror neurons" in monkeys in the early 1990s. Typical studies on mirror neurons include actions – for example, grasping hand. However, other types of studies have built on this to research other cognitive mechanisms – for example, action understanding, and how social behaviour could help to understand the intentions of others (theory of mind), or to provide a mechanism for recognising the observed acts. This is illustrated in the image below (Figure 49), where the context can help determine the nature of the action and the goal of the user (drinking or cleaning), (Iacoboni et al., 2005). The context in which the action will take place will give the meaning of the action. Out of context grabbing a cup can have different meanings, but in context, for example a cup on a clean table, the user intention is more likely to be interpreted correctly by others, in this instance drinking.

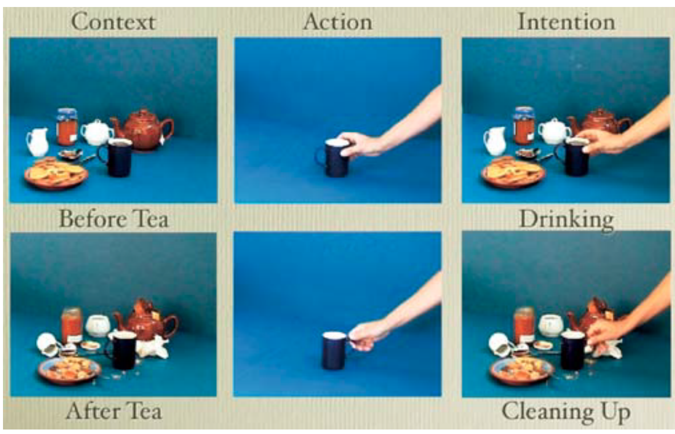


Figure 49. Context, Action and Intention (Kaplan & Iacoboni, 2006)

Other types of research interests that go beyond the simple action include eye movements (Litchfield & Ball, 2011); the perception of other people's emotions (Jabbi, Swart, & Keysers, 2007); selective attention (Frischen, Loach, & Tipper, 2009); other persons' errors (Schuch & Tipper, 2007); differences in recognition accuracy when one embodies a posture as compared to simply observing another (Winters, 2008); phantom limb phenomena (Ramachandran & Hirstein, 1998).

Mirror neurons are at their best when humans are face-to-face, but at least one study found that the cells (Murray, Liotti, Ingmundson, Mayberg, Pu, Zamarripa, Liu, Woldorff, Gao, & Fox, 2006) along with several brain areas involved in aggression were activated when children watched a violent television program. That activation increased the chances of the children behaving aggressively minutes or hours later. In yet another realm, mirror neurons are powerfully activated by pornography – for example, when looking at still pictures of naked people, the observer's mirror neurons spring into action, causing sexual arousal (Ponseti, Bosinski, Wolff, Peller, Jansen, Mehdorn, & Büchel, 2006). Similar ideas were raised by Bandura (1986) before the discovery of the mirror neurons, where learning from expert models, either live or on video, works because we can imitate but also infer intention, which can even lead to mental simulation.

Tipper investigated the hypothesis that witnessing another's selective reaching movements leads the observer to activate similar selective attention processes that are used by the agent to accomplish their goal. Tipper explains that witnessing a movement (such as reaching for a target stimulus) activates a corresponding action plan in the observer. Therefore, if the observed reaching movement is associated with certain attentional selection mechanisms (e.g. inhibition of salient distractors), then witnessing this movement should also activate those selection processes in the observer. This should lead the observer to inhibit distracting stimuli. Furthermore, if the observer not only activates a general selection mechanism but also simulates the agent's frame of reference, then they should most strongly inhibit those distractors that are most salient for the observed agent rather than those that are most salient according to their own frame of reference.

A point worth mentioning in Tipper's argument is the agent’s frame of reference. In order to achieve a simulation of another person’s actions that results in empathic understanding of them, the observer should be able to represent the world directly from the other person’s point of view. This third person or allocentric representation may be quite different to the egocentric or body-centred representations that are necessary to guide the observer’s own actions.

We reviewed various cognitive processes that could involve mirror neurons with a view to discovering whether episodic memory would be a good candidate. Learning by watching involves implicit learning/memory – for example, to learn how to kick a ball, what about retrieving the episodic memory of a person being observed? As it was mentioned earlier, direct evidence of the existence of mirror neurons has been obtained from single cell recordings in monkeys within specific brain regions. These include the ventral pre-motor cortex involved in motor control and the inferior parietal lobule concerned with the perception of emotions in facial stimuli and interpretation of sensory information (Rizzolatti & Sinigaglia, 2010), but what about other parts of the brain, would there be any other areas activated that could be involved with memory for example?

In a recent paper published by Mukamel, Ekstrom, Kaplan, Iacaboni and Fried (2010), a significant proportion of neurons in the supplementary motor area, the hippocampus, the anterior cortex and in the parahippocampal gyruss demonstrated excitation during action-execution and inhibition during action observation. It has also been shown by Gelbard-Sagiv, Mukamel, Malach and Fried, (2008) that the hippocampus and its associated structures in the medial temporal lobe also contain neurons that respond during the spontaneous recall of episodic memories. In this test, the experimenters asked subjects who were patients with pharmacologically intractable epilepsy to respond to cinematic sequences depicting specific episodes (doing different activities) and, later, subjects reported their experience in a free-recall situation. The results of this experiment with conscious human patients directly links free recall and neuronal replay in the hippocampus and the temporal lobe, structures that are usually associated with episodic memory. One could raise the question of how you can tell whether the neuronal response in an experiment is related to memory recall or to action observation/execution. For example, during action-execution, a memory of the executed action is formed, and during action-observation this memory trace is reactivated. This could possibly support the hypothesis of multiple mirroring mechanisms in the primate brain (Mukamel et al., 2010). Overall, these last findings suggest that multiple systems in humans may be endowed with neural mechanisms of mirroring for both the integration and differentiation of perceptual and motor aspects of actions performed by oneself and others.

Experiment 6

Introduction

In Experiment 5, a passive participant watched on its own the recorded video of an active participant operating the avatar. Consequently, the visual information displayed for each passive subject was the same as the one from the subject who interacted with the environment. Pursuing the idea of mirror neurons, the experiment tries to emulate the social interaction when someone watches someone else performing an action. This particular setting is different than the typical experiments, as reviewed with Tipper's experiments. Active and passive participants are doing the test at the same time, but in this occasion the passive participant observes the avatar inside the virtual world and not the active participant seat next to him doing an action in the real world, this added "layer" could have an influence on the experiment itself. However, the information about mirror neurons may be relevant in this case, as one could ask whether mirror neurons fire when combining the real with the virtual, or whether they fire, not only when a real action is performed, but also when we observe a virtual action performed by another?

Method

Participants

In this study, 54 participants took part (27 active, 27 passive). Most of the participants were students from Bangor University, recruited internally via a web-based advertisement system, as well as by word of mouth (friends and colleagues). All participants voluntarily took part in the study and Bangor students received course credits. The participants ranged in age from 18 to 40 years (M = 26; SD = 6.6). None of the participants reported having any memory deficit or other cognitive dysfunction

Apparatus & Stimuli

Stimuli were presented as in Experiment 5 using *Second Life* on a Mac Book Pro laptop with a 15'' monitor. Viewing distance was approximately 60cm. Manipulation of the avatar in *Second Life* was operated using a standard QWERTY keyboard (track pad to point at objects and arrow keys to move the avatar in the virtual environment).

However, in this particular experiment, some of the target and distractor objects from Experiment 5 were removed, as they were objects with a very low level of accuracy recall across the results (during full episodic recall), see Figure 50. Moreover, the colour of the flashing target objects was changed from black to red to increase the attention. This was changed easily in the script by modifying the RGB values. The rest of the environment remained unchanged.

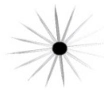
D: Lemon Juicer 	D: 3D Star 	D: Cup 	T: Sock 	T: Sun 
D: Bath Tube 	D: Pad Lock 	D: Egg Shape 	T: Leaf 	T: Ring 

Figure 50. Distractor (D) and target (T) - replaced objects

Procedure

Participants were tested together during the session. One participant (active) was sitting in front of the screen, operating the avatar; the other participant was sitting next to the active participant, and watched the avatar on the screen as shown in Figure 51. Both participants were shown a trial phase at the beginning, and were asked to choose which one of them would be the active participant. Once they started the test, they were not allowed to talk to each other. Once the encoding phase was over, each participant filled the online questionnaire at the same time. The passive participant used another computer in the testing room to complete the questionnaire, and the location of testing was kept identical whenever possible. The session consisted of two phases: an immediate recall phase, followed by a delayed recall phase with the same interference task as in other experiments.

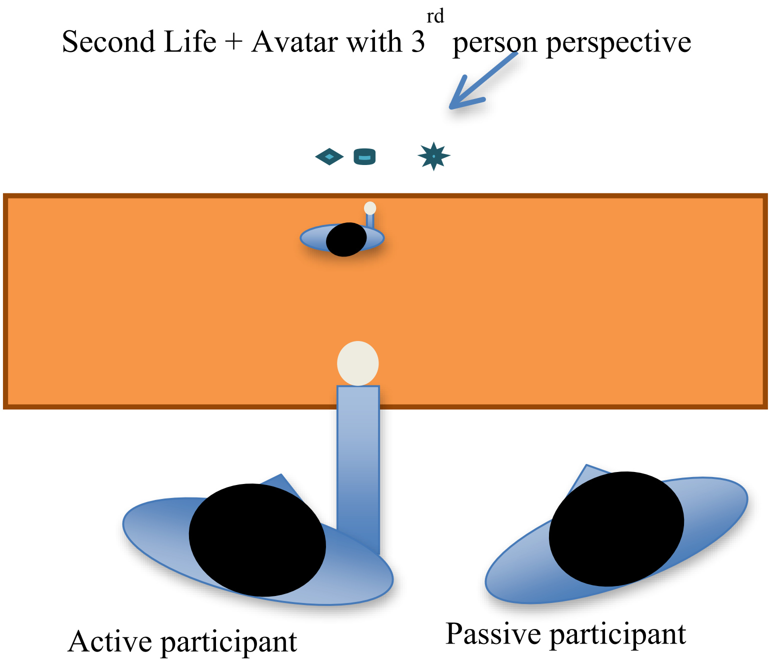


Figure 51. Experiment set up with two participants in front of the computer

Analysis

Means of overall accuracy rates from 46 participants were analysed through a 2 (Objects: Target, Distractor) x 2 (Temporal delays: Immediate, Delayed) x 2 (Modes: Passive, Active) mixed Factorial ANOVA where Objects and Temporal delays were manipulated within subject and the Mode was manipulated between groups.

Results

Data from two participants (one from the active group and one from the passive group) were removed due to technical errors while testing. Data from four additional participants in the passive mode and one from the active mode were removed as their accuracy levels for targets were very high and fell in the area of more than 3 times the IQR, the effects of the outliers can be found in Appendix H.

Full episodic recall

Overall, data failed to show a significant reduction in full episodic memory during delayed recall (F<1). Targets (18.2%) were slightly recalled better than distractors (15.2%), [$F(1,44)=3.88$, $p=.055$, $\eta^2_p=.081$].

Despite the lack of three-way interaction, it is worth investigating distractor suppression for this analysis as done previously. During immediate recall there was a trend for target to be selected (7.3%, $t(21)=1.93$, $p=.06$) in the active mode, but it was not replicated in the passive mode (0%, $p=1$). During delayed recall, there was no suppression of distractor objects in the active mode (6.2%, $p=.08$) or in the passive mode (0.5%, $p=.82$).

However there, there was no significant distractor suppression or target enhancement during immediate or delayed recall when looking at the role of the mode on the type of objects.

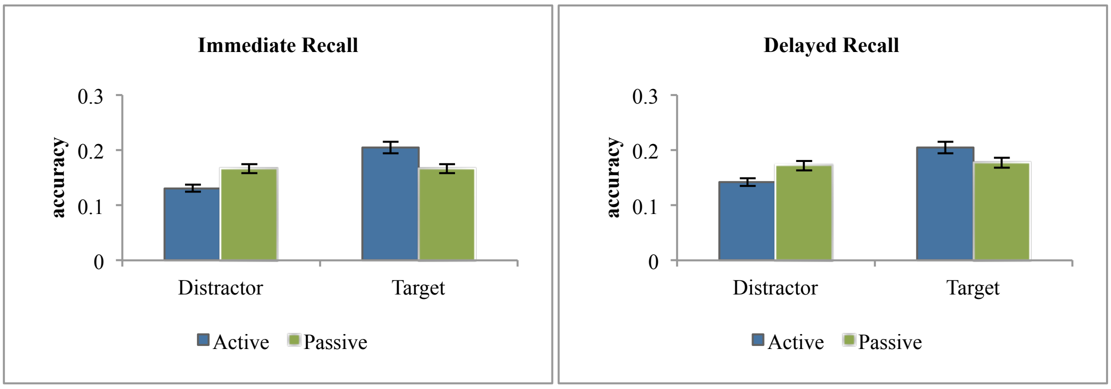


Figure 52. Exp 6: Mean accuracy recall for episodic memory recall during immediate and delayed recall. Note error bars denote one standard error around the mean

Results for object identity recall (what)

The analysis of object identity recall accuracy showed that target objects (75.3%) were better recalled than distractor objects (66.5%), [Object [$F(1,44)=16.87$, $p<.001$, $\eta^2_p=.277$]. No other interactions or main effects proved to be significant.

Despite the lack of other interactions, it is worth investigating distractor suppression for this analysis. During immediate recall there was a significant better recall of targets (13.6%, $t(21)=2.59$, $p=.017$) in the active mode, and it was also replicated in the passive mode (13%, $t(23)=2.65$, $p=.014$). For delayed recall, there was also a significant target selection in the active mode (13%, $t(21)=2.67$, $p=.014$) but not in the passive mode (2%, $p=.55$).

However there was a trend for distractor to be suppressed (12.1%, $t(44)=1.91$, $p=.063$) during delayed recall in the active mode, no other significant distractor suppression or target enhancement during immediate or delayed recall can be reported.

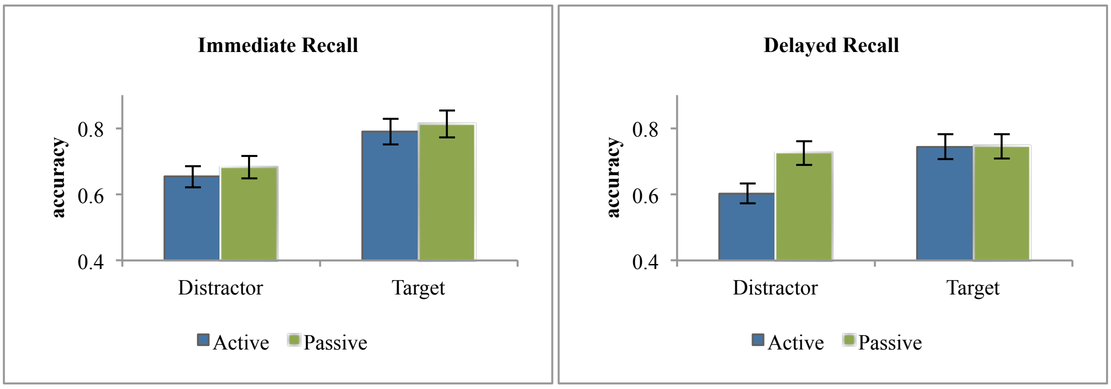


Figure 53. Exp 6: Mean accuracy recall for object identity during immediate and delayed recall. Note error bars denote one standard error around the mean.

Results for the spatial recall (where)

The analysis of spatial recall showed that target objects (29.3%) were better recalled than distractor objects (23.8%), [$F(1,44)=6.2$, $p=.017$, $\eta^2_p=.124$].

An object-mode interaction was also significant [$F(1,44)=8.7$, $p=.005$, $\eta^2_p=.166$]. Overall (both immediate and delay recall combined) a trend for distractor to be remembered better in the passive mode than in the active mode ($t(44)=1.69$, $p=.093$) can be observed, but it was not the case for the targets where there was no significant difference between active and passive mode.

Finally during immediate recall there was a significant better performance for selection of targets (11.8%, $t(21)=2.43$, $p=.024$), in the active mode, but it was not replicated in the passive mode (1%, $p=.81$). During delayed recall, there was also target selection in the active mode (12.5%, $t(21)=2.87$, $p=.009$) but not in the passive mode (1.3%, $p=.7$). There was no distractor suppression due to the type of mode for both immediate and delay recall.

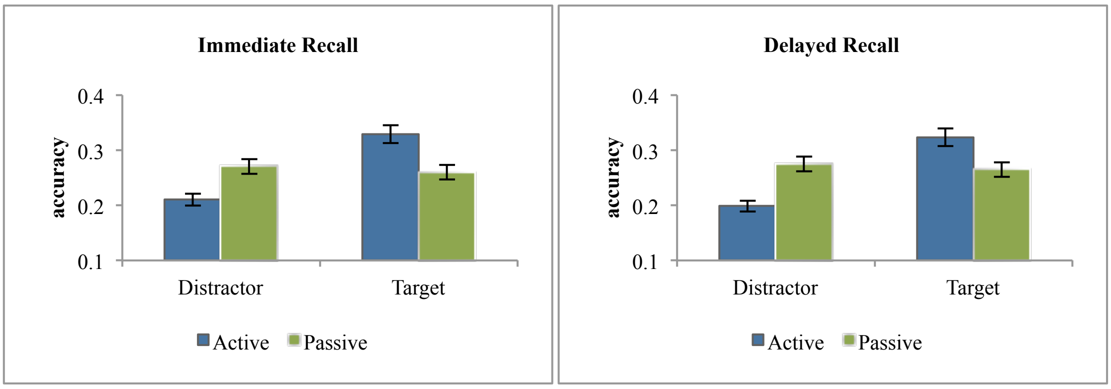


Figure 54. Exp 6: Mean accuracy recall for the spatial component during immediate and delayed recall. Note error bars denote one standard error around the mean.

Results for temporal recall (when)

The analysis of temporal recall showed that more objects were remembered during immediate delay (46.7%) than delayed recall (39.8%), [$F(1,44)=5.1$, $p=.03$, $\eta^2_p=.104$]. Target objects (47.8%) were also better recalled than distractor objects (38.8%), [$F(1,44)=12.3$, $p<.001$, $\eta^2_p=.219$].

Despite the lack of other significant interactions, it is worth investigating distractor suppression for this analysis. During immediate recall this time there was no significant target selection (7.3%, $p=.3$), in the active mode, but it was significant in the passive mode (15.6%, $p=.02$). During delayed recall, there was a better recall performance of targets in the active mode (15.6%, $t(23)=3.15$, $p=.004$) but not in the passive mode (2.5%, $p=.53$).

However there was no significant distractor suppression or target enhancement during immediate or delayed recall when comparing objects vs. modes.

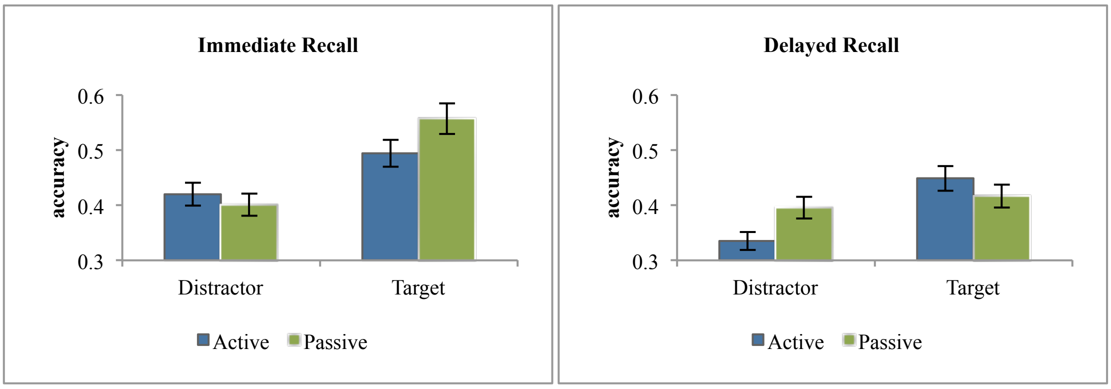


Figure 55. Exp 6: Mean accuracy recall for the temporal component during immediate and delayed recall. Note error bars denote one standard error around the mean

Comparison between Experiments 5 and 6 (Episodic memory, passive mode only)

Means of overall accuracy rates from Experiment 5 and 6 with in total 98 participants were analysed through a 2 (Objects: Target, Distractor) x 2 (Temporal delay: Immediate, Delayed) x 2 (Exp: Exp5, Exp6) mixed Factorial ANOVA where the type of object and the temporal delay were manipulated within subject and the different experiments (solo (Exp5) and duo (Exp6)) was manipulated between groups.

Only the results for passive participants will be highlighted; the results for the active participants between the two experiments did not bring any significant results. Out of all results an interaction was almost significant for the type of objects (distractors and targets) by experiments [$F(1,44)=3.24$, $p=.08$, $\eta^2_p=.07$] and demonstrated the effect of selective attention between the two experiments.

During immediate recall one can observed that Experiment 6 did not replicate the results observed for the active mode in Experiment 5 for distractor suppression, in Experiment 6 there was no distractor suppression (0%, $t(23)=0$, $p=1$), the same as in Experiment 5 for passive participants (6%, $t(21)=1.7$, $p=0.1$). In this instance the social interaction in Experiment 6 did not lead to embodiment as we suggested in the literature review. Moreover passive participants performed worse in Experiment 6 than when they were passive in Experiment 5 by just watching a movie. The recall of distractor objects (12.3%, $t(44)=2.85$, $p=.007$) and target objects (19.1%, $t(44)=3.62$, $p<.001$) were significantly lower than Experiment 6 for passive participants.

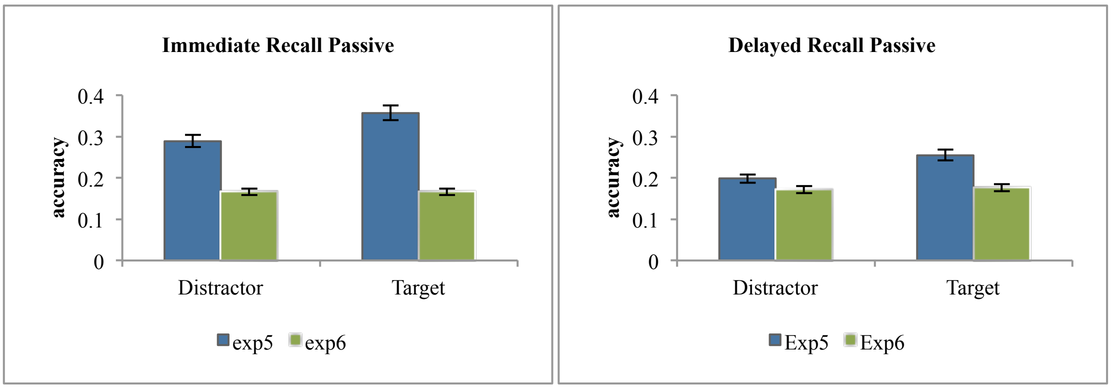


Figure 56. Mean accuracy recall for the full episodic recall across experiment 5 & 6 during immediate and delayed recall (passive mode only).

Discussion

The present experiment aimed to find what would be the impact of someone observing another person performing a motor action inside a virtual world. According to the prediction of the theory of mirror neurons, it was expected that passive participants would have replicated the same selective attention mechanisms (distractor suppression) observed with active participants during episodic retrieval.

Overall the results showed an absence of distractors suppression due to the action in all the component of episodic memory as well as the full episodic recall, which is novel, compared to the previous experiments. The results for the passive participants as to know if they are replicating the active participants' action are mixed. Because there is no control group it is not possible to observe the distractor suppression due to action and social interaction. But this can be observed if one look at active and passive mode separately as explained in Figure 21 (p. 81). During the full episodic recall (Figure 56) distractors were suppressed in the active mode (significant) but there were not in the passive mode (non-significant) highlighting the fact that overall the passive participants did not replicate the action due to the social interaction. These effects are however different with the individual components for example the object identity component during immediate recall shows equally distractor suppression in both modes (fewer distractor recalls). This is not however showing distractor suppression due to the action. Overall results are a mix and again it possibly demonstrates that object identity recall is the strongest components of the WWW task.

However it was interesting to observe what the impact of social interaction was when a passive participant either observes an active participant performing the test live or on his own watching a recorded movie from a previous active participant, as in Experiment 5, see Figure 57.

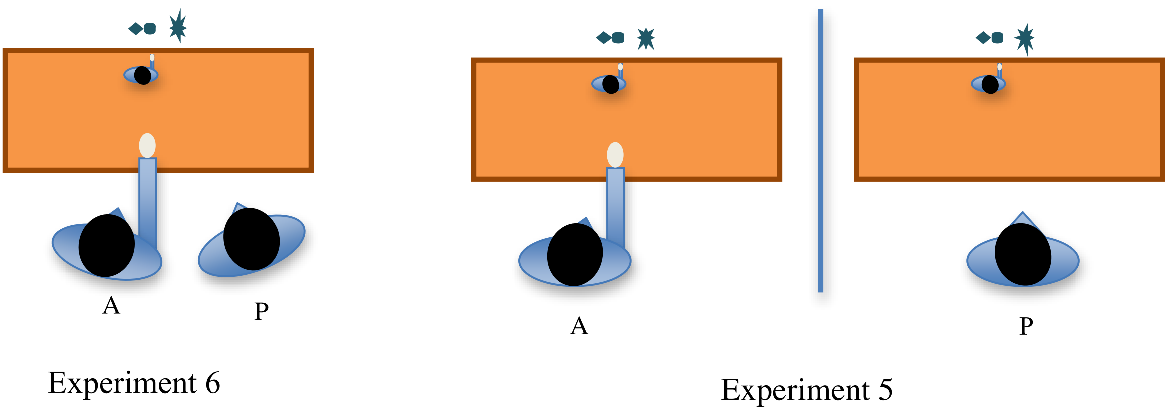


Figure 57. Social interaction, between experiments

Following the discussion on mirror neurons, embodiment should be expected from the passive participants and we should observe what the recurrent result in the thesis that is the suppression of distractors when participants are active. The results form the last analyse between the two experiments demonstrated a relative poor performance of passive participants in Experiment 6. This could be due to the fact that just watching someone else doing an activity led participants to relegate the responsibility to the other and performance could drop, in contrast if participants watch an activity on their own they would tend to be more engaged with it. During delayed recall the results were similar in term of embodiment, however we can observe that passive participants in Experiment 6 performed as well as passive participants of Experiment 5 for objects recall.

Chapter Summary

This chapter served to address an interesting idea based on social interaction inside and outside a virtual world based on the mirror system that plays an important role for understanding the actions of other people or learning new skills.

The results did not match the expectations. First of all the absence of significant distractor suppression due to the active mode during immediate recall was noticeable in most of the components. The social interaction did not have a strong impact as passive participants did not replicate fully the pattern observed for active participants; further investigation could possibly show more convincing results. However it is obvious that passive participants remembered fewer objects during episodic recall in this experiment than in Experiment 5 where they had to watch a recorded video.

The next chapter of the thesis focuses on the improvement of the *Second Life* test designed in Experiment 5, while Experiment 6 was an investigation of the mirror neuron phenomenon as theoretical motivation for this passive observer experiment and a slight digression from the main focus of the thesis. I decided to implement some changes in the encoding of the WWW task. Specifically I was not convinced that the previous spatial component of the task was very effective (square of colours). In doing these changes I hope to demonstrate more robust results for distractor suppression in the three components of the task.

CHAPTER 6: VARIATIONS OF EXPERIMENT 5

Experiment 7

Introduction

The purpose of this study was to address some of the flaws of the last two experiments in *Second Life;* namely to test the hypothesis that spatial and temporal accuracies could affect the results of the previous experiments conducted using *Second Life*. Indeed, in the two previous experiments, spatial location of objects was represented with coloured squares (spatial location of objects was represented by placing them above coloured squares). It was not an easy task for participants to recall, as the visual frame of reference was changing as they moved around the virtual world. Some objects did occasionally appear between the intersections of two squares, making it very unclear above which colour the object was located. Finally, depending on the avatar point of view, it was not always obvious where the object was; in fact, it was very subjective, since the marking of the spatial location by the experimenter had to be done manually after reviewing the recorded video (see Figure 58). A new spatial encoding strategy was implemented to facilitate the task and gain a better analysis of spatial location. Moreover, the encoding of the temporal data was also weak, which led to the analysis of a new set of data for the temporal component. In this instance, extreme objects were kept, as they are remembered better due to the recency and primacy effects (the serial position curve from Welch and Brunett, 1924).

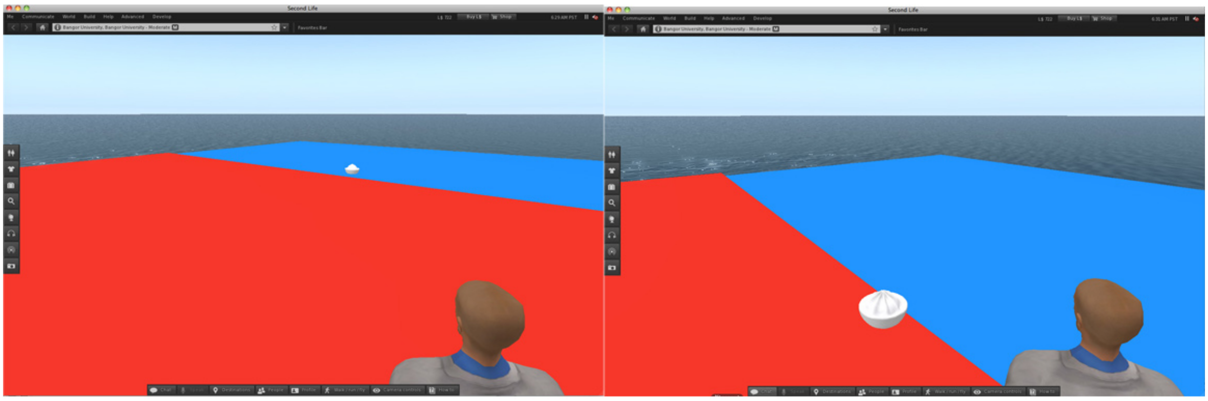


Figure 58. Example of problem for spatial location encoding (subjective view of the experimenter and participant). Screen Shot A: the participant can see the object above the blue square; Screen Shot B: by getting closer to the object it is above the red square. Depending how long the participant took to move close to the object during the test time, his encoding of the spatial location may have been different.

Method

Participants

In this study 43 participants took part, 21 participants in the active mode and 22 participants in the passive mode. Most of the participants were students from Bangor University, recruited internally via a web-based advertisement system. All participants voluntarily took part in the study and, on this occasion, received payment of £5 each. They ranged in age from 18 to 43 years (M = 24; SD = 6.6). None of the participants reported having any memory deficit or other cognitive dysfunction.

Apparatus & Stimuli

Objects to be encoded were the same objects as in Experiment 6. Four new prims were introduced (cylinders), and were present throughout the experiment. The four cylinders were used to mark the spatial location of objects. The cylinders were equally spaced to avoid chunking during encoding, and thus avoid learning strategy by increasing short-term memory (Miller, 1956). The background floor with the four coloured squares was removed and replaced by a less intrusive white colour (Figure 59). The survey[17] has also been modified to include a cue image of the new spatial location (a number 1- 4 was shown below each cylinder as a cue). The script in *Second Life* had to be modified to avoid a randomisation of objects inside the virtual world, and in order to make each target and distractor object appear above each cylinder (see appendix A for the new script).

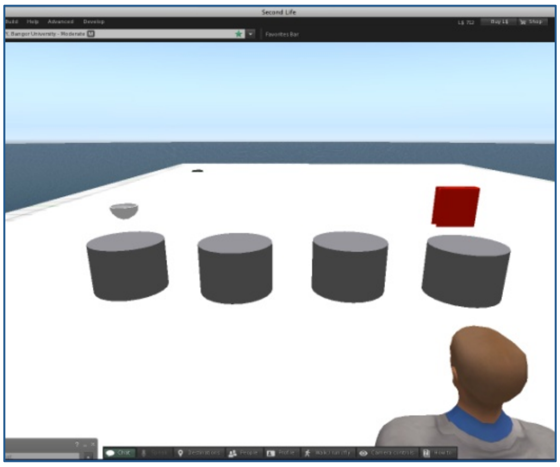


Figure 59. New set up for the spatial recall, cylinders are markers for spatial orientation

Procedure

The same experimental procedure was followed as per Experiment 5. Two groups of participants (passive and active) were submitted to the same stimuli as used in *Second Life*. Delayed recall was subject to the same distractor task for both participants. They were told not to go behind the cylinders and, if they failed to recognise an object before clicking (for the active mode), they could walk closer for better inspection. The time between each pair of objects was increased to 20 seconds to allow more time for navigation in *SL*. The same instructions were given to passive and active participants for encoding.

[17] Immediate recall: http://www.surveymonkey.com/s/set2a; delayed recall: http://www.surveymonkey.com/s/set2b (retrieved on the 16/02/2013).

Analysis

Means of overall accuracy rates from 43 participants were analysed through a 2 (Objects: Target, Distractor) x 2 (Temporal delays: Immediate, Delayed) x 2 (Modes: Passive, Active) mixed Factorial ANOVA where Objects and Temporal delays were manipulated within subject and the Mode was manipulated between groups.

Results

Data from 2 participants (1 from the active mode and 1 from the passive mode) were removed due to technical errors while testing. Data from 1 additional participant was removed as his accuracy level for recall was very high and fell in the area of more than 3 times the IQR (the effects of this outlier can be found in Appendix H).

Full episodic recall

Overall, data failed to show a significant reduction in full episodic memory after the delay with the interference task (F<1).

More interesting for the purposes of this study was that overall target objects (36%) were overall recalled better than distractor objects (29.1%), [$F(1,38)=7.01$, $p=.012$, $\eta^2_p=.15$], although this difference is almost entirely due to the target superiority observed in the active mode [$F(1,38)=5.29$, $p=.027$, $\eta^2_p=.12$]. Indeed, in the active mode there were more targets recalled (13.7%) than distractors [$t(19)=3.35$, $p=.003$], but this difference virtually disappeared in the passive mode (0.9%).

Importantly, the target superiority in the active mode cannot be interpreted as increased memory for the target information, as actively encoded targets were not remembered better than the more passive ones. If anything, overall scores for targets were slightly worse in the active mode. The entire difference arise from the distractor information, where passive distractors were significantly better encoded than the active ones [$t(38)=2.58$, $p=.014$].

Despite the lack of three-way interaction with delay, it is still relevant to investigate distractor suppression. During immediate recall there was distractor suppression (13.1%, $t(19) = 2.8$, $p=.011$) in the active mode, which was not replicated in the passive mode (2.5%, $p=.65$). Finally during delayed recall, the suppression in the active mode survived the interference task (13.7%, $t(19) = 2.8$, $p=.011$), in the passive mode the suppression was absent (0.5%, $p=.871$).

Moreover there was a significant distractor suppression (17.5%, $t(38)=2.55$, $p=.015$) during immediate recall in the active mode, no other significant distractor suppression or target enhancement during immediate or delayed recalls can be reported.

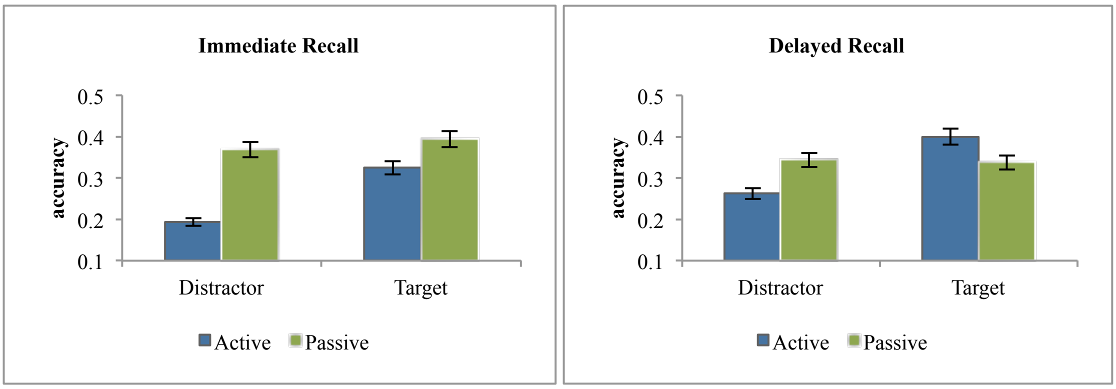


Figure 60. Exp 7: Mean accuracy recall for episodic memory during immediate and delayed recall. Note error bars denote one standard error around the mean.

Results for object identity recall (what)

The analysis of object identity recall accuracy showed that target objects were better recalled (84.1%) than distractor objects (73.3%), [$F(1,38)=20.16$, $p<.001$, $\eta^2_p=.352$]. Objects were also better remembered during immediate delay (81.3%) than during delayed recall

(75.9%), [F(1,38)=4.1, p=.049, η^2_p=.098]. There was also a two way interaction between object and temporal [F(1,38)=4.9, p=.033, η^2_p=.114].

Moreover a three-way interaction object - temporal - mode reached significance [F(1,38)=4.29, p=.045, η^2_p=.102]. This interaction demonstrated that during immediate recall there was better recall performance for targets (23.7%, t(19)=4.14, p<.001) in the active mode, which was also replicated in the passive mode (7.5%, t(19)=2.44, p=.024) to a less extent. During delayed recall activity, no difference between performance recall for targets and distractors was observed in the active mode (5%, p=.269) or in the passive mode (6.8%, p=.157).

Additionally, it was also found that memory from distractors during immediate recall was significantly reduced in the active mode (18.7%, t(38)=2.48, p=.017), while target memory was not enhanced in the active mode compared to the passive mode. After delayed recall, there was no evidence of distractor suppression or target enhancement benefiting from the type of mode.

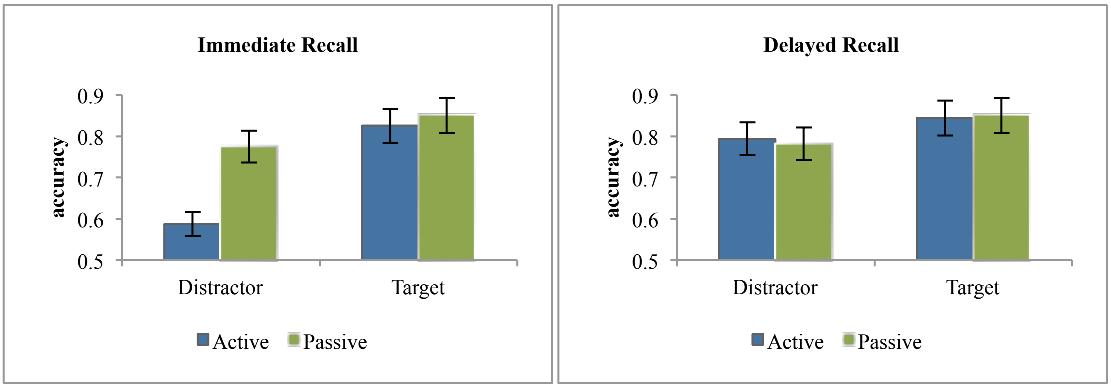


Figure 61. Exp 7: Mean accuracy recall for object identity during immediate and delayed recall. Note error bars denote one standard error around the mean

Results for spatial recall (where)

The analysis of spatial recall accuracy showed that target objects (48.7%) were better recalled than distractor objects (42.5%), [$F(1,38)=6.49$, $p=.015$, $\eta^2_p=.146$].

There was a two-way interaction between object and mode. [$F(1,38)=8.3$, $p=.006$, $\eta^2_p=.179$]. Indeed during the immediate recall there was again a strong target selection (11.2%, $t(19)=2.015$, $p=.058$) in the active mode, which was not replicated in the passive mode (5%, $p=.234$). During delayed recall, better recall performance of target objects was also observed in the active mode (11.8%, $t(19)=1.96$, $p=.06$) but not in the passive mode (3.7%, $p=.42$).

Additionally, we also found that memory from distractors during immediate recall was significantly reduced in the active mode (18.5%, $t(38)=2.32$, $p=.026$), while the target memory was not enhanced in the active mode. After delayed recall, there was no significant evidence of distractor suppression or target enhancement benefiting from the type of mode.

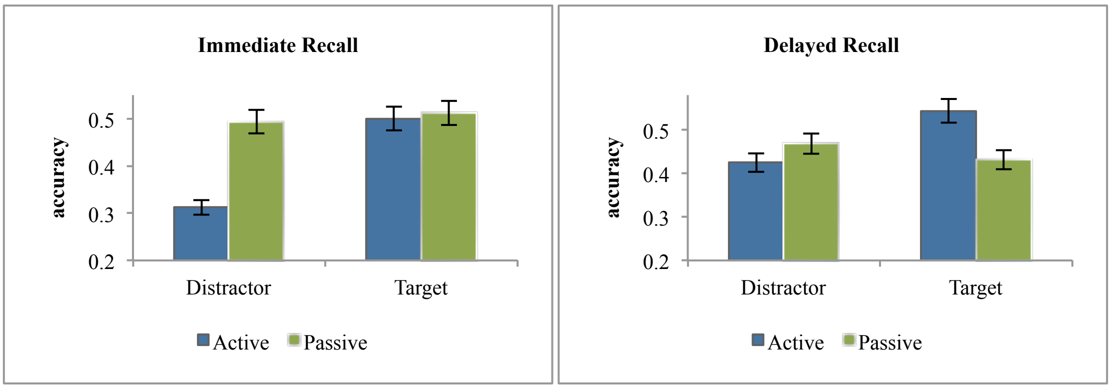


Figure 62. Exp 7: Mean accuracy recall for the spatial component during immediate and delayed recall. Note error bars denote one standard error around the mean.

Results for temporal recall (when)

The analysis of temporal recall accuracy showed that target objects (57.2%) were better recalled than distractor objects (47.5%), [$F(1,38)=10.34$, $p=.003$, $\eta^2_p=.214$].

There was no three-way interaction object – temporal – mode that reached significance. However during immediate recall there was strong targets selection (11.2%, $t(19)=2.015$, $p=.058$) in the active mode, which was not replicated in the passive mode (5%, $p=.234$). During delayed recall, there was a trend for better performance of target recall distractor in the active mode (11.8%, $t(19)=1.96$, $p=.06$) but not in the passive mode (3.7%, $p=.42$).

Additionally, we also found that memory from distractors during immediate recall was significantly reduced in the active mode (17.5%, $t(19)=2.54$, $p=.020$) compared to the passive mode. The other values remained non-significant or without trend.

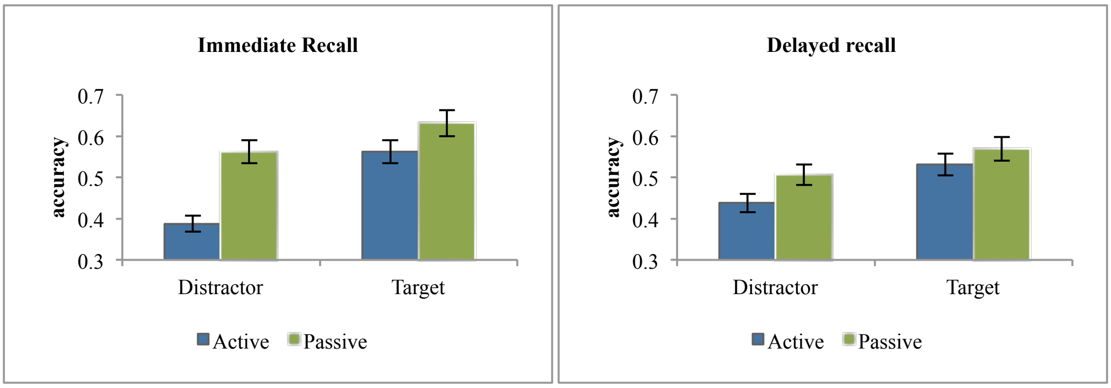


Figure 63. Exp 7: Mean accuracy recall for the temporal component during immediate and delayed recall. Note error bars denote one standard error around the mean

A manipulation of data to analyse the influence of temporal data recall on full episodic recall had to be done. Data were trimmed to exclude the middle pair of objects; out a sequence of 8 pairs of objects (1-8) to recall the middle 2 pairs (4-5) from the presentation were deleted for each participant recall. A similar statistical analysis was run to find out if any difference occurred for full episodic recall and its separate components.

New results for temporal recall (when)

Removing data had a significant impact over the temporal component on distractor suppression. Firstly there is a stronger target objects recall with better p value [$F(1,38)=12.42$, $p<.001$, $\eta^2_p=.246$]. Despite the lack other new significant interactions lets follow the same pattern of analysis as before.

During the immediate recall there was a stronger target selection (15.6%, $t(19)=2.63$, $p=.016$) in the active mode we had before a p value of 0.20, however we have also now a trend in the passive mode for distractor suppression ($p=.086$). During delayed recall, targets were also significantly selected in the active mode (9.3%, $t(19)=2.03$, $p=.05$) but not in the passive mode (3.7%, $p=.368$).

Additionally, we also found that memory from distractors during immediate recall was significantly reduced in the active mode (16.8%, $t(38)=3.39$, $p=.002$) we had before a p value of 0.11. The other values remained non-significant or without trend.

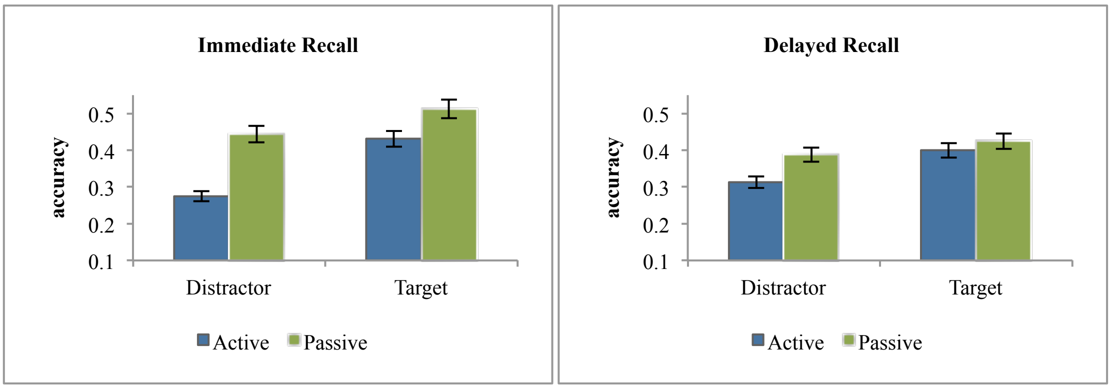


Figure 64. Exp 7: Mean accuracy recall for the temporal component during immediate and delayed recall. Note error bars denote one standard error around the mean

New results for the full episodic recall

Did it bring benefits to the full episodic recall for object suppression? Following the same pattern of analysis than in the previous experiments, the following descriptive data can be reported. There was still a two-way interaction between object and mode, [$F(1,38)=9.5$, $p=.024$, $\eta^2_p=.127$].

During immediate recall there was distractor suppression (13.7%, $t(19) = 3.03$, $p=.007$), before there was ($p=.011$) in the active mode, which was not replicated in the passive mode (2.5%, $p=.65$). Finally during delayed recall, suppression in the active mode survived the interference task (11.8%, $t(19) = 2.8$, $p=.011$): before there was ($p=.018$); in the passive mode suppression was absent (1.2%, $p=.755$).

Moreover there was stronger significant distractor suppression (15.6%, $t(38)=2.9$, $p=.006$) during immediate recall in the active mode: before there was a p value of .015, Moreover a trend showed that distractor suppression survived the interference task (9.3%, $p=.058$)

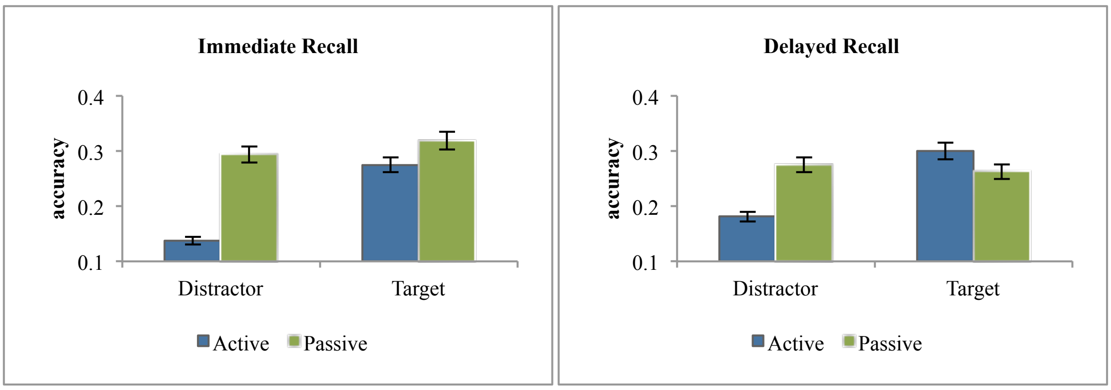


Figure 65. Exp 7a: Mean accuracy recall for episodic memory during immediate and delayed recall. Note error bars denote one standard error around the mean

Discussion

The results from this experiment clearly suggest that changing the design of the experiment with a more effective encoding method for spatial location, along with a trimming of data for temporal recall, had an effect on memory recall. Indeed it was found in all components that distractor suppression was due to the active mode while there was no difference due to the passive mode during immediate recall. The results during delayed recall also showed that suppression of distractors did not survive the interference task, see Table 8.

The results observed in this experiment replicate in some way the pattern observed in all experiments except for the findings of Experiment 6.

However to further investigate the impact of the changes operated in the last experiment it would be of interest to compare and analyse this experiment with the first experiment designed in *Second Life* (Experiment 5). If the modifications brought to this experiment are significant, the results for distractor suppression should be more pronounced for Experiment 7 than in Experiment 5 during the active mode. As in the previous chapter the means of overall accuracy rates from Experiments 5 and 7 for full episodic recall with in total 92 participants were analysed through a 2 (Objects: Target, Distractor) x 2 (Temporal delay: Immediate, Delayed) x 2 (Exp: Exp5, Exp7) mixed Factorial ANOVA, where the type of object and temporal delay were manipulated within subject and the different experiments (Experiments 5 and 7) were manipulated between groups.

In the analysis the passive mode between experiments did not produce any significant interactions. However the active mode analysis for both experiments showed a significant two way interaction between the types of experiment and the types of object [$F(1,48)=4.484$, $p=.039$, $\eta^2_p=.085$]. Despite the lack of three-way interaction during immediate recall, strong distractor suppression is demonstrated for both experiments, but more importantly it can be seen that there is a better recall of target objects in Experiment 7. This is however not significant (7%, p=.22). The real difference occurred during delayed recall where targets were better recalled during Experiment 7 (20.8%, $t(48) = 4.2$, p<.001).

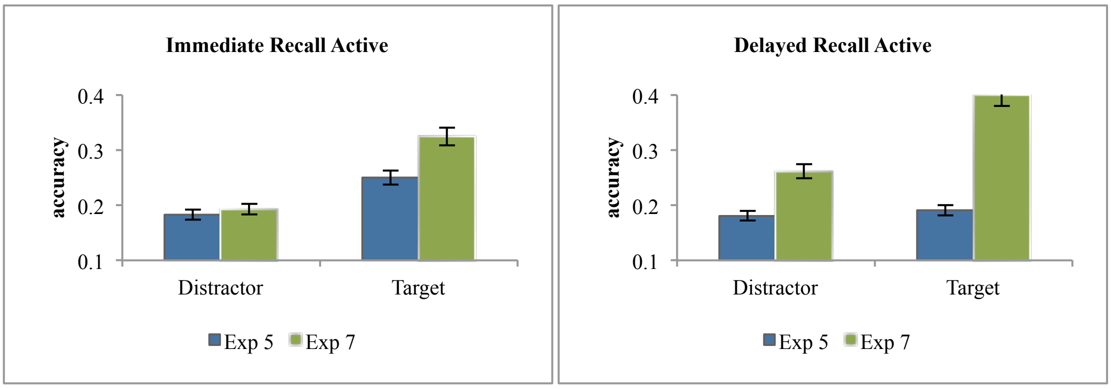
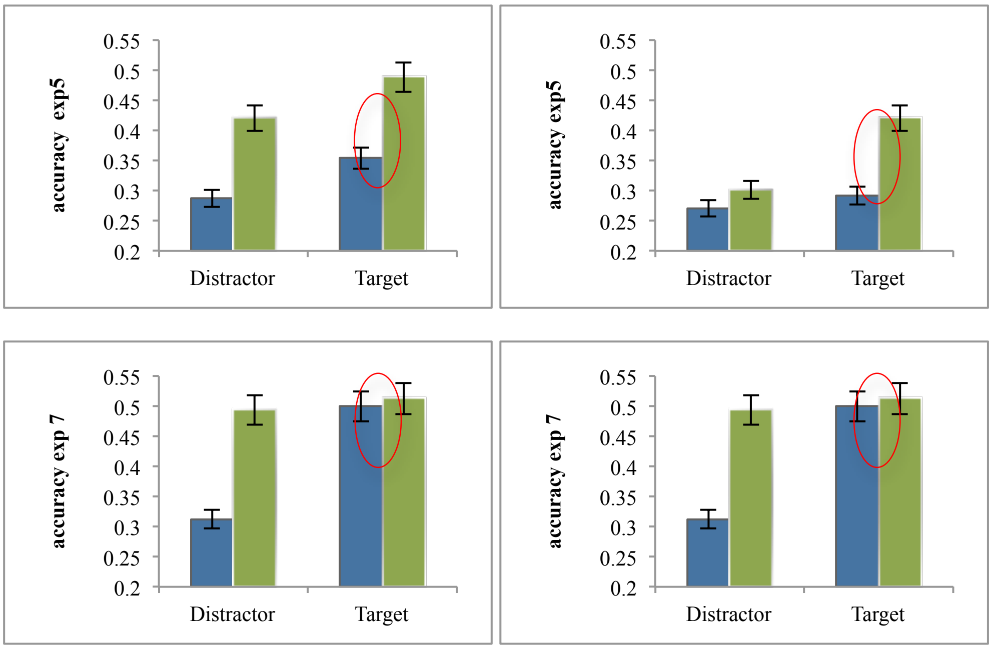


Figure 66. Mean accuracy recall for the full episodic recall task across Experiments 5 & 7 during immediate and delayed recall (active mode only). Note error bars denote one standard error around the mean.

Another aspect is worth mentioning when looking at the impact of this new experiment. In the spatial location results for Experiment 5, an enhancement of targets was observed for both immediate and delayed recall. But once the encoding mechanism was changed with the use of cylinders for location encoding in Experiment 7 (see Figure 67), target recall returned to values that were observed in other experiments, with no target suppression or enhancement due to the mode. This modification has also an impact on the full episodic recall which outlines the importance of spatial encoding for episodic recall and the binding process between different components, this will be discussed in the next chapter.

Spatial Component for Experiments 5-7



Full Episodic for Experiment 5-7

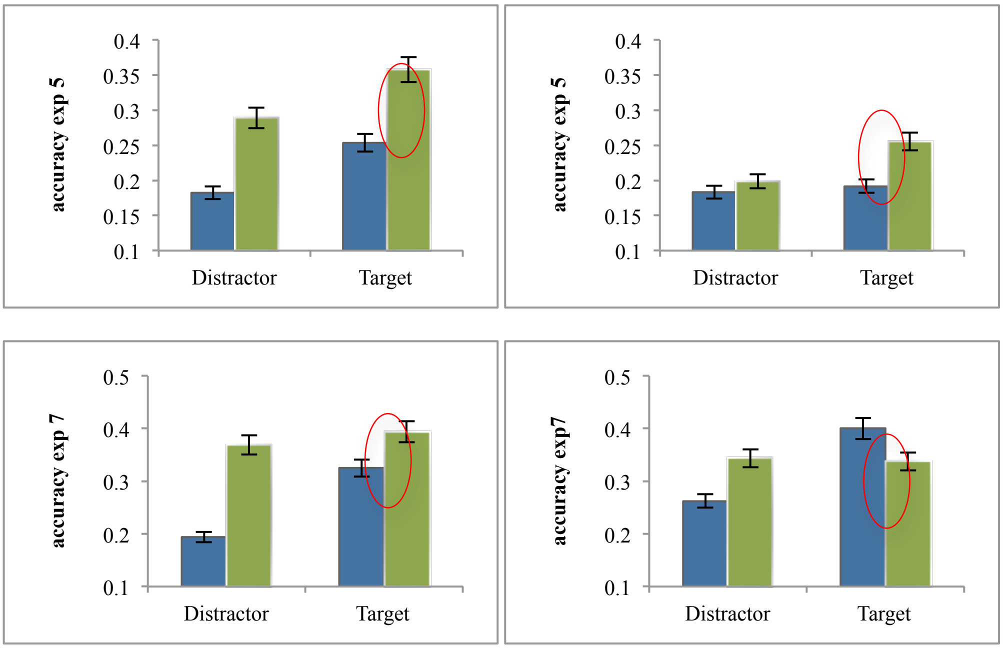


Figure 67. Impact on the new location-encoding task on the spatial component and full episodic recall

The active mode produced a significant interaction between the types of experiment and the types of object for the spatial component [$F(1,48)=4.5$, $p=.039$, $\eta^2_p=.086$]. The passive mode analysis showed no significance; this highlights the impact of the effects of the new location encoding between the two experiments during active encoding. During immediate recall there was a significant increase of target recall in Experiment 7 (14%, $t(48)=2.24$, $p=.03$). An increase of target recall was also observed after the interference task (25%, $t(48)=3.84$, $p<.001$). The impact on full episodic recall has also been shown to be of significance for the active mode in the previous cross analysis mostly during delayed recall.

Finally it was worth mentioning that for all *Second Life* experiments there is a yoked design, with one passive participant for every active participant watching exactly the same experience. Therefore an example has been redone in experiment 7 where the "mode" is set as a within subject variable. Redoing the analysis should increase statistical power to detect mode differences. The results outlined below are for the full episodic memory recall in experiment 7.

In the first set of analysis we had an significant object-mode interaction [$F(1,38)=5.29$, $p=.027$, $\eta^2_p=.12$] after removing one outlier. In the second set of analysis after estimating the difference between pairs of participants for the full episodic recall (Active (T1-D1) + (T2-D2))/2 + Passive (T1-D1) + (T2-D2))/2), one outlier was removed (pair of participants) using a boxplot for this difference. After running an ANOVA a slightly better significance for example is also observed for object and mode [$F(1,18)=6.4$, $p=.021$, $\eta^2_p=.26$] confirming the results of the previous analysis. Other results for the different components brought similar significances as well as increased statistical significance for object and mode interactions in all components, which were not present before. The full ANOVA tables are reported in Appendix H.

Chapter Summary

The improvements made in Experiment 7 are significant over the first *Second Life* experiment and this set up could be used to carry out more tests inside a virtual world as it produced robust results. This chapter leaves us with the question of whether there are any differences in doing that type of test inside a 3D world or would a standard 2D environment suffice? At first glance the analyses showed that there are no striking concluding differences between a 2D and 3D environment. However it would also prove that virtual worlds are suitable environments to carry out cognitive tests as other researchers in the same field have showed this. The final chapter will present more discussion on this matter.

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CHAPTER 7: GENERAL DISCUSSION

Across five experimental chapters and seven experiments, I have investigated the impact of selective attention and action on episodic memory and its individual components using an innovative and quantitative approach. Despite the different types of recall environments the effects found are prima facie quite similar. I begin the discussion section by giving an overview of the effects found for all the experiments and how they relate to some of the key findings described in the literature review before proposing some possible practical applications.

Overview of Findings

The first part of this thesis focussed on the theoretical foundations that lead to an innovative approach to measuring episodic memory quantitatively, as well as a review of the theory of selective attention and the contradicting views on the role of action.

The second part of this thesis investigated different experimental settings across seven experiments using more than 320 participants. As explained during the first statistical analysis many interactions did not reach significance (they may have reached significance with more participants) but the liberty was taken to explore further the trends observed in the descriptive data and perform extra statistical analysis. Experiments 1 and 2 were set up to explore different variables that could influence episodic retrieval using the WWW task. The results have been presented according to the type of background (2D and 3D) with the future work to be done inside virtual environments in mind. Overall, during the immediate recall we observed distractor suppression for active participants with the full episodic recall as well as for each individual component when the free recall technique was employed: this was the case for both types of background. The main difference occurred during the delayed recall with the 2D background: significant target enhancement was observed across all components of episodic memory as well as the full episodic recall. This suggests that these results could be due to the nature of the test used in these experiments (free recall, pilot tests and role of the interference task).

In Experiments 3 and 4, the background images were removed, different objects were used, new software was introduced and different retrieval methods (cue and recognition for object identity) were used to conduct the experiments. During immediate recall distractor suppression was also observed highlighting the role of action in selective attention. The results were less pronounced than in the previous experiments (selectivity was not present in all components of episodic memory) but floor effects were not observed as they were with free recall. The distractor suppression overall was not carried out after the interference task in most of the cases. This set of experiments extended the belief that while performing an episodic memory task consistent selective attention effects would be observed.

Experiment 5 intended to replicate the previous tests inside a 3D virtual world. Founded on the literature review it was suggested that virtual reality is a popular tool because it enables researchers to create situations that are close to daily life with experimental control (ecologically valid). This experiment provided further evidence of distractor suppression while performing an active task during the immediate recall. The suppression was only observed to survive the delayed recall for the spatial component of the memory task.

A variation of the task in Experiment 6 was set up to explore the possible effects of social interaction when performing episodic memory tests. In this experiment it was expected that passive participants would replicate the actions of the active participants: however it was illustrated that this was not the case in most components, it was also shown that passive participants recalled fewer objects (distractors and targets) when compared with passive participants in Experiment 5 possibly due to the relegation of responsibility during the passive observer experiment (similar to a passenger in a car). This experiment was also the weakest in terms of selective attention performance for active participants.

Finally, given the findings of the previous experiments, Experiment 7 was an attempt to address some of these shortcomings for the location and temporal component of the test. This last experiment provided further evidence on the role of action for distractor suppression during immediate recall and the effects of the interference task. It was also shown that the results observed in the 2D environment were also observed in a 3D environment.

The accuracy of memory was relatively consistent with expectations. Immediate recall responses were consistently high in accuracy compared to delayed recall, reflecting the effectiveness of the interference task performed by participants (see Table 4 in Appendix A). Table 5 highlights the fact that targets were better remembered across all experiments compared to distractors. In Table 6 it is clearly shown that overall when you are a passive participant you remember more objects but this will not predict exactly what you recall.

The dominant theme throughout this thesis is that during episodic memory recall tasks either the full episodic recall or in some parts its individual components, distractor suppression rather than target enhancement occurs as observed in six out of seven experiments that were conducted (16 interactions out of 24). This is due to user action during immediate recall. Results after a distractor task, despite being less reliable, tended to show that distractor suppression did not survived the interference task. However, given the variety of effects observed and the variables involved, further discussion is necessary.

Role of the Action

The importance of movement has been demonstrated by the "Kitten Carousel" experiment (Held & Hein, 1963). The objective of this study was to investigate the role of experience in perceptual-motor development. In this experiment two kittens were attached to a carousel, which was propelled by the movements of one active kitten, who was given the ability to move freely at its own discretion when in the carousel. As the active kitten propelled itself though space, visual experience tied to its motions occurred. The passive kitten received an equal amount of visual experience but these experiences were not related to movements; the passive kitten could not move. Both kittens were later released. The passive kitten showed no evidence of perceiving depth. The active kitten was indistinguishable from normally raised kittens. The findings fit the idea that self-produced movement and concurrent visual feedback are essential for perceptual learning to form foundations for complex cognitive processes (Kellman, 2002). However a closer link to cognitive human development linked to movement are the Piaget stages (Piaget, 1952), which are a blueprint that describes the stages of normal intellectual development. For Piaget the first stage in his theory of cognitive development is the sensorimotor stage. In Piaget's view, this stage begins at birth and continues until about age two. Because they don't yet know how things react, they are experimenting with activities such as shaking or throwing things, putting things in their mouths, and learning about the world through trial and error. A major source of inspiration for the theory was Piaget's observations of his own children and because a small research sample of other children used in his studies, it is difficult to generalize his findings to a larger population and it has led to criticism. However modern cognitive scientists such as Rutkowska (1996), trough behaviour-based robotics, has been assessing the role of the action and its outcome on infant development. Going a step further, controversial educationists Paul and Gail Dennison (1989) have based their work on Piaget educational philosophy to assess how the integration of movement activities in the classroom could enhance learning (therefore memory), the theories used by Dennisons however are still a matter of scientific debate among neuroscientists. However the embodied cognition approach suggests that motor output is integral to cognition, and the converging evidence of multiple avenues of research further indicate that the role of our body in memory processes may be much more prevalent than previously believed (Madan & Singhal, 2012a).

In the present context, it is important to define the role of an action. Motor action has been conducted using a mouse to point and click at an object on the screen; this is considered a physical action with motor information. This action may be considered weak compared to the use of a joystick or an even stronger motor application with a full arm movement, for example. Nevertheless, according to Gagné (1985, p. 199), this weak interaction or "fine performance" as he describes it justifies the classification of motor sensory activation. However, there is also selective attention with an action triggered by a visual cue, e.g. the green star inside the 2D interface or the objects flashing in *Second Life*. This design helped to dissociate both actions from the passive mode - the visual cue only and the active mode - the visual cue plus the action with the mouse. In the passive condition, the exogenous cue is working to direct attention towards the target objects and helps to weaken the encoding of the distractors. This design allowed a real measure of the passive mode to be obtained, which can be identified as the distractor object.

The action has been directed towards the target, not the distractor, and we can observe superiority in memory recall for target objects (Table 5). The results are compatible with other research findings that discuss the implication of an action and the boosting of memory (Zimmer et al., 2001; see also Engelkamp & Zimmer, 1994) but the results under discussion here are also compatible with people finding the passive mode superior. Indeed, the distractor suppression effect that can be observed on episodic recall when comparing an active vs. a passive mode mostly during the short term delay may explain why Plancher et al. (2007) found a superiority for the passive condition over the active one. In the active mode, even if all participants pay attention to all the objects, they will select target objects and, when they do that, all other objects are suppressed. In the passive mode, this does not occur. Therefore, participants are likely to remember more objects in the passive mode (Table 6). When attention is directed towards a target, the distractor is suppressed, and this has been discussed in the bulk of literature on negative priming. A prediction from the negative priming literature (Tipper, 1985, 2001) is that, during selective attention, the distractor information that may compete with the target for selection becomes inhibited below resting level. This inhibitory model predicts that distractors in our active task will not be as well encoded as the ones in the passive condition, as they will be suppressed. This is what happened during immediate recall.

By separating target and distractor objects with the use of selective attention, we can explain the conflicting views. Our passive condition would be an active condition for any other study due to target objects that are always salient for both modes. If this is the case, then the results are novel and dissociate different impacts of active states in memory encoding. Indeed, the passive condition could be seen as a selective attention state with no behavioural goals associated to the selection of the target, while our active condition would be concerned with the explicit definition of a goal (or task) upon target information The implications of this research are critical to studies evaluating memory encoding in virtual environments – for example, where the selection of objects and environments is influenced by the individual's actions. Our passive condition could also be a model of passive settings, such as watching TV, or listening to the radio where targets are given by selective attention cues and which require limited motor action in order to be selective and retain information. In short, the main benefit of using an active state of encoding would be when separating target from distractor information in short-term memory for example, in learning contexts. This advantage seems to disappear over time or after an interference task. Finally the role of the action has also been highlighted in the context of gaming; action games develop the ability to exploit task-relevant information more efficiently while better suppressing irrelevant potentially distracting sources of information (Bavelier et al., 2012). This will be discussed further in the section entitled "Learning and Memory".

The Role of Cue Types

The effect of cues is more difficult to assess. During free recall situations people use their own cues and it is difficult to assess what triggers the retrieval of memory, but when they are cued to retrieve information, more control is possible and the effect of each cue can be observed. Usually episodic memory is attained when cues are presented for the retrieval of the episodic event. If one is using free recall techniques it will require more translation to retrieve the information. In the current setting we could look at the full episodic recall and the object identity cues. The "what" was subject to free recall, cue recall and recognition in Experiments 1 to 4. In this thesis the effect of the type of cue has been demonstrated with Experiments 3 & 4 when switching from recognition to cue recall for object identity. The results highlighted the fact that was no target enhancement in cue recall when comparing to recognition recall for the object identity in the passive mode. However these results are to be taken with caution and would need to be investigated further.

Selective Attention and the Role of the Interference Task

Two mechanisms of selection are explained in the literature review: objects to be selected can be enhanced, as proposed by the spotlight models of attention (Broadbent, 1958) or/and distractors can be suppressed (Tipper, 1985). In the first mechanism, the enhancement of objects ensures that the representation of attended stimulus will be more prominent than those of distractors (Van der Heijden, 1981). In the second mechanism, the internal representation of ignored objects is associated with inhibition during selection and response to the target. To observe these inhibitory processes, priming procedures have been developed by Neill (1977) and Tipper (1985).

One topic of discussion in the literature review presented in this thesis was that inhibition decays rapidly (Mayr & Buchner, 2007). Inhibitory suppression is suspected to be short-lived, while episodic retrieval is supposed to last longer. This was supported by the work of Neill and Westberry (1987) who investigated the persistence of negative priming in a Stroop colour-word task, by varying the interval between subjects' response and presentation of the next stimulus (response-stimulus interval). Their results contradicted the view of Tipper, Driver and Weaver (1991) that found negative priming could persist for longer periods.

However in Neill et al. (1992) they carried new manipulation procedures in their tasks and results supported the view of Tipper. They concluded that inhibition decay depended very much on the temporal discriminability of the priming episode. The tasks carried out in this thesis are dissimilar from the ones carried out by these researchers. However in many of the experiments, the distractor suppression did not survive the interference task. This could relate to the early model of inhibition proposed by Tipper with only a transient inhibition, not the episodic retrieval model with longer-term inhibitory traces that could be established and retrieved with appropriate contextual cues (Tipper et al., 1991). The Episodic retrieval account is the most influential anti-inhibition account of negative priming, the issue of whether or not inhibition is involved in the negative priming phenomenon is important. However, negative priming effects are not observed in this thesis but the comparison of a well explained phenomenon serves as a good yardstick. The effects detected in the experiments come close to the inhibition model of Tipper: in many of our experiments the distractor suppression did not survive the interference task. If they had survived discussion about episodic memory retrieval would ensue. It is important to note that selective attention tasks in Tipper or others' similar experiments measure response times and are of the order of milliseconds. The results detailed in this research measure accuracy recalls and the time scale is too long for inhibition but is also too short for real episodic memory testing. The time scale in which all experiments have been designed have operated in a different time domain, which are different from inhibition tasks discussed in the literature review. However a standard selective attention effect was observed with distractor suppression; this could still show a weak episodic recall but which faded too early. Looking back at the analogy of negative priming, Tipper in his last review on the matter emphasised that both mechanisms could coexist.

> The characterisation of inhibition and episodic retrieval accounts of negative priming as forward and backward acting, respectively, does not stand up to careful scrutiny: both

must involve forward-acting (encoding) and backward-acting (retrieval) processes if they are to be complete explanations of the phenomenon (Tipper, 2001).

Priming paradigms are indirect measures of memory (implicit memory), as participants never get asked to actively remember what they saw. In this instance previous distractor encoding is inferred because a subsequent response is either facilitated (positive priming) or delayed (negative priming). To our knowledge, direct measures of explicit memory have never been taken following a selective attention task. These kinds of tests will not only study the status of different types of objects (targets and distractors) during selection, but they will also address the consequences of this status, whether the information is only temporarily unavailable for an action or it is withdrawn from memory access.

Binding

The approach to the WWW task is a minimalistic one, and is also the theoretical position espoused by Tulving in 1972: “Episodic memory receives and stores information about temporally dated episodes or events, and temporal-spatial relations among these events” (p 385). The tasks developed by Clayton and Dickinson (1998) interpret this sentence to mean that, as long as a creature can recall, on the basis of a single past experience, what happened where and when (WWW henceforth), it is utilising episodic memory. This is a definition based on evidence, stripped of any phenomenological characteristics, which is appropriate as a quantitative approach is being used without assessing the phenomenological aspect of episodic memory.

For Russell and Hanna (2012), episodic memory can be viewed as all-of-a-piece (Binding of the “what”, “where” and “when” component), exemplifying the synthetic unity of which Kant also discussed to make sense of the world, whereas semantic memory can be atomistic and punctual. In one of their experiments on episodic memory with young children, they devised a binding coefficient that measures the probability of a third W if the two other

Ws are correct during recall tests. They discovered that, given accuracy on the “what” and “where”, the “when” was 100% correct. Even if they mentioned that the data gave only preliminary results, the idea of a binding coefficient for that sort of experiment established the validity of quantitative measurement for episodic memory as used in the design of experiments detailed in this discussion.

Moreover, the results achieved offer a possibility to study which component of the WWW task influences overall episodic recall even if it has already been mentioned the pure role of the individual component is not accessible, there is a binding of the “what-when” and “what-where” episodic component in each results. However, to study temporal-spatial relations for the task itself is not appropriate. Indeed, the level of difficulty is not the same for each task and, therefore, they cannot accurately be compared. There are different tasks for example in Experiment 3 and 4– cue recall for the “what” component vs. recognition for the “when” and “where” components, plus a different level of difficulty in both experiments; 4 choices for object location and 2 choices for temporal sequence. It was therefore decided to be more conservative in approach and to compute results only for the true episodic memory encoding by looking solely at the combined accuracy value for the “what”, “where” and “when” tasks.

Holland and Smulders (2011) designed an interesting WWW task (hiding coins in different locations and on two separate occasions) and compared it to a real world episodic test (a set of questions relating to the task given to participants after the WWW task) to see if participants used episodic memory to solve the WWW task. They had two groups of participants; incidental and intentional encoding (in this thesis there was only intentional encoding). For the incidental encoding all aspects of the WWW task were predicted by the real episodic test, however for the intentional encoding, the episodic memory performance only predicted performance on the “what” aspect of the WWW task. Moreover in the WWW task participants were better at remembering the “where” and the “when”. Why? First of all they mentioned a ceiling effect with the "when" and "where" so they could not find enough variability to make a correlation with the episodic memory performance. Secondly, the use of strategy during intentional encoding was suggested as a possible impact and finally they outlined the possibility of different memory systems (non-episodic potentially semantic) used to encode the "when" and "where" information, the involvement of another type of memory when using recognition for the "what" component was also suggested in the Chapter 3 conclusion. They also suggested that the link between object with location is the more robust aspect of the WWW memory task using episodic memory system but not the temporal aspect, which is also another observation made in this thesis, for example in Table 3 summary found in the Appendix section, the "what" component was responsible for most of the three-way interaction found during statistical analysis.

In another study, Trinkler, King, Spiers and Burgess (2002), examined in a virtual test task whether events are the units of episodic memory (a series of events in which the participant encountered a person in a place and received an object from them). They were interested to know if episodic memory is holistic: when an event is remembered, all of its elements including the spatiotemporal context are remembered together. In contrast, if this viewpoint were completely untrue, memory for different elements of an event might be remembered or forgotten independently. Between these theoretical extremes, they characterized the argument that episodic memory for events is holistic in terms of the size of the correlation between performance when an event is retrieved via one cue and performance when the same event is retrieved via another cue. They concluded that the identity of person (who) was better than temporal and location.

What are the implications for us looking back at these studies: what is the worst component of EM in our scenario?

First in all the thesis experiments, participants were told that it will be a memory test, (intentional encoding) and were made aware of the need to pay attention to all the objects, both distractors and targets which is somehow a different condition from Holland and Smulders set of experiments (both intentional and incidental encoding). However, it became obvious to participants that, after the immediate recall test, they could use a strategy for the delayed recall test. As in Holland and Smulders this could have an impact on the WWW task and its individual components. It was also mentioned previously that the temporal and the spatial component of the WWW memory task is the most difficult to recall in experiments due to the complexity of the task. However in Experiment 7 after some modifications all components followed the same pattern as the full episodic recall thus replicating Holland and Smulders results during the incidental encoding (passive mode) where the real episodic memory test predicted all components of the WWW task.

3D Environment

Virtual reality is popular because it enables researchers and clinicians to create situations that are close to daily life with experimental control (Plancher et al., 2011). Most studies of attention discussed in this thesis have presented 2D images on computer and required indirect actions such as key-press responses on keyboard in a location separate from that of the selected object. Tipper, Howard and Jackson (1997), questioned what methods are most appropriate for understanding how the mammalian brain works. They explained that the current approach of cognitive psychology has been to develop highly controlled experimental procedures that have revealed properties, for example, of selective attention systems. These artificial situations however have not taken into account the ecological constraints that humans are faced with on a daily basis. Through the medium of *Second Life* an attempt was made to provide an alternative to 2D interface tests. To a large extent they replicated the results observed in the previous 2D experiments. This will prove that using more complex environments could be used as a base line to study more complex cognitive tasks that would allow good interaction techniques as being ‘‘natural’’ or at least ‘‘similar’’ to the physical world.

Other interesting results linked to the interference task are that results in Table 3 tend to suggest that memories created in *Second Life* are more resistant to interference tasks or better encoded inside a 3D environment due to the greater realism of the environment. The section in Table 3 referred to as “Interference Task” illustrates the impact of the interference task on the type of mode (active (A)/passive (P)) and the type of the object (distractor (D)/target (T)). If there is a significant interaction ($p<.05$), a star is present. Counting the number of significant interactions for the group of experiments in *Second Life* there are 7 interactions compared to 28 for the group of experiments with a 2D interface.

One aspect of the findings that has not been researched is the impact of the 3rd person and the 1st person perspective when users are operating an avatar inside 3D environments. There has already been a considerable body of research on the question as to what extent the use of different perspectives influences user behavior in virtual environments, for example in learning scenarios or gaming experiences (e.g. see Salamin, Tadi, Blanke, Vexo, & Thalmann, 2010). In the context of educational purposes, research asked to what extent the 1st person perspective leads to better learning results than the third person perspective. For example Lozano, Hard and Tversky (2006) showed that taking an actor perspective as opposed to an observer perspective when viewing an assembly task (assembling a piece of furniture) resulted in higher proficiency in learning the task when participants were asked to perform the task themselves.

Gaming researchers have demonstrated that if the avatar is shown with the 1st person perspective, it will lead to better engagement from the user because of a more natural optical perspective: the user will have a better natural experience (Hoffman, Haferkamp, Klatt, Lam-Chi, & Kramer, 2012). However experimental results have shown that the 3rd person perspective led to better recall of free recall activities (Lindgren, 2009). Participants had to watch a video that showed an expert using a virtual training simulation. The video was recorded either from the expert's (first-person) perspective or from an objective third-person perspective. Afterwards, participants used the simulation themselves before they had to complete various learning tasks. Participants who watched the video in a third-person perspective performed better during the simulation, free-recall activity and a diagramming task. The virtual world experiments have been conducted with the 3rd perspective; it remains to be explored if any of the experimental results would have changed depending on the avatar perspective to reveal any benefits for episodic memory tasks.

Mirror Neurons

The results in Experiment 6 did not bring the same results as in the other batch of experiments. The definition of embodiment in *Second Life* mentioned in Chapter 5 emphasised that it is "performative" in nature and less about physicality. It was also discussed that *Second Life* has not yet caught up with other interactive virtual tools, which makes it less interesting and powerful for the research undertaken with mirror neurons where a more physical interaction could have had a stronger impact in this experiment.

The mirror neuron experiment has been explorative, but one could bring an interesting spin and set up a condition where the passive participant also has its own avatar inside *Second Life* (passive avatar). The passive avatar would follow the active avatar automatically and the passive participant could observe the scene with its own avatar point of view. This type of experiment would be interesting to study in a social cognition context and a real dissociation between the user and the avatar could be observed. The avatar would have the limitations not the user.

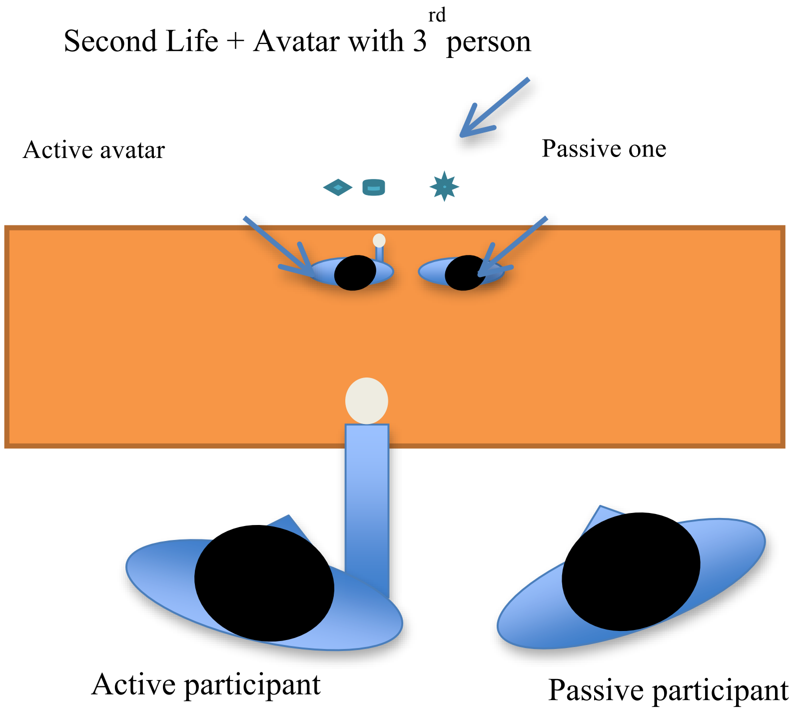

Figure 68. Alternative set up for the mirror neurons experiment, passive participant + his passive avatar in *SL*

Practical Implication of the Research

In his seminal work *Principles of Psychology,* William James (1890) raised the idea of attention training for children proposing it would be "the education by excellence".

> But, whether the attention comes by grace of genius or by dint of will, the longer one does attend to a topic the more mastery of it one has. ... An education which should improve this faculty would be *the* education *par excellence*. (James, 1890, p. 424)

The following section will discuss some possible implications of selective attention and memory in an educational context.

Learning and Memory

The main discovery to realise from the research is the role of action on selective attention during episodic recall. Whilst performing an action, we tend to suppress distractor objects;

whilst this does not enhance target objects, the role of the interference task seems to play an important part in the quality of recall. This section explores the potential application of the results observed in the experiments. One avenue of interest to explore is learning and memory.

Learning and memory are two sides of the same coin (Lieberman, 2012, p. 45). Although one concentrates on the acquisition of knowledge, the other is concerned with its retention. They are both interlinked - to study learning, one must be able to test the acquisition of knowledge on participants, whilst to study memory, one must first expose participants to learning. They are both the product of a unified system of encoding, storing and retrieving information.

A recent report from Technology Enhanced Learning[18] (TEL) has outlined the next vision for education in the UK (2012). This report highlights the fact that we should find innovative ways to teach and assess new skills relevant to the academic world in the 21st century, in the same way as we have been developing new online skills from playing or shopping because of a reluctance to change what is taught and what is learned for new things that matter in the 21st century (e.g. professional life have been transformed by technology) (Noss, 2012, p. 2). One avenue of change is the use of technology, and a shift beyond keyboard and mouse in order to engage students in a different way.

> In order to understand how new technologies can enhance embodied learning; we first of all need to identify the relationship between thoughts and actions. In this respect, concepts that were once considered rather 'abstract,' such as many mathematical ideas, are now being examined in terms of embodiment, raising the possibility of using new technologies to enhance learning in these areas (Manches, 2012, p. 33).

[18] http://tel.ioe.ac.uk/

The above quote identifies an obvious link between thought and actions, highlighting how more active engagement of the learner will have a direct impact on learning and, therefore, memory performance. Images that can be enlarged or reduced by using a “pinching” gesture on a touch screen are an example of similar motor actions and interaction with technology, which can help learning. In this thesis, only weak motor actions have been studied, such as mouse clicks or navigation of the avatar with a computer keyboard, but the results do prove that memory recall (in this case, episodic recall) is affected by the action.

Tim Guerra and Dan Heffernam (2004) have developed an interactive scale with different levels for online user experience (see Figure 69). This scale highlights the level of interactivity with learning materials on a scale of 1 (less active, as in reading a text document) to 10 (to more active user experience that includes more complexity, functionality, and development time, with a virtual reality environment for example). This scale dates back to 2004, and new technologies can also be added onto the scale, such as mobile platforms, augmented reality and so on. However, the principle is clear, and other educationalists have applied this scale to online learning environments like *Moodle* to maintain engagement with students. Guerra and Hefferman highlighted the optimal learning experience between level 4 and 5, probably due to the complexity at the time (2004) of manipulating new emerging tools like virtual worlds and virtual reality. Maybe due to new insights such as the one identified in this thesis, the optimal online user experience could be pushed to higher levels of interactivity and immersion especially since the level of entry to new technology is made easier for non-technical educationalists.

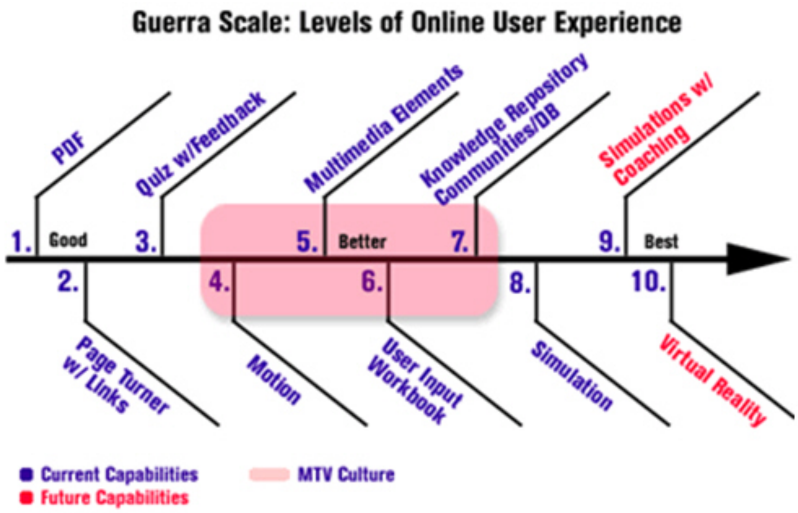

Figure 69. The Guerra Scale

However, some of the reliable effects observed in some experiments did not persist after the interference task, and a mixed set of results were gained. In the context of learning, we are more interested in long-term retention and, so, two examples of cognitive process will be mentioned, that have a practical implication in learning in both the short and long term: the remember/know paradigm shift, often called "schematization" (Conway, Gardiner, Perfect, Anderson, & Cohen, 1997), and the encoding hypothesis (Anderson & Armbruster, 1986).

The remember/know paradigm shift originated from Tulving's proposed distinction between different types of memory systems; semantic and episodic. In a real world situation, this has been applied to learning experience in the classroom. Conway et al. (1997) examined how material processed in specific episodes, such as university lectures, can over a period of learning become conceptual knowledge (semantic) rather than isolated memory episodes (episodic). Two processes are suggested as responsible for the remember-to-know shift; a loss of access to episodic details, and the development of conceptual organisation (Conway et al., 1997; see also Herbert & Burt, 2001). However, it is proposed that students' schematized knowledge of their course material retains some details of memory episodes, rather than simply being an abstract framework in which knowledge has been generalised across specific experiences (Herbet & Burt 2004; Munro, 2007). Using the schematisation process, Herbet and Burt (2004) conducted a research whereby university students were required to either learn material rich in distinctive features that may serve as cues to episodic memory, such as sections of italicised text (targets), or material lacking in these features. After a time delay of a couple of days, students who learned the distinctively rich material were able to recall more detail than those who did not.

Another avenue, which merits exploration, is the encoding hypothesis (the actual process of taking notes helps the note taker learn and remember information, an idea that was first suggested by the educator Seward in 1910). This idea was proposed in a technical report published by Anderson and Armbruster in 1986, which dealt with the value of taking notes during lectures, and which supports their reasoning on conceptual frameworks such as the levels of processing (Craig & Lockhart, 1972) and the transfer of appropriate processing (Morris, Bransford, & Franks, 1977).

One implication of this research is that students can remember more about the main points of a lecture if they take notes during the lecture, rather than merely listening without taking notes. However, this is true only if the note taking is realised under certain conditions - for example, during low cognitive load (information density and presentation rate) - so that it does not interfere with taking notes. Also, the notes taken by students need to entail a deep processing of the input information (e.g. cues outlining the exam questions by the teacher). This application again outlines the fact that being active when learning will help with remembering the key points (targets), a potentially obvious fact but one which is backed up by theoretical research and empirical studies. The information density plays an important role where the ambiguity of the information not the nature of the task may be critical in memory retrieval and the role of the action. For example while attending a lecture in mathematics or chemistry the information is complex and potential to make mistakes are more likely, as there is a high level of distractors, it would be better to be active (writing for example) to suppress irrelevant information. On the other hand a lecture on history with a more linear story would be already "cleaned up" and being passive (listening) could be a better way to retain knowledge.

Another avenue that the research is potentially interesting related to learning is gaming for educational purposes or it can be referred as gamification, which is the use of game elements and game design techniques in non-game contexts (Werbach, 2012). Various behavioural and neural base studies have been conducted on the impact of gaming on cognitive abilities (Bavelier et al., 2102; Green & Bavelier, 2007; Stevens & Bavelier, 2012; Wu et al., 2012). In the context of this thesis it can be noted that some of the results observed for most of the experiments concur in what has been observed in studies linked to selective attention and gaming. For example it has been suggested that action video games players were found to have superior attentional control skills and the ability to exploit more efficiently information while better suppressing distractor tasks (Bavelier et al., 2012; Mishra, Zinni, Bavelier, & Hillyard, 2011). Across seven experiments in this research study there have been no distinctions made between gamers or non-gamers but the suppression of distractors has been largely observed for active participants. Another point worth mentioning is that high attention control skills for participants playing video games is mostly marked for action video games (e.g. *Medal of Honor*, *Call of Duty*, *and Unreal Tournament*) which are highly interactive games and make use of the 3D environment to its full potential. On the other hand the enhancement in attention has not been observed in games such as *Tetris* or *The Sims* (Stevens & Bavelier, 2012), which traditionally use less of the 3D feature available to the game. These latest observations would tend to contradict the results observed for the 2D and 3D tests where selective attention is observed in both environments. Bavelier et al. (2012) have also highlighted the fact that action games play an important role in improving selective attention over space, over time and objects. Here we cannot help but find a close link with the "where", "when" and "what" task for episodic memory. The role in playing games and episodic memory is also mentioned by Kapp (2011, p. 68). Games can help to create strong episodic memory; they have visual and temporal-spatial association to provide a strong and rich association between what the user is doing in the game and his long-term memory. The importance for episodic memory for learning is also to provide a schema for the learner that enables him to recall information and applies his knowledge for a particular application.

Finally, I would like to mention memory and learning, and what initially inspired me to undertake a PhD involving General Artificial Intelligence. In a recent TED talk[19] given by Ken Jennings, who played a challenge match against supercomputer Watson for the US game show Jeopardy in 2011, concerns surrounding the power of machines making our lives and our brains obsolete were presented. As we increasingly rely on our electronic devices, will learning and memory become outmoded functions, or is this an evitable path? After all, learning is not solely about collecting data, but is also about building an efficient and interesting way of thinking using the data.

Limitations of the research

Given the variety of effects explored in this thesis, and the challenges, which have arisen in some parts with regard to explaining certain results, which may be due to the experimental conditions, I will outline possible limitations.

Firstly, in order to produce a more effective cross-experimental study, more consistency across all experiments is needed - specifically, for example, with objects, the interference task, exposure time between each slides, location of testing and time, participant age groups and skills in gaming.

In Experiments 1 and 2, the basic technology used to perform the test - i.e. a *PowerPoint* presentation and manual data input for scoring purposes - may have led to human error.

[19] www.ted.com/talks/ken_jennings_watson_jeopardy_and_me_the_obsolete_know_it_all.ht

Additionally, memory tests were performed over a wider age group than in other experiments; tests were taken at different times of the day, at a variety of locations, where participants were not always at their best to perform. In addition, participants also had varying degrees of exposure to the cognitive tests, compared to the psychology students used in the subsequent tests, as they were already familiar with these types of tests. The naming convention used during the free recall with similar objects may have produced errors - in Experiments 1 and 2, the choice of objects was made randomly and some had similarities in terms of affordance (Gibson, 1977). For example, a chair, an armchair and a bench or backpack and bag objects were used, making the free recall more difficult to score. This was rectified in the following experiments by using the Snodgrass and Vanderwart database.

On the subject of virtual worlds, improvements were made in the *Second Life* set up in Experiment 7, such as new location cues for objects, substitution of some of the prims and trimming of temporal data. One piece of information could have been improved, as the temporal component was the hardest to remember due to the fact that the given cues “begin” and “end” for the test were difficult to encode, tricky to explain to participants and not reliable. An alternative method would have been to present a distractor event such as “flash” to participants during the test sequence, and to ask them during retrieval whether they saw the objects before or after the “flash” like it was set up in Experiment 1 and 2. Another major issue observed in *SL* was the lack of ready-made communication tools available to connect with the external “world”, as with the psychology software *Eprime* used in the 2D experiments, which records participant responses and provides export files ready-made for statistical analysis. To carry this out in *SL,* one could have used a parcel region scanner that allowed the export of data as a comma-separated values (csv) file - for example, some modifiable scripts already exist and can be bought in the *SL* online shop. This modified tool would have given an output of the parcels/plots of the region with additional information about prims and owner, etc., and would have allowed the export of the sequence of objects, the location of objects with "xyz" coordinates, as well as the names of the objects. This method would avoid the need for manual scoring for each participant, therefore reducing possible human error as in the free recall test in Experiments 1 and 2. However, in order to take it to another level, the use of an alternative 3D gaming engine like *Unity3D* would be a possibility and a recommended move, as it is a more flexible tool with which to explore the 3D environment, as already discussed in the section about Artificial Intelligence. This tool allows better graphic physics, but can mostly be used as a stand-alone tool without network connection preventing network downtime or delay. The learning curve for *Unity3D* would be steep, but would be worth the effort in the long run in order to carry out cognitive tests with a better ecological validity (closer representation of the real world).

The mixed results obtained in passive and active mode during the delayed recall can be explained as one of the limitations of the study, and it may be that the interference task given to participants was not as effective as it should have been. A longer timescale for the experiment could be a possibility, as the average time for each experiment was about 30-40minutes. Performing the tests over a period of a few days would have shown clearer results for the delayed recall memory test. However, one would have needed to design experiments with better contexts, such as with a story or learning motives, so that participants could better remember cues. Shapes which have no meanings attached to them would not be an effective method for encoding on a longer timescale, and similar ideas were discussed in the above chapter on taking notes during classes.

The idea of using 3D environments or action video games is appealing, and despite the fact that games are certainly effective teaching tools, they are also very complex and can make it difficult to derive and test underlying learning principles. Using simpler, easier to characterise tasks like 2D interface tools, to ask how the computational demands of the learning environment influence the generality/specificity of learning and the depth of learning is recommended (Green, 2013). Therefore careful care in the design of cognitive tests inside a gaming environment is necessary if this avenue was to be explored in future research.

Finally, there is a wealth of other data that has not been investigated such as gender, response time or calculation of d-prime[20]. This data could raise more information relevant to the thesis.

[20] Sensitivity which refers to an observer's ability to discriminate between two different stimuli (signal or noise) and incorporates both 'false-alarm' and 'hit' rates

Conclusion

Coming back to the early stage of my research, I set up the initial research in an explanatory fashion to investigate episodic memory within different types of retrieval environment and the role of an action upon memory. As things started to develop I presented a new method of assessing episodic-like memory based on Kantian foundations. I have then applied this method not only across different types of environments but more importantly I have investigated selective attention using episodic memory tasks and what could be the importance of its individual components. This novel approach led to many consistent results usually observed in traditional attention tasks. I have observed inhibitory effects linked to the role of the action, as well as a possible effect on the role of an interference task.

There was no major impact of replicating the experiment inside a virtual world compared to traditional 2D interfaces. Nevertheless it allowed us to put forward the impact of individual components such as spatial location in episodic recall. The results would imply that 3D environments have replicated to a great extent what has been accomplished with the 2D experimental results proving that virtual worlds can be used as a valid platform to perform cognitive tasks. It remains for future work to take into account the limitation of the research to further investigate the results observed to explore the full potential of virtual environments and their impacts on learning and memory.

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APPENDICES

Appendix A – Summary tables for all experiments

Appendix B – *Second Life* scripts

Appendix C – List of all objects used in experiments

Appendix D – Distractor task

Appendix E – Latin squares

Appendix F – False alarms count in all experiments

Appendix G – Summary of all experiments

Appendix H – Table of main effects and interactions

Appendix A

Table 2: Summary of experiment changes

Exp	**Part**	**Background**	**Recall object identity**	**Object sets**	**Fix delay (passive)**	**Time marker (slide)**	**Interference task**
1	Solo	2D	Free	Set 1	5s	Yes	Immediate test (2D or 3D)
2	Solo	3D	Free	Set 1	5s	Yes	Immediate test (2D or 3D)
3	Solo	None	Rec	Set 2	5s	No	Arithmetic test
4	Solo	None	Cue	Set 2	5s	No	Arithmetic test
5	Solo	*Second Life* Colour floor	Cue	Set 3	10s	No	Arithmetic test
6	Duo	*Second Life* Colour floor	Cue	Set 4	10s	No	Arithmetic test
7	Solo	*Second Life* Cylinders & white floor	Cue	Set 4	20s	No	Arithmetic test

- Each participant (passive and active) followed the same set of verbal instructions before testing (only difference was to use the keyboard an mouse for the active participants)
- Objects: different set of objects
- Delay: delay between each pair of objects (before moving to the next set of objects automatically)

Table 3: Suppression and enhancement of object recalls + role of the interference task

	Immediate Recall				**Delayed Recall**				**Interference Task**			
	A.P (1)		**D.T (2)**		**A.P (1)**		**D.T (2)**					
	D	T	A	P	D	T	A	P	D.A	D.P	T.A	T.P
Exp1												
EM	*	-	*	-	-	*	*	-	-	*	-	*
What	*	-	*	-	-	*	*	-	-	*	-	*
Where	*	-	*	-	-	*	*	-	-	*	-	*
When	*	*	*	-	-	*	*	-	-	*	-	-
Exp2												
EM	*	-	*	-	*	-	*	-	-	-	-	-
What	*	-	*	*	-	-	*	*	-	-	*	*
Where	*	-	*	*	*	-	*	-	-	-	*	-
When	*	-	*	*	-	-	*	-	*	-	-	-
Exp3												
EM	*	-	*	-	-	-	-	-	*	*	*	*
What	*	*	*	*	*	-	*	-	-	-	-	-
Where	-	-	*	*	-	-	*	*	*	*	*	*
When	-	-	-	-	-	-	*	-	-	-	-	*
Exp4												
EM	-	-	*	-	-	-	-	*	*	*	*	*
What	*	-	*	-	-	-	*	-	-	*	-	-
Where	*	-	*	-	-	-	-	*	*	*	*	*
When	-	-	-	-	-	-	-	-	*	*	-	-
Exp5												
EM	*	-	*	-	-	-	-	-	-	*	-	-
What	*	-	*	-	-	*	-	-	-	-	*	-
Where	*	*	-	-	-	*	-	*	-	*	-	-
When	*	-	*	-	-	-	-	-	-	-	*	*
Exp6												
EM	-	-	*	-	-	-	-	-	-	-	-	-
What	*	-	*	*	-	-	*	-	-	-	*	-
Where	-	-	*	-	-	-	*	-	-	-	-	-
When	-	-	-	*	-	-	*	-	-	-	-	*
Exp 7												
EM	*	-	*	-	-	-	*	-	-	-	-	-
What	*	-	*	*	-	-	-	-	*	-	-	-
Where	*	-	*	-	-	-	*	-	-	-	-	-
When	*	-	*	-	-	-	-	-	-	-	-	-

This table can be read as: In Exp7 during immediate recall for full episodic memory. Distraction suppression comparing the type of mode and poorer recall performance of distractors compared to target objects for the active mode.

Distractor suppression and performance (selection) * Target enhancement * Trend distractor suppression (p<.06), * Three-way interactions

Table 4: Interference task (immediate-delay) main effects

	Em1	**Em2**	**What1**	**What2**	**Where1**	**Where2**	**When1**	**When2**
1	10%	6%	19.5%	12%	14%	6.8%	n/a	n/a
	-4%		**-7.5%**		**-7.2%**		**n/a**	
2	n/a	n/a	18.6%	12.7%	12%	8.5%	n/a	n./a
	n/a		**-5.9%**		**-3.5%**		**n/a**	
3	42.7%	15%	n/a	n/a	60.3%	23.2%	60.3%	52.7%
	-27.7%		**n/a**		**-37.1%**		**-7.6%**	
4	39.5%	12.9%	n/a	n/a	51.1%	23.2%	54%	45%
	-26.6%		**n/a**		**-27.9%**		**-9%**	
5	27.1%	20.7%	72.5%	67.8%	38.7%	32%	48.5%	39%
	-6.4%		**-4.7%**		**-6.7%**		**-9.5%**	
6	n/a	n/a	n/a	n/a	n/a	n/a	46.7%	39.8%
	n/a		**n/a**		**n/a**		**-6.9%**	
7	n/a	n/a	81.3%	75.9%	n/a	n/a	n/a	n/a
	n/a		**-5.4%**		**n/a**		**n/a**	

This table demonstrates the effect of the interference task for full episodic memory (Em) and its individual components (what, where and when). "n/a" refers to no significant effects of the interference task could be observed on accuracy recalls (p<.05). Overall the task had an impact on recall, participants remembered fewer objects after the interference task (arithmetic interference task or just a chat between two experiments (1-2)). In red is the drop in percentage of recall. It can also be noted that the drop due to the interference task is much higher for Experiments 3 and 4 than for the other experiments.

Table 5: Object (Target / Distractor)

	TEM	DEM	TWhat	Dwhat	Twhere	Dwhere	Twhen	Dwhen
1	7.3%	1.3%	n/a	n/a	13.2%	5.1%	12.8%	9.4%
	-6%		**n/a**		**-8.1%**		**-3.4%**	
2	8.4%	3.8%	23.6%	7.3%	12%	8.6%	14.4%	5.2%
	-4.6%		**-16.3%**		**-3.4%**		**-9.2%**	
3	35%	22%	86.3%	74.4%	47.9%	35.5%	60.6%	52.4%
	-13%		**-11.9%**		**-12.4%**		**-7.9%**	
4	28.6%	23.2%	77.4%	65.7%	41.1%	33.1%	n/a	n/a
	-5.4%		**-11.7%**		**-8%**		**n/a**	
5	26%	21.3%	73.7%	66.6%	38.8%	32%	47.5%	40%
	-4.7%		**-7.1%**		**-6.8%**		**-7.5%**	
6	18.2%	15.2%	75.3%	66.5%	29.3%	23.8%	47.8%	38.8%
	-3%		**-8.8%**		**-5.5%**		**-9%**	
7	36%	29.1%	84.1%	73.3%	48.7%	42.5%	57.2%	47.5%
	-6.9%		**-10.8%**		**-6.25**		**-9.7%**	

The above table demonstrate the percentage of recall for distractor and target objects for each component of episodic memory and full recall. From this table it is clear that more targets are remembered than distractors in all experiments. Of course this table doesn't tell anything about the role of action on the type of object.

Table 6: Mode

	PEM	AEM	PWhat	AWhat	PWhere	AWhere	PWhen	AWhen
1	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	n/a		**n/a**		**n/a**		**n/a**	
2	8.1%	4.2%	18%	13.1%	n/a	n/a	13.2%	6.6%
	-3.9%		**-4.9%**		**n/a**		**-6.6%**	
3	n/a	n/a	86%	75%	n/a	n/a	n/a	n/a
	n/a		**-11%**		**n/a**		**n/a**	
4	n/a	n/a	77.8%	65.2%	n/a	n/a	n/a	n/a
	n/a		**-12.6%**		**n/a**		**n/a**	
5	27.5%	20.3%	75.2%	65.1%	40.7%	30%	48.1%	39%
	-7.2%		**-10.1%**		**-10.7%**		**-9.1%**	
6	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	n/a		**n/a**		**n/a**		**n/a**	
7	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	n/a		**n/a**		**n/a**		**n/a**	

In the table labelled "Mode" the influence of the mode on object recall in all experiments is presented for immediate and delayed recall combined. From this it is clear that participants, while passive, recall more objects than participants who are active for most experiments. This of course doesn't show if recall is better for target or distractor objects. This will be shown in the next table.

Table 7: Cross Experiments: Interactions (full EM and object identity component)

	TEM		**DEM**		**TWhat**		**DWhat**	
	Passive	Active	Passive	Active	Passive	Active	Passive	Active
1	5.5%	14%	5.7%	4.6%	16.9%	23.75%	15%	8.1%
	+8.5%		**-1.1%**		**+6.85%**		**-6.9%**	
2	n/a	n/a	6.8%	0.9%	n/a	n/a	11.6%	3.12%
	n/a		**-4.6%**		**n/a**		**-5.72%**	
3	n/a	n/a	28.8%	16.9%	n/a	n/a	10.3%	8.3%
	n/a		**-11.9%**		**n/a**		**-2%**	
4	n/a	n/a	n/a	n/a	n/a	n/a	9.4%	6.8%
	n/a		**n/a**		**n/a**		**- 2.4%**	
5	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	n/a		**n/a**		**n/a**		**n/a**	
6	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	n/a		**n/a**		**n/a**		**n/a**	
7	n/a	n/a	35.6%	22.7%	n/a	n/a	n/a	n/a
	n/a		**-12.9%**		**n/a**		**n/a**	

The first two columns shown on the table represent episodic recall for target and distractor objects (passive vs. active), the last two columns represent object identity for target and distractor objects (passive vs. active). It can be observed target enhancement in Experiment 1 is due to the active mode and not target distraction. This is also shown in Table 3 with the green stars. Distractor suppression is also shown in this table with percentage values in red.

Table 8: Passive vs. active recall means

	D immediate		D delay		T immediate		T delay	
	P	**A**	**P**	**A**	**P**	**A**	**P**	**A**
EM	2.95	1.55	2.75	2.1	3.14	2.6	2.7	3.2
What	6.2	4.7	6.24	6.32	6.6	6.8	6.8	6.74
Where	3.9	2.5	3.7	3.4	4	4.1	3.44	4.34
When	4.5	3.1	4	3.5	5	4.5	4.5	4.24

This table puts forward distractor suppression in all components and full episodic recall for Experiment 7. In grey there is no significant impact of the type of mode for each object. In white there is significant impact of the type of mode for each object.

Appendix B

Second Life Script for Experiment 5, 6 & 7

This code is attached to the prime (the box) via the script interface

```
-----------------------------------------------------------------------------------------------------------------------

//~~Don't change this area below, variables declaration~~

integer start = 0;  //controls what happens at the touch, 0 for start, 1-7 for middle, and 8 for end.

integer setone = 0; //Link number for the even prims.

integer settwo = 0; //Link number for the odd prims.

integer count = 0;

integer step = 0;

list used = []; // used in the report function. to store selected numbers.

list even = [2,4,6,8,10,12,14,16]; //link numbers of the even prims.

list odd =  [3,5,7,9,11,13,15,17]; //Link numbers of the odd prims.

list origin = [];   //Will be used to store the current two Active prims name and position while they are
out

vector test = <-3.61726, -4.50004, 0.00001>; // Start position of the first 8 relative to the box

vector testtwo =  <-4.61726, -4.50005, 0.00001>; // Start position of the second 8 relative to the box

//~~don't change this area above~~

-----------------------------------------------------------------------------------------------------------------------

// Function for generating the random positions relative to the box where the items will be moved to.

vector ranpos()

        {

        vector pos=llGetPos(); // sets the prims current vector to pos.

          pos.x+=llFrand(10.0)-5.0; // uses 'pos' x vector and subtracting a random float value from it

          pos.y+=llFrand(10.0)-5.0; // uses 'pos' x vector and subtracting a random float value from it

          pos = pos - llGetRootPosition(); // subtracts root prims position allowing the linked prims to move
          using the local position

          return pos;

        }

-----------------------------------------------------------------------------------------------------------------------

//Function that makes use of the 'used' list and then
```

Report ()

{

list names = []; ***// Clears the names list***

string indexes = ""; ***// Clears the string 'indexes'***

integer i ; ***//declares the integer i local to the function***

for (i = 0; i < llGetListLength(used);i++) ***// i starts at 0, while it is less then the length of the 'used' list add 1 to i.***

{

// adds the sentence 'item number #' then the number i then 'is a ' then name of the prim that is in the position i in the used list

indexes = indexes

+ " Item number # "

+ (string)(i + 1)

+ " is a "

+ (string)llGetLinkPrimitiveParams(llList2Integer(used,i),[PRIM_NAME])+ "\n";

}

llInstantMessage(llGetOwner(),"\n" + indexes); ***// sends the string value 'indexes' to the prim owner***

}

//Function that randomly picks from the selected list of odd or even and adds it to the used list.

RanDer (list input, integer i)

{

integer num = llList2Integer(llListRandomize(input,1),0); ***// randomly selects an item from the 'input' list and changes it into an integer then sets it to num***

integer index = llListFindList(input,[num]); ***//Checks the position of num in the list 'input' and sets that to index***

used = (used=[]) + used + num; ***// adds the integer num to the 'used' list***

if (llGetListLength(input) != 0) ***// checks if the list 'input' is not empty***

{

if (i == 0)

{

setone = num; ***//sets the value of integer'num' to integer 'setone'***

even = llDeleteSubList(input,index,index); ***//Deletes the entry in 'input' starting at 'index' and ending at index' then sets the updated list to even***

}

```
            else
            {
               settwo = num; //sets the value of integer 'num' to integer 'settwo'
               odd = llDeleteSubList(input,index,index); //Deletes the entry in 'input' starting at 'index' and ending at index'   then sets the updated list to even
            }
         }
      else // if the list 'input' is empty
         {
            llResetScript();
         }
      }
      ------------------------------------------------------------------------------------------------------------------------
      //Function that records the current position of prims out into the list origin.
      Ori ()
      {
         origin = []; // clears the 'origin' list
            vector first = llList2Vector(llGetLinkPrimitiveParams(setone,[PRIM_POSITION]),0); // Sets the global vector of the child prim number 'setone' to vector 'first'
            vector second = llList2Vector(llGetLinkPrimitiveParams(settwo,[PRIM_POSITION]),0); // Sets the global vector of the child prim number 'settwo' to vector 'second'
            origin = (origin=[]) + origin
            + setone
            + ( first - llGetRootPosition() )
            + settwo
            + ( second - llGetRootPosition() );
//Sets the value of 'setone', and first with the Root position subtracted from it, and the value of 'set two', and second with the Root position subtracted from it
      }
      ------------------------------------------------------------------------------------------------------------------------
      ------------------------------------------------------------------------------------------------------------------------
//function that moves the prims into place selected by the Rand
Mover ()
{
      if (llGetListLength(origin) == 0 )
```

```
            {
               Ori();
            }
            else
            {
//set the prim number using entry 0 in the list 'origin' then using entry 1 it sets the prims position and the colour to white.
               llSetLinkPrimitiveParamsFast(llList2Integer(origin,0),
               [PRIM_POSITION,llList2Vector(origin,1),
               PRIM_COLOR,ALL_SIDES,<1,1,1>,0.0] );
//set the prim number using entry 2 in the list 'origin' then using entry 3 it sets the prims position and the colour to white.
               llSetLinkPrimitiveParamsFast(llList2Integer(origin,2),
               [PRIM_POSITION,llList2Vector(origin,3),
               PRIM_COLOR,ALL_SIDES,<1,1,1>,0.0] );
               Ori();
              }
            start = start + 1; //increments start by 1
            count = 0; //sets the integer count to 0 to be used in the timer
//sets the prim with link number 'setone' to a position from the function ranpos() and applies the colour white to it.

          llSetLinkPrimitiveParamsFast(setone,[PRIM_POSITION,ranpos(),PRIM_COLOR,ALL_SIDES,<1,1,1>,1.0]);
//sets the prim with link number 'setone' to a position from the function ranpos() and applies the colour white to it.
          llSetLinkPrimitiveParamsFast(settwo,[PRIM_POSITION,ranpos(),PRIM_COLOR,ALL_SIDES,<1,1,1>,1.0]);
          llSetTimerEvent( 1.0 ); //starts the timer to run at 1 second intervals.
          firstcheck = FALSE;
}
          ------------------------------------------------------------------------------------------------------------------------
default
          {
            state_entry() // the name of the event that is fired when the prim is reset or started, not dropped on the ground.
            {
```

```
        llSetText("",<1,1,1>,0.0); //clears any hover text that may have been left over.

        integer i; //declares integer i locally.

        for ( i = 2; i <=llGetNumberOfPrims(); i ++ ) // i starts at 2, while it is less then or equal to the number of prims in the link set add 1 to i.

        {

          if ( i <= 9 )

          {

            test = test + <0,1,0>; //adds 1 to the y vector of test

llSetLinkPrimitiveParamsFast(i,[PRIM_POSITION,test,PRIM_COLOR,ALL_SIDES,<1,1,1>,0.0]); //sets the prim with link number 'i' to a position from 'test' and applies the colour white to it and makes it transparent.

          }

          else

          {

            testtwo = testtwo + <0,1,0>; //adds 1 to the y vector of testtwo

llSetLinkPrimitiveParamsFast(i,[PRIM_POSITION,testtwo,PRIM_COLOR,ALL_SIDES,<1,1,1>,0.0]); //sets the prim with link number 'i' to a position from 'testtwo' and applies the colour white to it and makes it transparent.

          }

        }

          llSetAlpha(1.0,ALL_SIDES); //makes the box visible

      }

      touch_start(integer total_number)

      {

        if ( start == 0 )

        {

          llSetText("Active Stage",<1,1,1>,1.0); // set hovertext 'Active stage' in white and visible

          llSetAlpha(0.0,ALL_SIDES); // makes the box transparent

          RanDer(even,0); // inserts the list 'even' and the integer 0 into the function RanDer

          RanDer(odd,1);  // inserts the list 'odd' and the integer 1 into the function RanDer

          Mover(); //Activates the 'mover' function

        }

 // touched prim has the same number as the one presently set in 'setone' and the integer 'start' is less then or equal to 7

        else if ( (llDetectedLinkNumber(0) == setone ) && ( start <= 7 ) )

        {
```

```
        llSetText("Active Stage",<1,1,1>,0.0); // set hovertext 'Active stage' in white and transparent
        RanDer(even,0); // inserts the list 'even' and the integer 0 into the function RanDer
        RanDer(odd,1);  // inserts the list 'odd' and the integer 1 into the function RanDer
        Mover(); //Activates the 'mover' function
      }
      else if ( start == 8)
      {
        Report(); //Activates the report function
        llResetScript();
      }
    }
    timer()
    {
      count = count + 1; //increments count by 1
      if ( count == 10 )
      {
        llSetTimerEvent( 0.0 ); // stops timer
        llSetLinkPrimitiveParamsFast(setone,[PRIM_COLOR,ALL_SIDES,<1,1,1>,1.0]); //sets the
prim with link number 'setone' to the colour white.
        RanDer(even,0); // inserts the list 'even' and the integer 0 into the function RanDer
        RanDer(odd,1);  // inserts the list 'odd' and the integer 1 into the function RanDer
        Mover(); //Activates the 'mover' function
      }
      if ( ( start == 8 )  && ( count == 9 ) ) // when start is 7 and count is 9
      {
        Report(); //Activates the report function
        llResetScript();
      }
      else
      {
        if (step == 0)
        {
          llSetLinkPrimitiveParamsFast(setone,[PRIM_COLOR,ALL_SIDES,<1,1,1>,1.0]); //sets the
prim with link number 'setone' to the colour white.
```

```
                step++; //increments step by 1

            }

        else

            {

                LlSetLinkPrimitiveParamsFast(setone,[PRIM_COLOR,ALL_SIDES,<1,0,0>,1.0]);//sets the prim with link number 'setone' to the colour red.

                step--; //decreases step by 1

            }

          }

        }

      }
```

Extra code for experiment 7 to avoid random location of the objects

```
integer start = 0;  //controls what happens at the touch, 0 for start, 1-7 for middle, and 8 for end.

integer setone = 0; //Link number for the even prims.

integer settwo = 0; //Link number for the odd prims.

integer count = 0;

integer step = 0;

integer firstcheck = FALSE;

integer ale;

float sum;

list used = []; // used in the report function. to store selected numbers.

list even = [2,4,6,8,10,12,14,16]; //link numbers of the even prims.

list odd =  [3,5,7,9,11,13,15,17]; //Link numbers of the odd prims.

list origin = [];   //Will be used to store the current two Active prims name and position while they are out

vector test = <-3.61726, -4.50004, 0.00001>; // Start position of the first 8 relative to the box

vector testtwo =  <-4.61726, -4.50005, 0.00001>; // Start position of the second 8 relative to the box

//~~don't change this area above~~

// Function for generating the random positions relative to the box where the items will be moved to.

vector ranpos()

{

   vector pos=llGetPos(); // sets the prims current vector to pos.

 // uses 'pos' x vector and subtracting a random float value from it

 if (firstcheck == FALSE){
```

```
  firstcheck = TRUE;
   ale = (integer)llFrand(3);
  if (ale == 0){sum = 0.5;}
   if (ale == 1){sum = 1.5;}
   if (ale == 2){sum = -0.5;}
   if (ale == 3){sum = -1.5;}}
   else if (firstcheck == TRUE) {firstcheck = FALSE;
        ale = (integer)llFrand(2);
        if (sum == 0.5){
           if (ale == 0){sum = 1.5;}
   if (ale == 1){sum = -1.5;}
   if (ale == 2){sum = -0.5;}
            }
             else if (sum == 1.5){
           if (ale == 0){sum = -0.5;}
   if (ale == 1){sum = -1.5;}
   if (ale == 2){sum = 0.5;}
            }
             else if (sum == -0.5){
           if (ale == 0){sum = 1.5;}
   if (ale == 1){sum = -1.5;}
   if (ale == 2){sum = 0.5;}
            }
             else if (sum == -1.5){
           if (ale == 0){sum = 1.5;}
   if (ale == 1){sum = 0.5;}
   if (ale == 2){sum = -0.5;}
            }
        }
   pos.y+=sum*2  // uses 'pos' x vector and subtracting a random float value from it
   pos = pos - llGetRootPosition(); // subtracts root prims position allowing the linked prims to move using the local position
return pos;
```

Appendix C

Table 9: Experiments 1 & 2

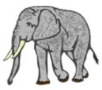
T1: apples 	T2: guitar 	T3: backpack 	T4: bag 
T5: knife 	T6: bench 	T7: bicycle 	T8: taxi 
T9: champagne 	T10: bottle 	T11: keys 	T12: chair 
T13: computer 	T14: eye glasses 	T15: fan 	T16: table lamp 

D1: arm chair 	D2: gun 	D3: hot dog 	D4: jackpot machine 
D5: clock 	D6: bed 	D7: lamp post 	D8: microscope 
D9: palm tree 	D10: pen 	D11: shoes 	D12: statue 
D13: flowers 	D14: table 	D15: bin 	D16: television 

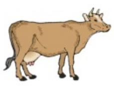
Experiments 3 & 4

Objects presented during immediate recall: Name agree: H.00 %100

D1: Balloon 	D2: Barbell 	D3: Bell 	D4: Book 
D5: Chair 	D6: Fish 	D7: Umbrella 	D8: Sun 

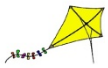
T1: Ashtray 	T2: Banana 	T3: Bed 	T4: Belt 
T5: Crown 	T6: Elephant 	T7: Dress 	T8: Tree 

False Alarms

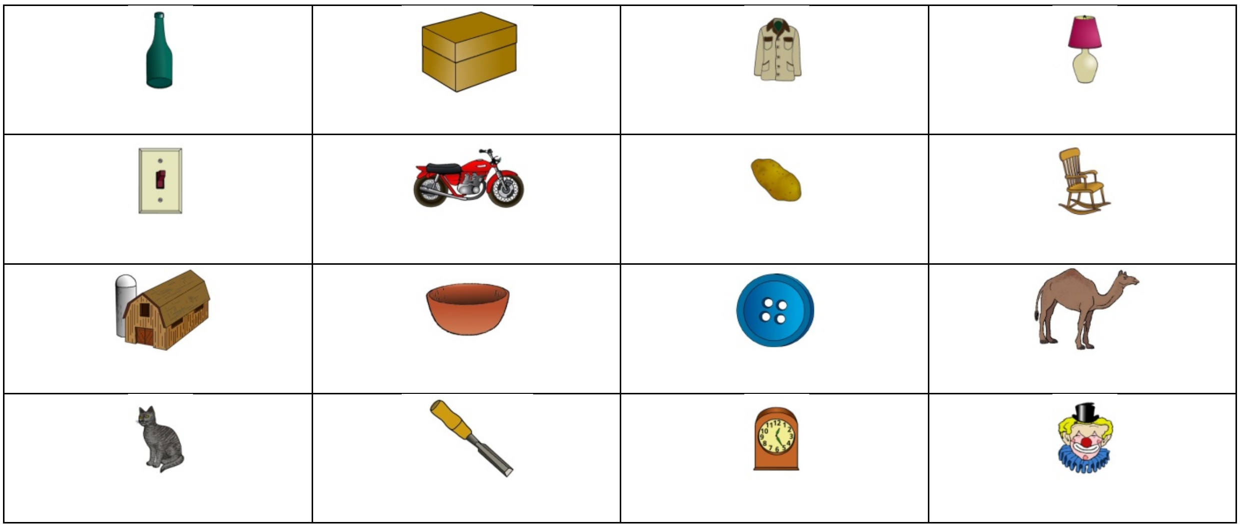
			
			
			
			

Object presented during delayed recall

D9: Hammer	D10: Key	D11: Fork	D12: Rabbit
			
D13: Pen	D14	D15: Sock	D16
			

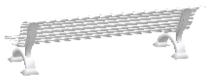
T9: Star	T10: Snow Man	T11: Lemon	T12: Frog
			
T13: Sandwich	T14: Pineapple	T15: Kyte	T16: Butterfly
			

False Alarms



Experiment 5

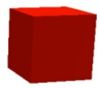
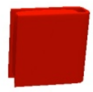
Objects presented during immediate recall

D1: Bench	D2: Femur Bone	D3: Padlock	D4: Cog
			
D5: Pyramid	D6: Bottle	D7	D8: Mushroom
			

T1: Wolf Head	T2: Dolphin	T3: Mexican Hat	T4: Heart
			
T5: Table	T6: Hand	T7: Used Hat	T8: Ladder
			

Object presented during delayed recall

D9: Cylinder 	D10: egg shape 	D11: Wheel 	D12: Chair 
D13: Bath tube 	D14: Bowl 	D15: Balloon 	D16: Prism 

T9: Hammer 	T10: Pen	T11: Bell 	T12: Cube 
T13 	T14: Ring 	T15: Leaf 	T16: Book 

Appendix D

Arithmetic interference task for Experiments 3-7

5x3 + 2+2 =?

8 x3 – 2+2=?

10+1 – 3+1 =?

18-2 + 3+4=?

10-3 -4+1=?

7+3-4x2=?

Appendix E

Latin Square

Trivial example of a 2 x2 Latin Square

A	B
B	A
Time →	

Using the Latin Squares Balanced Block Mixer the series of slides were arranged as.

Table 10: Permutation (Orthogonal Latin Squares Balanced Block Mixer)

TaDa	TbDb	TcDc	TdDd	P1
TbDd	TaDc	TdDb	TcDa	P2
TcDb	TdDa	TaDd	TbDc	P3
TdDc	TcDd	TbDa	TaDb	P4

Active, 2D, LTM, TaDa block

T1			T2	D3			D4
	D1	D2			T3	T4	

Active, 2D, STM, TbDb block

T5					D7	D8	T8
D5		T6	D6		T7		

Active, 3D, LTM, TcDc block *

D9	T9	D10			D11	T12	
			T10	T11			D12

Active, 3D, STM, TdDd block

	D13			T15		D16	T16
	T13	T14	D14	D15			

Figure 70. Participant 1 (P1), basic permutation of slides

Below are other examples of permutations for other participants (P2-P4):

Active, 2D, LTM, TbDd block

T5	D13					D16	T8
		T6	D14	D15	T7		

Active, 2D, STM, TaDc block

T1	D9	D10	T2		D11		
					T3	T4	D12

Active, 3D, LTM, TdDb block

				T15	D7	D8	T16
D5	T13	T14	D6				

Active, 3D, STM, TcDa block

	T9			D3		T12	D4
	D1	D2	T10	T11			

Passive, 2D, LTM, TcDb block

	T9				D7	T12 D8	
D5			T10 D6	T11			

Passive, 2D, STM, TdDa block

				D3	T15		D4 T16
	T13 D1	T14 D2					

Passive, 3D, LTM, TaDd block

T1	D13		T2			D16	
			D14	D15	T3	T4	

Passive, 3D, STM, TbDc block

T5 D9		D10			D11		T8
		T6			T7		D12

Passive, 2D, LTM, TdDc block

D9		D10		T15	D11		T16
	T13	T14					D12

Passive, 2D, STM, TcDd block

	T9 D13					T12 D16	
			T10 D14	T11 D15			

Passive, 3D, LTM, TbDa block

T5				D3			D4 T8
	D1	T6 D2			T7		

Passive, 3D, STM, TaDb block

T1			T2		D7	D8	
D5			D6		T3	T4	

Appendix F

False alarms to total correct responses (hits) ratio for all experiments (Targets + Distractors)

Experiments	Passive Mode	Active Mode
1	29/40	32/59
	72.5%	54.2%
2	30/66	27/44
	45.4%	61.3%
3	28/221	52/316
	12.6%	16.4%
4	45/182	Data unavailable
	24.7%	
5	62/319	64/192
	19.4%	33.3%
6	57/153	50/140
	37.2%	35.7%
7	25/246	39/192
	10.1%	20%

Appendix G

Summary

1. Full episodic recall (Experiment 1 to 7)

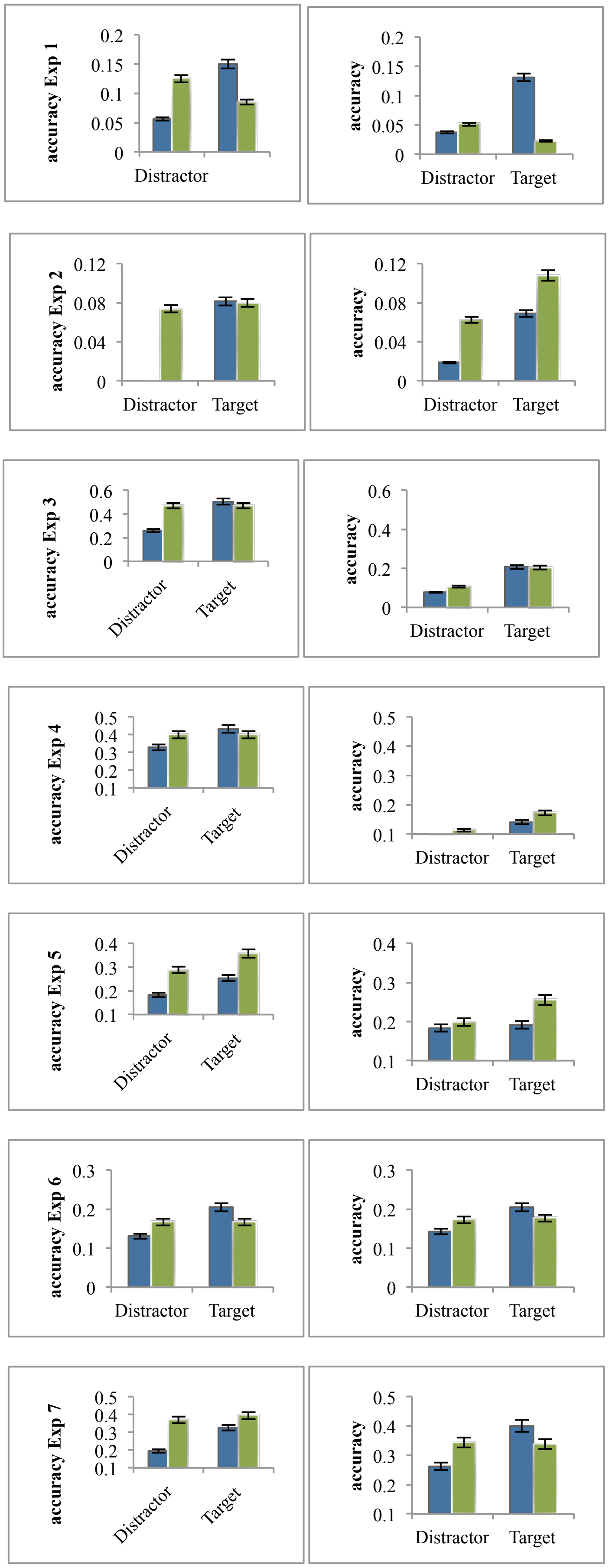
2. Object identity recall (Experiment 1 to 7)

3. Spatial recall (Experiment 1 to 7)

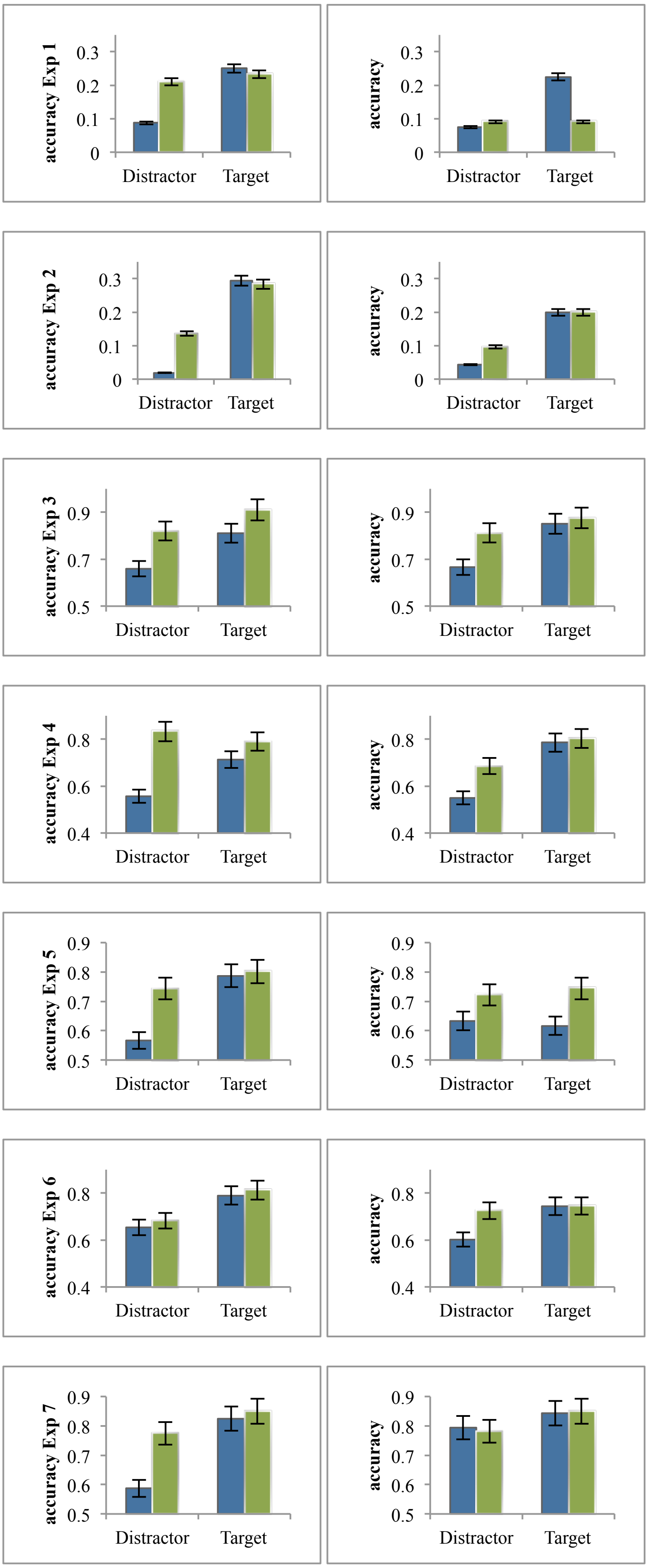
4. Temporal recall (Experiment 1 to 7)

PS: Some legends have been removed for readability: in blue is the active mode; in green is the passive mode.

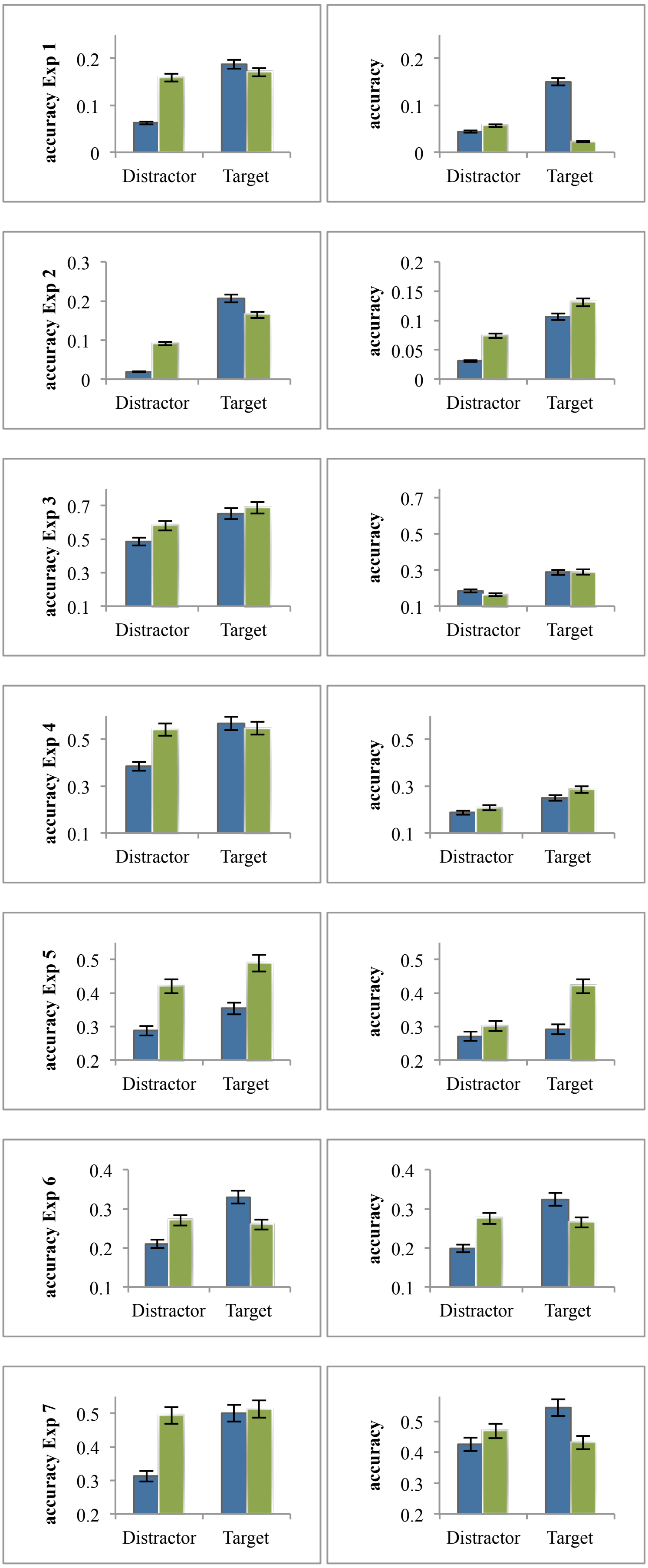
Episodic memory



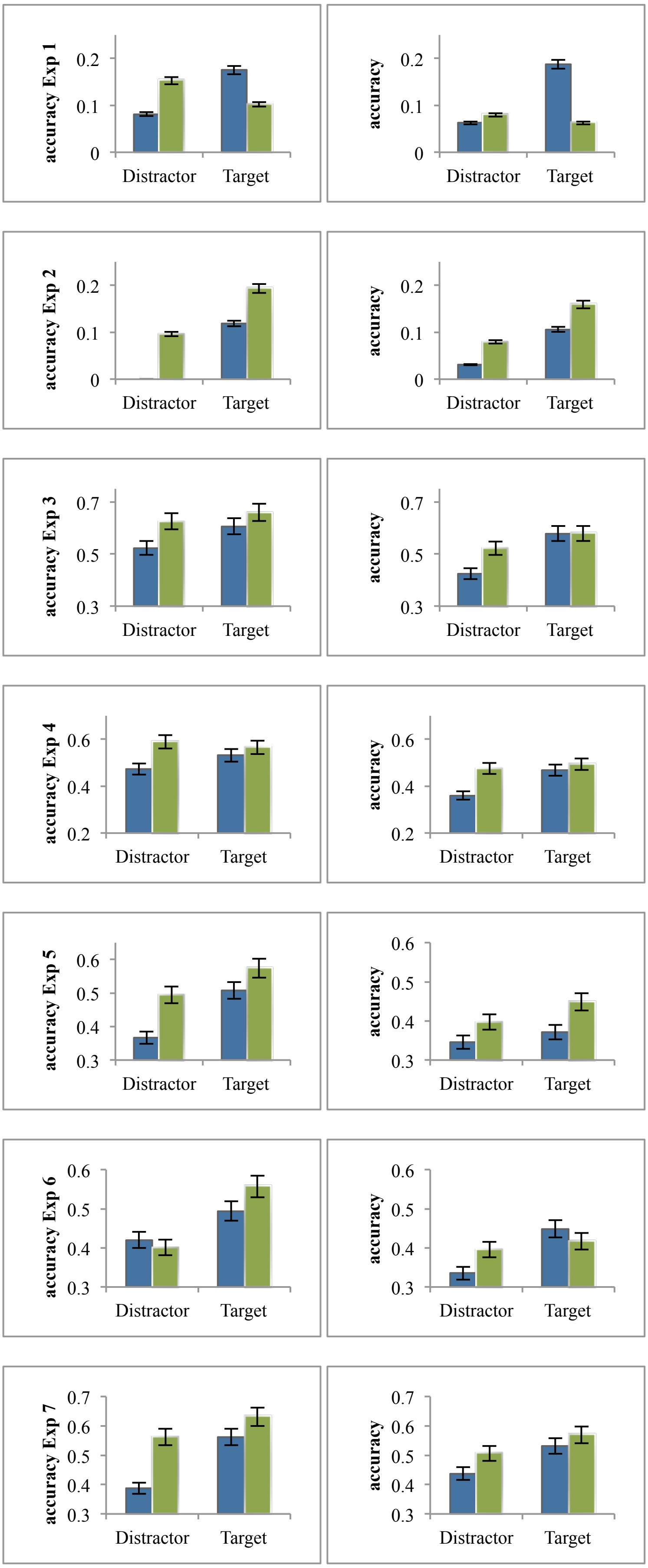
Object identity component



Spatial component



Temporal component



Appendix H

List of all main effects and intercations for all experiements

Experiment 1 (2D)

In all tables

- SL refers to short (S) for immediate recall and long (L) for delay recall *(within subjects)*
- DT refers to distractor (D) and target (T) objects *(within subjects)*
- Mode refers to passive and active mode *(between subjects)*
- Significance level at .05

1) Full episodic memory recall accuracy

Main Effects and Interactions

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
SL	5.067	1	5.067	6.755	.013	.144
SL * Mode	1.638	1	1.638	2.184	.147	.052
Error(SL)	30.005	40	.750			
DT	2.386	1	2.386	4.130	.049	.094
DT * Mode	10.958	1	10.958	18.963	.000	.322
Error(DT)	23.114	40	.578			
SL * DT	.022	1	.022	.062	.805	.002
SL * DT * Mode	.022	1	.022	.062	.805	.002
Error(SL*DT)	13.955	40	.349			
Mode	1.385	1	1.385	2.165	.149	.051
Error	25.591	40	.640			

2) What component

Main Effects and Interactions

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
SL	14.972	1	14.972	15.758	.000	.283
SL * Mode	8.400	1	8.400	8.841	.005	.181
Error(SL)	38.005	40	.950			
DT	18.837	1	18.837	16.718	.000	.295
DT * Mode	14.075	1	14.075	12.492	.001	.238
Error(DT)	45.068	40	1.127			
SL * DT	.208	1	.208	.329	.569	.008
SL * DT * Mode	.018	1	.018	.028	.869	.001
Error(SL*DT)	25.268	40	.632			
Mode	.026	1	.026	.028	.869	.001
Error	37.950	40	.949			

3) Where component

Main Effects and Interactions						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
SL	15.721	1	15.721	15.628	.000	.281
SL * Mode	6.292	1	6.292	6.255	.017	.135
Error(SL)	40.238	40	1.006			
DT	7.288	1	7.288	10.068	.003	.201
DT * Mode	10.812	1	10.812	14.936	.000	.272
Error(DT)	28.956	40	.724			
SL * DT	.691	1	.691	1.424	.240	.034
SL * DT * Mode	.120	1	.120	.246	.622	.006
Error(SL*DT)	19.410	40	.485			
Mode	.201	1	.201	.242	.626	.006
Error	33.328	40	.833			

4) When component

Main Effects and Interactions						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
SL	2.409	1	2.409	2.557	.118	.060
SL * Mode	1.933	1	1.933	2.051	.160	.049
Error(SL)	37.692	40	.942			
DT	3.800	1	3.800	3.969	.053	.090
DT * Mode	13.800	1	13.800	14.412	.000	.265
Error(DT)	38.301	40	.958			
SL * DT	.716	1	.716	1.633	.209	.039
SL * DT * Mode	.001	1	.001	.003	.956	.000
Error(SL*DT)	17.528	40	.438			
Mode	1.974	1	1.974	2.221	.144	.053
Error	35.556	40	.889			

Experiment 1 (3D)

In all tables

- SL refers to short (S) for immediate recall and long (L) for delay recall *(within subjects)*
- DT refers to distractor (D) and target (T) objects *(within subjects)*
- Mode refers to passive and active mode *(between subjects)*
- Significance level at .05

1) Full episodic memory recall accuracy

Main Effects and Interactions

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
SL	.130	1	.130	.233	.632	.006
SL * Mode	.273	1	.273	.489	.489	.012
Error(SL)	22.328	40	.558			
DT	9.141	1	9.141	14.307	.001	.263
DT * Mode	.141	1	.141	.220	.641	.005
Error(DT)	25.556	40	.639			
SL * DT	.304	1	.304	.909	.346	.022
SL * DT * Mode	.066	1	.066	.198	.659	.005
Error(SL*DT)	13.392	40	.335			
Mode	7.130	1	7.130	8.607	.006	.177
Error	33.137	40	.828			

2) What component

Main Effects and Interactions

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
SL	8.486	1	8.486	12.906	.001	.244
SL * Mode	.105	1	.105	.159	.692	.004
Error(SL)	26.300	40	.657			
DT	70.819	1	70.819	51.693	.000	.564
DT * Mode	3.771	1	3.771	2.753	.105	.064
Error(DT)	54.800	40	1.370			
SL * DT	6.403	1	6.403	13.430	.001	.251
SL * DT * Mode	1.832	1	1.832	3.842	.057	.088
Error(SL*DT)	19.073	40	.477			
Mode	6.109	1	6.109	7.785	.008	.163
Error	31.391	40	.785			

3) Where component

Main Effects and Interactions						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
SL	3.222	1	3.222	4.707	.036	.105
SL * Mode	.222	1	.222	.324	.573	.008
Error(SL)	27.380	40	.684			
DT	2.813	1	2.813	5.210	.028	.115
DT * Mode	1.527	1	1.527	2.829	.100	.066
Error(DT)	21.598	40	.540			
SL * DT	25.913	1	25.913	23.725	.000	.372
SL * DT * Mode	2.913	1	2.913	2.667	.110	.062
Error(SL*DT)	43.689	40	1.092			
Mode	1.601	1	1.601	1.595	.214	.038
Error	40.143	40	1.004			

4) When component

Main Effects and Interactions						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
SL	.176	1	.176	.239	.628	.006
SL * Mode	.819	1	.819	1.111	.298	.027
Error(SL)	29.467	40	.737			
DT	22.933	1	22.933	25.791	.000	.392
DT * Mode	.052	1	.052	.058	.810	.001
Error(DT)	35.567	40	.889			
SL * DT	.620	1	.620	1.253	.270	.030
SL * DT * Mode	.120	1	.120	.242	.626	.006
Error(SL*DT)	19.785	40	.495			
Mode	12.416	1	12.416	14.107	.001	.261
Error	35.203	40	.880			

Experiment 3 (recognition)

In all tables

- SL refers to short (S) for immediate recall and long (L) for delay recall *(within subjects)*
- DT refers to distractor (D) and target (T) objects *(within subjects)*
- Mode refers to passive and active mode *(between subjects)*
- Significance level at .05

1) Full episodic memory recall accuracy

Main Effects and Interactions

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
SL	3.717	1	3.717	90.721	.000	.659
SL * Mode	.072	1	.072	1.750	.192	.036
Error(SL)	1.926	47	.041			
DT	.674	1	.674	33.530	.000	.416
DT * Mode	.235	1	.235	11.686	.001	.199
Error(DT)	.945	47	.020			
SL * DT	.001	1	.001	.060	.807	.001
SL * DT * Mode	.137	1	.137	7.415	.009	.136
Error(SL*DT)	.866	47	.018			
Mode	.127	1	.127	1.917	.173	.039
Error	3.115	47	.066			

2) What component

Main Effects and Interactions

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
SL	.001	1	.001	.026	.873	.001
SL * Mode	.029	1	.029	1.093	.301	.023
Error(SL)	1.263	47	.027			
DT	.688	1	.688	21.692	.000	.316
DT * Mode	.099	1	.099	3.130	.083	.062
Error(DT)	1.491	47	.032			
SL * DT	.001	1	.001	.044	.834	.001
SL * DT * Mode	.013	1	.013	.512	.478	.011
Error(SL*DT)	1.153	47	.025			
Mode	.577	1	.577	8.425	.006	.152
Error	3.220	47	.069			

3) Where component

Main Effects and Interactions						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
SL	6.682	1	6.682	134.115	.000	.740
SL * Mode	.070	1	.070	1.396	.243	.029
Error(SL)	2.342	47	.050			
DT	.745	1	.745	22.596	.000	.325
DT * Mode	.005	1	.005	.156	.694	.003
Error(DT)	1.550	47	.033			
SL * DT	.005	1	.005	.271	.605	.006
SL * DT * Mode	.023	1	.023	1.174	.284	.024
Error(SL*DT)	.930	47	.020			
Mode	.041	1	.041	.644	.426	.014
Error	2.984	47	.063			

4) When component

Main Effects and Interactions						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
SL	.285	1	.285	9.995	.003	.175
SL * Mode	.010	1	.010	.343	.561	.007
Error(SL)	1.342	47	.029			
DT	.324	1	.324	10.567	.002	.184
DT * Mode	.064	1	.064	2.083	.156	.042
Error(DT)	1.442	47	.031			
SL * DT	.026	1	.026	1.061	.308	.022
SL * DT * Mode	.007	1	.007	.273	.604	.006
Error(SL*DT)	1.140	47	.024			
Mode	.193	1	.193	2.395	.128	.048
Error	3.780	47	.080			

Experiment 4 (cue)

In all tables

- SL refers to short (S) for immediate recall and long (L) for delay recall *(within subjects)*
- DT refers to distractor (D) and target (T) objects *(within subjects)*
- Mode refers to passive and active mode *(between subjects)*
- Significance level at .05

1) Full episodic memory recall accuracy

Main Effects and Interactions

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
SL	3.047	1	3.047	96.294	.000	.691
SL * Mode	.001	1	.001	.033	.856	.001
Error(SL)	1.361	43	.032			
DT	.130	1	.130	6.531	.014	.132
DT * Mode	.026	1	.026	1.312	.258	.030
Error(DT)	.858	43	.020			
SL * DT	.000	1	.000	.008	.927	.000
SL * DT * Mode	.035	1	.035	1.909	.174	.043
Error(SL*DT)	.785	43	.018			
Mode	.025	1	.025	.477	.494	.011
Error	2.221	43	.052			

2) What component

Main Effects and Interactions

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
SL	.013	1	.013	.327	.571	.008
SL * Mode	.117	1	.117	2.856	.098	.062
Error(SL)	1.765	43	.041			
DT	.613	1	.613	19.535	.000	.312
DT * Mode	.275	1	.275	8.752	.005	.169
Error(DT)	1.350	43	.031			
SL * DT	.160	1	.160	6.563	.014	.132
SL * DT * Mode	.019	1	.019	.785	.381	.018
Error(SL*DT)	1.047	43	.024			
Mode	.710		.710	7.786	.008	.153
Error	3.924	43	.091			

3) Where component

Main Effects and Interactions						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
SL	3.488	1	3.488	88.230	.000	.672
SL * Mode	.016	1	.016	.392	.534	.009
Error(SL)	1.700	43	.040			
DT	.292	1	.292	13.476	.001	.239
DT * Mode	.068	1	.068	3.155	.083	.068
Error(DT)	.932	43	.022			
SL * DT	.008	1	.008	.379	.541	.009
SL * DT * Mode	.108	1	.108	5.101	.029	.106
Error(SL*DT)	.911	43	.021			
Mode	.110	1	.110	1.653	.205	.037
Error	2.854	43	.066			

4) When component

Main Effects and Interactions						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
SL	.366	1	.366	10.253	.003	.193
SL * Mode	.000	1	.000	.004	.948	.000
Error(SL)	1.535	43	.036			
DT	.072	1	.072	2.651	.111	.058
DT * Mode	.083	1	.083	3.059	.087	.066
Error(DT)	1.173	43	.027			
SL * DT	.025	1	.025	.878	.354	.020
SL * DT * Mode	.000	1	.000	.011	.918	.000
Error(SL*DT)	1.205	43	.028			
Mode	.238	1	.238	2.916	.095	.063
Error	3.513	43	.082			

Effect on including one outlier for the full episodic recall

Main Effects and Interactions						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
SL	3.340	1	3.340	92.666	.000	.678
SL * Mode	.010	1	.010	.267	.608	.006
Error(SL)	1.586	44	.036			
DT	.150	1	.150	7.459	.009	.145
DT * Mode	.035	1	.035	1.728	.195	.038
Error(DT)	.887	44	.020			
SL * DT	.002	1	.002	.127	.723	.003
SL * DT * Mode	.023	1	.023	1.172	.285	.026
Error(SL*DT)	.859	44	.020			
Mode	.003	1	.003	.050	.823	.001
Error	2.768	44	.063			

Comparison between 3-4, What component

Main Effects and Interactions							
Mode	Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
	SL	.038	1	.038	.867	.356	.017
	SL * Exp	.002	1	.002	.049	.825	.001
	Error(SL)	2.148	49	.044			
	DT	1.644	1	1.644	33.312	.000	.405
Active	DT * Exp	.012	1	.012	.247	.622	.005
	Error(DT)	2.418	49	.049			
	SL * DT	.046	1	.046	1.313	.257	.026
	SL * DT * Exp	.004	1	.004	.122	.729	.002
	Error(SL*DT)	1.702	49	.035			
	Exp	0.473	1	0.473	4.533	0.38	.085
	Error	5.116	49	.104			
	SL	.101	1	.101	4.697	.036	.103
	SL * Exp	.017	1	.017	.803	.376	.019
	Error(SL)	.880	41	.021			
	DT	.136	1	.136	13.201	.001	.244
Passive	DT * Exp	.013	1	.013	1.289	.263	.030
	Error(DT)	.423	41	.010			
	SL * DT	.051	1	.051	4.208	.047	.093
	SL * DT * Exp	.090	1	.090	7.437	.009	.154
	Error(SL*DT)	.498	41	.012			
	Exp	.273	1	.273	5.515	.024	.119
	Error	2.028	41	0.49			

Experiment 5 (Second Life)

In all tables

- SL refers to short (S) for immediate recall and long (L) for delay recall *(within subjects)*
- DT refers to distractor (D) and target (T) objects *(within subjects)*
- Mode refers to passive and active mode *(between subjects)*
- Significance level at .05

1) Full episodic memory recall accuracy

Main Effects and Interactions

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
SL	13.276	1	13.276	6.338	.015	.112
SL * Mode	3.468	1	3.468	1.656	.204	.032
Error(SL)	104.739	50	2.095			
DT	8.465	1	8.465	8.102	.006	.139
DT * Mode	.427	1	.427	.408	.526	.008
Error(DT)	52.242	50	1.045			
SL * DT	1.108	1	1.108	.631	.431	.012
SL * DT * Mode	.531	1	.531	.302	.585	.006
Error(SL*DT)	87.830	50	1.757			
Mode	17.052	1	17.052	5.390	0.24	.097
Error	158.193	50	3.164			

2) What component

Main Effects and Interactions

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
SL	6.854	1	6.854	4.739	.034	.087
SL * Mode	.123	1	.123	.085	.772	.002
Error(SL)	72.314	50	1.446			
DT	16.346	1	16.346	9.130	.004	.154
DT * Mode	3.154	1	3.154	1.762	.190	.034
Error(DT)	89.514	50	1.790			
SL * DT	14.979	1	14.979	7.324	.009	.128
SL * DT * Mode	8.402	1	8.402	4.108	.048	.076
Error(SL*DT)	102.266	50	2.045			
Mode	33.672	1	33.672	10.622	.002	.175
Error	158.496	50	3.170			

3) Where component

Main Effects and Interactions						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
SL	14.441	1	14.441	4.700	.035	.086
SL * Mode	2.383	1	2.383	.776	.383	.015
Error(SL)	153.617	50	3.072			
DT	15.358	1	15.358	10.978	.002	.180
DT * Mode	2.031	1	2.031	1.452	.234	.028
Error(DT)	69.950	50	1.399			
SL * DT	.006	1	.006	.003	.958	.000
SL * DT * Mode	1.910	1	1.910	.935	.338	.018
Error(SL*DT)	102.071	50	2.041			
Mode	36.943	1	36.943	6.767	.012	.119
Error	272.980	50	5.460			

4) When component

Main Effects and Interactions						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
SL	29.313	1	29.313	14.170	.000	.221
SL * Mode	.813	1	.813	.393	.534	.008
Error(SL)	103.433	50	2.069			
DT	17.955	1	17.955	9.123	.004	.154
DT * Mode	.263	1	.263	.134	.716	.003
Error(DT)	98.405	50	1.968			
SL * DT	4.274	1	4.274	1.909	.173	.037
SL * DT * Mode	1.582	1	1.582	.707	.405	.014
Error(SL*DT)	111.933	50	2.239			
Mode	21.201	1	21.201	7.728	.008	.134
Error	137.160	50	2.743			

Experiment 6 (Second Life)

In all tables

- SL refers to short (S) for immediate recall and long (L) for delay recall *(within subjects)*
- DT refers to distractor (D) and target (T) objects *(within subjects)*
- Mode refers to passive and active mode *(between subjects)*
- Significance level at .05

1) Full episodic memory recall accuracy

Main Effects and Interactions

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
SL	.134	1	.134	.074	.786	.002
SL * Mode	.003	1	.003	.002	.966	.000
Error(SL)	79.111	44	1.798			
DT	3.681	1	3.681	3.884	.055	.081
DT * Mode	3.159	1	3.159	3.334	.075	.070
Error(DT)	41.694	44	.948			
SL * DT	.007	1	.007	.011	.917	.000
SL * DT * Mode	.050	1	.050	.079	.780	.002
Error(SL*DT)	28.194	44	.641			
Mode	4.117E-005		4.117E-005	.000	.996	.000
Error	88.853	44	2.019			

2) What component

Main Effects and Interactions

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
SL	3.880	1	3.880	1.615	.210	.035
SL * Mode	1.598	1	1.598	.665	.419	.015
Error(SL)	105.728	44	2.403			
DT	30.380	1	30.380	16.872	.000	.277
DT * Mode	2.011	1	2.011	1.117	.296	.025
Error(DT)	79.228	44	1.801			
SL * DT	2.935	1	2.935	2.335	.134	.050
SL * DT * Mode	1.566	1	1.566	1.246	.270	.028
Error(SL*DT)	55.304	44	1.257			
Mode	7.091	1	7.091	2.191	.146	.047
Error	142.387	44	3.236			

3) Where component

Main Effects and Interactions						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
SL	.008	1	.008	.004	.951	.000
SL * Mode	.139	1	.139	.065	.799	.001
Error(SL)	93.106	44	2.116			
DT	9.173	1	9.173	6.202	.017	.124
DT * Mode	12.912	1	12.912	8.731	.005	.166
Error(DT)	65.072	44	1.479			
SL * DT	.006	1	.006	.006	.941	.000
SL * DT * Mode	.006	1	.006	.006	.941	.000
Error(SL*DT)	47.239	44	1.074			
Mode	.020	1	.020	.005	.943	.000
Error	166.833	44	3.792			

4) When component

Main Effects and Interactions						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
SL	14.042	1	14.042	5.103	.029	.104
SL * Mode	.042	1	.042	.015	.902	.000
Error(SL)	121.072	44	2.752			
DT	24.411	1	24.411	12.370	.001	.219
DT * Mode	.020	1	.020	.010	.920	.000
Error(DT)	86.833	44	1.973			
SL * DT	1.680	1	1.680	.928	.341	.021
SL * DT * Mode	5.637	1	5.637	3.114	.085	.066
Error(SL*DT)	79.652	44	1.810			
Mode	.951	1	.951	.334	.566	.008
Error	125.163	44	2.845			

5) Effect before removing four variables on the full episodic recall (no DT*Mode interaction)

Main Effects and Interactions

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
SL	.000	1	.000	.000	.994	.000
SL * Mode	.080	1	.080	.037	.848	.001
Error(SL)	103.420	48	2.155			
DT	9.071	1	9.071	7.086	.011	.129
DT * Mode	1.231	1	1.231	.962	.332	.020
Error(DT)	61.449	48	1.280			
SL * DT	.074	1	.074	.090	.765	.002
SL * DT * Mode	.074	1	.074	.090	.765	.002
Error(SL*DT)	39.346	48	.820			
Mode	.477	1	.477	.189	.665	.004
Error	120.843	48	2.518			

6) Cross Experiment 5-6

Main Effects and Interactions

Mode	Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
	SL	.531	1	.531	.258	.614	.005
	SL * Exp	1.108	1	1.108	.539	.466	.011
	Error(SL)	102.830	50	2.057			
	DT	9.434	1	9.434	8.105	.006	.139
Active	DT * Exp	.664	1	.664	.571	.453	.011
	Error(DT)	58.196	50	1.164			
	SL * DT	1.108	1	1.108	.882	.352	.017
	SL * DT * exp	.531	1	.531	.423	.519	.008
	Error(SL*DT)	62.830	50	1.257			
	Exp	3.468	1	3.468	1.479	.230	.029
	Error	117.239	50	2.345			
	SL	5.790	1	5.790	3.144	.083	.067
	SL * exp	8.007	1	8.007	4.349	.043	.090
	Error(SL)	81.020	44	1.841			
	DT	3.114	1	3.114	3.833	.057	.080
Passive	DT * Exp	2.635	1	2.635	3.245	.079	.069
	Error(DT)	35.740	44	.812			
	SL * DT	.007	1	.007	.006	.940	.000
	SL * DT * Exp	.050	1	.050	.042	.839	.001
	Error(SL*DT)	53.194	44	1.209			
	Exp	32.393	1	32.393	10.980	.002	.200
	Error	129.808	44	2.950			

Experiment 7 (Second Life)

In all tables

- SL refers to short (S) for immediate recall and long (L) for delay recall *(within subjects)*
- DT refers to distractor (D) and target (T) objects *(within subjects)*
- Mode refers to passive and active mode *(between subjects)*
- Significance level at .05

1) Full episodic memory recall accuracy

Main Effects and Interactions

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
SL	.625	1	.625	.269	.607	.007
SL * Mode	8.100	1	8.100	3.487	.070	.084
Error(SL)	88.275	38	2.323			
DT	13.225	1	13.225	7.002	.012	.156
DT * Mode	10.000	1	10.000	5.294	.027	.122
Error(dt)	71.775	38	1.889			
SL * DT	.100	1	.100	.104	.749	.003
SL * DT* Mode	.225	1	.225	.233	.632	.006
Error(SL*DT)	36.675	38	.965			
Mode	11.025	1	11.025	2.502	.122	.062
Error	167.475	38	4.407			

2) What component

Main Effects and Interactions

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
SL	8.556	1	8.556	4.140	.049	.098
SL * Mode	7.656	1	7.656	3.704	.062	.089
Error(SL)	78.538	38	2.067			
DT	29.756	1	29.756	20.676	.000	.352
DT * Mode	3.306	1	3.306	2.297	.138	.057
Error(DT)	54.688	38	1.439			
SL * DT	6.006	1	6.006	4.910	.033	.114
SL * DT * Mode	5.256	1	5.256	4.297	.045	.102
Error(SL*DT)	46.488	38	1.223			
Mode	6.806	1	6.806	1.549	.221	.039
Error	166.937	38	4.393			

3) Where component

Main Effects and Interactions						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
SL	.400	1	.400	.131	.719	.003
SL * Mode	11.025	1	11.025	3.609	.065	.087
Error(SL)	116.075	38	3.055			
DT	13.225	1	13.225	6.495	.015	.146
DT * Mode	16.900	1	16.900	8.300	.006	.179
Error(DT)	77.375	38	2.036			
SL * DT	2.500	1	2.500	2.376	.131	.059
SL * DT * Mode	.025	1	.025	.024	.878	.001
Error(SL*DT)	39.975	38	1.052			
Mode	2.5	1	2.5	.373	.545	.010
Error	254.375	38	6.694			

4) When component

Main Effects and Interactions						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
SL	1.806	1	1.806	1.038	.315	.027
SL * Mode	3.306	1	3.306	1.900	.176	.048
Error(SL)	66.137	38	1.740			
DT	24.806	1	24.806	10.343	.003	.214
DT * Mode	3.306	1	3.306	1.379	.248	.035
Error(DT)	91.137	38	2.398			
SL * DT	1.056	1	1.056	.657	.423	.017
SL * DT * Mode	1.056	1	1.056	.657	.423	.017
Error(SL*DT)	61.138	38	1.609			
Mode	20.306	1	20.306	4.917	.033	.115
Error	156.937	38	4.130			

5) New results for the when after trimming temporal data

Main Effects and Interactions						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
SL	2.756	1	2.756	1.773	.191	.045
SL * Mode	3.906	1	3.906	2.512	.121	.062
Error(SL)	59.088	38	1.555			
DT	20.306	1	20.306	12.418	.001	.246
DT * Mode	3.306	1	3.306	2.022	.163	.051
Error(DT)	59.088	38	1.555			
SL * DT	1.406	1	1.406	1.209	.278	.031
SL * DT * Mode	.156	1	.156	.134	.716	.004
Error(SL*DT)	44.188	38	1.163			
Mode	18.9	1	18.9	7.125	.011	.133
Error	100.83	38	1.153			

6) Effect on keeping one outlier on EM (no DT * Mode interaction and stronger DT interaction after removing outlier)

Main Effects and Interactions						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
SL	.857	1	.857	.376	.543	.010
SL * Mode	7.589	1	7.589	3.328	.076	.079
Error(SL)	88.923	39	2.280			
DT	21.715	1	21.715	7.623	.009	.164
DT * Mode	4.935	1	4.935	1.732	.196	.043
Error(DT)	111.090	39	2.848			
SL * DT	.142	1	.142	.151	.700	.004
SL * DT * Mode	.289	1	.289	.306	.583	.008
Error(SL*DT)	36.809	39	.944			
Mode	13.130	1	13.130	3.007	.091	.133
Error	170.309	39	4.367			

7) Cross Experiment 5-7 (Active Mode only)

Main Effects and Interactions							
Mode	Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Active	SL	1.267	1	1.267	.593	.445	.012
	SL * Exp	8.167	1	8.167	3.824	.056	.074
	Error(SL)	102.512	48	2.136			
	DT	23.241	1	23.241	15.100	.000	.239
	DT * Exp	6.901	1	6.901	4.484	.039	.085
	Error(DT)	73.879	48	1.539			
	SL * DT	.608	1	.608	.455	.503	.009
	SL * DT * Exp	.907	1	.907	.679	.414	.014
	Error(SL*DT)	64.113	48	1.336			
	Exp	26.107	1	26.107	8.726	.005	.154
	Error	143.612	48	2.992			

Experience 7 a

Mode as a within subject variable, full episodic recall

In all tables

- SL refers to short (S) for immediate recall and long (L) for delay recall *(within subjects)*
- DT refers to distractor (D) and target (T) objects *(within subjects)*
- Mode refers to passive (P) and active (P) mode *(within subjects)*
- Significance level at .05

1) Before removing outliers

Main Effects and Interactions

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
AP	9.506	1	9.506	1.777	.198	.086
Error(AP)	101.619	19	5.348			
SL	.506	1	.506	.206	.655	.011
Error(SL)	46.619	19	2.454			
DT	20.306	1	20.306	5.907	.025	.237
Error(DT)	65.319	19	3.438			
AP * SL	8.556	1	8.556	4.007	.060	.174
Error(AP*SL)	40.569	19	2.135			
Mode * DT	5.256	1	5.256	2.201	.154	.104
Error(AP*DT)	45.369	19	2.388			
SL * DT	.056	1	.056	.052	.822	.003
Error(SL*DT)	20.569	19	1.083			
AP * SL * DT	.156	1	.156	.192	.666	.010
Error(AP*SL*DT)	15.469	19	.814			

2) After estimating the difference between pairs of participants, one outlier was removed (pair of participants) there is significance between the type of mode and objects.

Full episodic recall

Main Effects and Interactions

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
AP	7.164	1	7.164	1.297	.270	.067
Error(AP)	99.461	18	5.526			
SL	.059	1	.059	.025	.876	.001
Error(SL)	42.566	18	2.365			
DT	11.059	1	11.059	4.677	.044	.206
Error(DT)	42.566	18	2.365			
AP * SL	7.164	1	7.164	3.227	.089	.152
Error(AP*SL)	39.961	18	2.220			
AP * DT	10.007	1	10.007	6.406	**.021**	.262
Error(AP*DT)	28.118	18	1.562			
SL * DT	.007	1	.007	.006	.940	.000
Error(SL*DT)	20.118	18	1.118			
AP* SL * DT	.164	1	.164	.191	.667	.011
Error(AP*SL*DT)	15.461	18	.859			

What component

Main Effects and Interactions

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
AP	5.158	1	5.158	.964	.339	.051
Error(AP)	96.342	18	5.352			
SL	6.737	1.000	6.737	3.759	.068	.173
Error(SL)	32.263	18.000	1.792			
DT	11.605	1.000	11.605	6.873	.017	.276
Error(DT)	30.395	18.000	1.689			
AP * SL	5.158	1	5.158	2.246	.151	.111
Error(AP*SL)	41.342	18.000	2.297			
AP * DT	11.605	1	11.605	10.500	**.005**	.368
Error(AP*DT)	19.895	18.000	1.105			
SL * DT	16.447	1.000	16.447	9.690	.006	.350
Error(SL*DT)	30.553	18.000	1.697			
AP* SL * DT	.237	1.000	.237	.221	.644	.012
Error(AP*SL*DT)	19.263	18.000	1.070			

Where component

Main Effects and Interactions						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
AP	13.322	1	13.322	1.895	.186	.095
Error(AP)	126.553	18.000	7.031			
SL	5.533	1	5.533	1.560	.228	.080
Error(SL)	63.842	18	3.547			
DT	26.112	1	26.112	11.530	.003	.390
Error(DT)	40.763	18	2.265			
AP * SL	.533	1	.533	.224	.642	.012
Error(AP*SL)	42.842	18	2.380			
AP * DT	8.059	1	8.059	4.708	**.044**	.207
Error(AP*DT)	30.816	18	1.712			
SL * DT	.059	1	.059	.058	.812	.003
Error(SL*DT)	18.316	18	1.018			
AP* SL * DT	2.375	1	2.375	1.379	.256	.071
Error(AP*SL*DT)	31.000	18	1.722			

When component

Main Effects and Interactions						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
AP	3.184	1	3.184	.606	.446	.033
Error(AP)	94.566	18	5.254			
SL	16.447	1	16.447	7.832	.012	.303
Error(SL)	37.803	18	2.100			
DT	9.500	1	9.500	2.886	.107	.138
Error(DT)	59.250	18	3.292			
AP * SL	15.158	1	15.158	7.258	.015	.287
Error(AP*SL)	37.592	18	2.088			
AP * DT	8.526	1	8.526	6.754	**.018**	.273
Error(AP*DT)	22.724	18	1.262			
SL * DT	3.789	1	3.789	2.203	.155	.109
Error(SL*DT)	30.961	18	1.720			
AP* SL * DT	.237	1	.237	.178	.678	.010
Error(AP*SL*DT)	24.013	18	1.334			