Aiding Episodic Autobiographical Memory

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Abstract

The aim of this PhD research is to examine different strategies for enhancing the recollection of autobiographical memories and to explore the neurophysiological mechanisms underlying the retrieval of such memories. Case studies have shown that the sequential review of wearable camera photos leads to intense recollections of memories, which tend to be more vivid and detailed relative to memories recalled after reading diary entries. This process is also thought to have a long-term effect, enhancing the future recollection of memories. While the use of cameras as a means to aid the recollection of memories seems promising, this process has not been examined in a controlled environment. In addition, the long-term effectiveness of wearable camera photo review relative to other memory aids is not known. For example, testing participants memories of learnt material improves future memory performance more relative to restudying the material, an effect known as retrieval practice. While this effect has been studied in educational and laboratory settings, its effectiveness for real-world episodic autobiographical memories has not been examined and its effectiveness relative to long-term effects of wearable camera photo review is not known. The first study in this thesis examined the sequential presentation of wearable camera photos in healthy individuals and the second study examined in CR, a person with memory impairment. In the third study, the long-term effect of wearable camera photo review was contrasted with the effect of retrieval practice in healthy individuals. Finally, in the fourth study, the neurophysiological mechanism underlying the retrieval of these memories was measured using the EEG during a recognition task. For this, both event-related potentials and time-frequency analysis were employed. The first two studies showed that the sequential presentation of wearable camera photos can be beneficial in aiding the recognition of memories when the overall memory performance is good – for healthy individuals when tested with one-week retention interval and CR when tested with a three hours retention interval. However, the sequential presentation had a negative impact when the overall memory was poor – for CR when tested with one-week retention interval. This highlights the potential negative impact of using wearable camera photos as means to recollect autobiographical memories in people with memory impairment. The third study showed that as a means to enhance future memory performance, retrieval practice is more beneficial than reviewing wearable camera photos when memories are tested with a free recall task, and the opposite pattern is present when memories are tested

with a recognition task. Finally, the fourth study emphasised the role of sensory information in neurophysiological signatures for the recognition of autobiographical memories. Overall, the findings provide valuable information in creating strategies for improving episodic autobiographical memory.

Chapter 1: General Introduction

While memory has a pervasive role in our lives, it is often taken for granted until a moment of forgetting takes our attention followed by yet another realisation that memory is not perfect. Forgotten names or experiences are rarely surprising to us. Indeed, observation of human memory in the real world and in the laboratories points at many memory distortions and errors (Brainerd & Reyna, 2005; Loftus, 2004; Schacter, 2001). These include but are not limited to the inability to remember information when needed, remembering information incorrectly, and the distortions in how we remember information based on how we are questioned. This might lead us to think mother nature has made tremendous mistakes during the course of evolution. However, memory, like most cognitive functions, is also an adaptive function of the brain (Schwartz et al., 2013). Its goal is not to record and store all the information available to us in a similar manner to a video camera, but to help us make sense of the world and survive while not exhausting brain's finite limits. As Schacter puts it, memory errors and distortions are "a price we pay for processes and functions that serve us well in many respects" (Schacter, 2001, p. 184). Although, these types of explanations have received considerable criticism in the past for being mere post hoc explanations without providing substantial empirical support for a causal relationship between adaptive nature of memory and memory errors (Gould & Lewontin, 1979). There is now a growing consensus among memory researchers that at least some of these errors have an adaptive nature (Otgaar et al., 2013; Schacter et al., 2011).

While some memory errors can be described as the by-product of the otherwise adaptative mechanisms of memory formation, more severe memory errors can arise from neuroanatomical changes in the brain. Such neuroanatomical changes may be caused by neurodegenerative conditions such as Alzheimer's disease (Becker & Overman, 2002) or brain lesions in the medial temporal lobe as a result of viral infections or physical damage (O'Connor & Verfaellie, 2002). Memory impairments as a result of such neuroanatomical changes can have devastating effects on people's quality of life (Lyketsos et al., 2003). However, despite the importance of memory improvement and the benefit it could have in our lives, very little attention has been given to the optimisation of memory such as memory enhancement or memory aid strategies (Herrmann & Searleman, 1992). Only, in the past decade or so has memory improvement been examined by the scientific community (Karpicke et al., 2017; Silva et al., 2016). While understanding memory enhancement can be useful in healthy individuals, they are especially important for people with memory impairments.

The aim of this thesis is to explore memory improvement strategies for real-world autobiographical memories as well as the electrophysiological mechanisms underlying the retrieval of these memories. In the following sections, a description of autobiographical memory is provided, memory enhancement strategies are discussed, and later the neurophysiological mechanism of retrieval of memories are discussed.

1.1 Autobiographical Memory

While we all seem to know what memory is, providing a precise definition for it is difficult. As Schacter states it is easier to tell what is not memory, memory is not a single entity or concept (Gazzaniga, 2009, p. 655). Generally, memory refers to the dynamic process of storing, retaining, and retrieval of information either consciously or unconsciously (Gazzaniga, 2009). Very broadly, during encoding, sensory information is perceived and stored. This information is then retained if 'offline' consolidation processes successfully strengthen the neural networks that are storing this information (Alvarez & Squire, 1994; Manley, 2013). During retrieval, internally or externally generated memory cues lead to a recollection of the encoded information. It is important to note that these three stages are not interdependent of each other. For example, the retrieval of information enhances the consolidation process (Ferreira et al., 2018).

One of the crucial conceptualisations in memory research has been made by Tulving (1972). He famously distinguished semantic memories from episodic memories. He suggested that episodic memory consists of temporally dated events along with the temporal or spatial relationship between them (Tulving, 1972, p. 385) while semantic memories consist of definitions in a manner similar to a thesaurus which supports the language (Tulving, 1972, p. 386). Using this distinction, in order to remember that trains run on tracks, we are utilising the semantic memory and in order to remember our last train journey we are utilising our episodic memory. This distinction has provided a useful framework to study memory (Tulving & Craik, 2000). However, some argue that this distinction is not as clear as it may seem (Greenberg & Verfaellie, 2011). It appears that this distinction only works for extreme cases and many memories do not easily fit in these categories. While laboratory-based studies are able to examine these two distinct types of memories, many memories fall somewhere in between, and many are difficult to categorise. One such example is memories using a kitchen utensil. While this memory is not quite episodic since it is not an event and does not have a temporal date, it is also not quite semantic since it is not fully decontextualized (Greenberg et al., 2009).

Taking a more ecologically valid approached, memories are also described within the framework of autobiographical memories. Autobiographical memory refers to real-world memory for specific and episodic memory along with autobiographical knowledge which contains our conceptual, generic, and schematic knowledge about our lives (Conway & Williams, 2008). Within this framework, the episodic memories and the autobiographical knowledge are interconnected. Furthermore, our sense of self is constructed based on autobiographical knowledge (Conway, 2005; Conway & Pleydell-Pearce, 2000; Conway & Williams, 2008). With these in mind, in the context of this thesis, episodic autobiographical memories are referred to memories of personally experienced events that have temporal and spatial information. Furthermore, autobiographical memories are referred to memories of personally experienced events without them necessarily being episodic.

1.2 Memory Improvement

This section chronicles some of the main memory improvements and discusses their relevance to the aim of this thesis.

1.2.1 History of Memory Improvement and Mnemonics

Accounts of understanding what improves memory using mnemonics have been documented as early as during ancient Greeks (Luria, 1969; Yates, 1966) and even during pre-literate cultures (Kelly, 2016). A mnemonic device is a mental strategy that uses the already known knowledge in order to allow or ease the recollection of the to-be-remembered information. One of the oldest recorded mnemonic devices is thought to be inscribed by the poet Simonides of Ceos in 3rd century BC (Yates, 1966) and is called the ‘method of loci’. This technique, also known as the ‘memory palace’ in the popular media, requires the person to use layouts already known to them such as that of their house, some building, or any other geographical structures with numerous discrete locations in the layout (‘loci’) and then ‘attach’ or associate the to-be-remembered information to one of the loci of the layout. This creates a 'mental structure' and when the information is needed, the person 'walks' through the loci and obtains the information. The effectiveness of the method of loci has been shown in laboratory settings where participants are able to perform better in a word recall task if they employ the method of loci compared to when they do not (Crovitz, 1969; Ross & Lawrence, 1968). More intriguingly, the method of loci is used by memory athletes, who are able to memorise 1000s of random digits in 30 minutes or memorise π to more than 2^{16} decimal places (Maguire et al., 2003; Raz et al., 2009).

The method of loci is thought to rely on spatial and navigational mechanisms to support the memory of the material that themselves are not necessarily spatial. For this reason, some argue that the beneficial effects of the method of loci are due to its use of spatial and navigational mechanisms, which are cognitive mechanisms closely linked with memory processes (Rolls, 2017). This notion is supported by findings that the hippocampus and the surrounding regions contain cells that are selective to locations cues (e.g. place cells) that also code for events associated with those locations (Moser et al., 2015). This notion is also supported by neuroimaging findings that memory athletes showed a higher correlation in the activity of hippocampal and surrounding regions (Müller et al., 2018). However, this increased correlation was not associated with within-subject performances, leaving open the possibility that it may not directly explain the effectiveness of the method of loci.

An alternative explanation of the method of loci is that it is simply the use of already known information that benefits the memory. This notion is supported by a study in which the environment used as the basis of the method of loci were manipulated (Caplan et al., 2019). Here, participants were instructed to learn one of three different environments (an apartment, an open field, and a radial-arm maze) and use it in the method of loci in order to learn a list of unrelated words. The manipulation of environments characteristics allowed researchers to examine whether the environments with more spatial information (an apartment) yield a stronger memory effect in the method of loci, compared to environments with fewer spatial information (an open field). While there was a difference in participants performance depending on the environment they had used, these differences were small in magnitude. Overall, this suggests that while spatial and navigational mechanisms occur during the method of loci, they may not necessarily be directly responsible for its effectiveness.

Moreover, simply associating the to-be-remembered material with already known information has been described as a power mnemonic device. This method, known as the ‘peg method’ involves the use of ‘peg lists’ (Borges et al., 1976). These peg lists are a set of numbers (typically from 1 to 20) each associated with an object that rhythms with it. For example, a popular peg list starts as one – gun, two – shoe, three – tree, and so on. Once this list is learned, it can function in the same way as the physical layout in the case of the method of loci, allowing the learner to attach each piece of information to an object in the list. During the retrieval, the peg list is then recalled aiding the recall of the material. When tested in laboratory settings, the peg method and the method of loci show a similar memory enhancement effect. Roediger (1980) compared participant free recall performance for unrelated lists of words, while they were assigned to use one of five memory enhancement strategies, including, the method of loci, the pegs method, simply repeating the learned material, visualising the words, and visualising the words but also relating them to the previous word. The results showed that the method of loci and peg method were equally superior relative to other methods.

Overall, mnemonic devices provide powerful memory improvement strategies for information that is difficult or impossible to remember. They do, however, have some drawbacks. They require some form of training and, more importantly, are not versatile in the type of information they can aid memory with. For example, while they can help one remember a long number of digits, they cannot aid the memory for the subjective experience of attending a music concert. For these reasons, mnemonics are not useful for real-world memories such as episodic autobiographical memories.

1.2.2 Retrieval Practice

Another memory improvement strategy is simply the retrieval of the learned information. In 1620, Francis Bacon described "If you read a piece of text through twenty times, you will not learn it by heart so easily as if you read it ten times while attempting to recite from time to time and consulting the text when your memory fails" (Jardine & Silverthorn, 2000, p. 143). While Bacon emphasised the role of feedback in testing one's memory, the benefits of testing memory is present even when there is no feedback. This phenomenon, known as the 'retrieval practice' (or 'testing effect') has been discussed as a psychological concept by Abott (1909) and Gates (1917). It has also been tested thoroughly in the field of educational psychology aimed at improving students learning outcomes (Roediger & Karpicke, 2006b).

The general structure of these studies is as follows. Participants, typically students, study a set of material in the learning phase. After this those in the retrieval practice condition perform an initial memory test that requires them to retrieve the learned material. These tests can be a recognition test, a recall test, or any task that requires participants to retrieve the learned information. In the control condition, participants may re-study the material or do nothing. All participants then take part in a final memory test, sometimes shortly after the initial tasks (Rowland & DeLosh, 2015) and sometimes weeks or months after (Carpenter et al., 2009). The finding of these studies is that participants in the retrieval practice conditions perform better on the final memory task compared to those in the control condition (see Karpicke et al., 2017 for an extensive review). In order to examine which conditions, provide the best retrieval practice effect, some studies have manipulated the initial memory test. In one such study, participants learned lists of words, and then either restudied them or took one of the three initial retrieval tests, a yes-no recognition task, a free recall, and a cued recall where the first letters of the words were presented (Carpenter & DeLosh, 2006). After five minutes, participants performed the final test, which again was either a recognition test, free recall, or a cued recall test. Regardless of the final memory test, the initial free recall induced the strongest retrieval practice effect. This type of finding is common and is taken to suggest that 'effort' plays a role in retrieval practice (Rowland, 2014).

Retrieval practice has also been found to be effective for people with accelerated long-term forgetting (ALF) a form of memory impairment in which memories are forgotten much faster than usual, resulting in an inability to form long-term memories. In one study, three participants with ALF learned a set of stories given in texts (Ricci et al., 2017). After the learning session, they either performed repeated recall of the stories, repeated recall followed by discussions, or no recall. Stories which were recalled either with or without discussion were remembered better two weeks after the initial learning phase relative to stories not recalled. This study indicated that people with ALF might still benefit from retrieval practice. Moreover, the authors of this study point to real-world applications of retrieval practice as the next step for such research.

There are however a few drawbacks to retrieval practice. The first is the interfering effect of retrieval. While retrieval of learned information increases the chances of it being retrieved in future, it can also impair the retrieval of other studied material, an effect known as the retrieval-induced forgetting (Anderson, 2003). During the retrieval, the competing items – items related to those retrieved such as those learned at the same session or context are suppressed (Wimber et al., 2015). This process reduces the distraction the competing items may produce and is, therefore, is considered to be an adaptive mechanism (Kuhl et al., 2007). However, as a result of this process, retrieval of items can weaken the memory for competing items, making them less likely to be remembered in future.

Another drawback of retrieval practice is the negative suggestion effect, the possibility of picking up new erroneous information during the retrieval practice. For example, in multiple-choice memory tests, there is usually only one correct answer and the rest of the choices are incorrect. As a result participants partially take up some of the incorrect information presented in the incorrect choices (Koediger & Marsh, 2005). While this effect is important to consider, it does not outweigh the positive effects of retrieval practice. It can either be eliminated simply by using memory tests without any biases, or by not providing incorrect information during the retrieval phase or even, for example in the case of multiple-choice questions, by providing the correct answer after the tests.

Overall, retrieval practice is a robust memory improvement strategy that can allow the already learned information to be retained for a longer period of time. Unlike mnemonics, retrieval practice does not aid the learning of material such as arrays of random digits that are very difficult or impossible to learn. However, its simplicity makes it easy for it to be used in a real-world setting such as in an educational setting. While in theory, it is possible to apply retrieval practice for improving episodic autobiographical memory, in practice, the majority of studies interested in retrieval practice have used educational or laboratory-based stimuli and therefore its effectiveness for episodic autobiographical memories remain unclear.

1.2.3 Wearable Cameras

Memory improvement strategies mentioned so far rely on mental processes, here a memory improvement strategy using an external device, the wearable camera, is discussed. Relative to other memory enhancement strategies, wearable cameras are specifically designed to aid memory for real-word autobiographical memories. Wearable cameras are small devices which automatically take photos from the perspective of the wearer during mundane (e.g. trip to the grocery store) or special (e.g. a wedding) events (Hodges et al., 2011). These photos are later reviewed in order to aid the recollection of autobiographical memories that were created during those events or to help future retrieval of these memories (for reviews, see Chow & Rissman, 2017; Silva et al., 2016).

Important characteristics of these cameras include their capacity to automatically take a photo every 10 to 30 seconds, depending on the model of the device as well as its configurations, and their use of sensors for light, colour, temperature, and motion to identify the ‘best’ time for taking a photo. As a result wearable cameras produce a lot of photos for daily events, taking, for example, between 120 to 360 photos in one hour. Furthermore, since they are either hung from the neck of the wearer or clipped in the same location to wearer's clothing, photos captured have a similar perspective to what the viewer observes.

Soon after these cameras were developed a series of case studies have tested their effectiveness as a means to recollect memories of personally experienced events in people with memory impairments (Berry et al., 2007; Browne et al., 2011; Loveday & Conway, 2011). These studies typically asked people with amnesia to wear the camera during a set of events as well as take diary notes. After some retention interval of a week, participants report a more detailed and vivid recollection of the events when observing the wearable camera photos relative to reading their written diary entries.

Similar findings are observed in healthy individuals. In one study young and older adults were asked to wear the camera during a set of everyday events as well as create names for those events (Mair et al., 2017). After two weeks, participants recalled more episodic and semantic details after being given their self-generated titles along with wearable camera photos compared to a condition where they were only given their self-generated titles for those events. In another study, participants were able to better answer who, what, where, & when questions after reviewing the wearable camera photos relative to a condition with no photo review (Sellen et al., 2007).

While these studies outline the short-term effects of cameras as powerful memory cues, other studies have shown that wearable camera photo review not only aids the recollection of those memories at the time of the review but can also enhance the future recollection of them. For instance, in one study, participants wore the camera for five consecutive days. For three days (review days) they reviewed the photos in the evening, and for two days (non-review days) they did not. (Finley et al., 2011).

When performing memory tests one, three, and seven weeks after, participants memory performance was higher in recognition and cued recall tasks for events from the review days relative to non-review days.

A different set of studies have shown that the ways in which wearable camera photos are reviewed influence the future memory for those events (St. Jacques et al., 2015; St. Jacques & Schacter, 2013). Here, participants were taken on a museum tour while wearing the cameras. At the same time, experimenters also used the cameras to take photos of the same events, but from a different perspective. Participants then reviewed these photos 48 hours after the museum tour. In one experiment, some participants were presented with the photos in their natural order – 'temporal order match', and some were presented with the photos in random order – 'temporal order mismatch'. In a different experiment, some participants were presented with photos from their own perspective – 'perspective match', and some were presented with photos that were taken by the experimenter from a different angle – 'perspective mismatch'. Finally, 48 hours after the review session, participants performed a recognition task. Both match conditions led to an increased likelihood of participants correctly identifying photos of items they had seen but also an increased likelihood in falsely recognising photos of items from places they had not visited.

While wearable cameras seem to only aid episodic autobiographical memories, at least for people with memory impairments their benefit is thought to go beyond this by also improving their mental well-being. This notion has so far been explored in one case study (Browne et al., 2011). In this study, a patient with memory impairment as a result of mild cognitive impairment used either wearable camera photo review or a written diary in order to aid memory. In addition to measuring memory performance, emotional and social well-being questionnaires were also used. The results showed an increase in confidence and a decrease in anxiety as a result of using the wearable camera in aiding memory (Browne et al., 2011). One explanation for this was that since autobiographical memories and the subjective sense of self are interlinked (Conway, 2005), aiding autobiographical memories may in turn help with the subjective sense of self thus contributing to participants mental well-being.

Overall, the wearable camera seems to be a useful memory improvement tool however there are a few limitations regarding the extent of their support and the underlying mechanisms of it. There are a number of studies outlining the beneficial effect of wearable camera photo review as powerful memory cues which help the recollection of autobiographical memories, fewer studies have explored whether wearable camera photo review can enhance the recollection of those memories in future as well (Finley et al., 2011). Therefore, the long-term effects of wearable camera photo review remain unclear.

Additionally, the exact mechanism underlying how reviewing the wearable camera photos acts as a strong memory cue is unclear. Berry has proposed two explanations on short term effects of wearable camera photo review as memory cues (Hodges et al., 2011). One explanation is that since wearable cameras take many photos from the same memory episode, they may capture the exact moment those memories are encoded. Therefore, by presenting all photos taken from the camera one or some photos corresponding to that moment can reactivate the memories of that event. Another explanation is that the sequential presentation of the photos apparently resembles the way memories are stored, and it could, therefore, be a good memory cue for this reason. While these may be plausible explanations they have not been put to test.

Moreover, the conditions under which wearable camera photo review produce the greatest effect has not been explored (Barnard et al., 2011). For instance, it is not known how many photos should be presented for a given event, in what frequency, and how long after the experienced event in order to create the most optimal memory aid. While there is theoretical importance in understanding these conditions, understanding them can, more importantly, allow the development of better-optimised strategies for memory improvement using wearable cameras.

1.3 EEG of Memory Retrieval

1.3.1 A Brief Overview of EEG as a Neurophysiological Measure

Electroencephalogram (EEG) is a functional neuroimaging technique that provides information about summed cortical neural activity (see Luck, 2014 for a detailed overview). In a standard EEG set up, the participants wear an EEG cap that contains 32, 64, or 128 electrodes that are connected through amplifiers to a recorder, usually a computer. With the application of a conductive gel or liquid between the scalp and the electrodes, the electrodes make a stable connection with the scalp. Once this connection is established, the signals from the electrodes are captured with the recorder, usually with a very high sampling rate (e.g. 1000 Hz). As a result, the EEG is able to continuously record voltage fluctuations from the scalp, of which some reflects summations of postsynaptic potentials (PSPs) as well as action potentials (APs), for example in auditory responses (Buzsáki et al., 2012). When PSPs (or APs) occur simultaneously in the similarly oriented neurons, the resulting voltage changes summate and almost instantaneously reach the scalp. For this reason, EEG provides a very fast and direct measure of the neural activity. This is also its main advantage over functional Magnetic Resonance Imaging (fMRI), which relies on changes in blood oxygenation level-dependent (BOLD) signal which is a delayed response to neural activity.

The commonly used methods for analysing the EEG signal are the Event-related potentials (ERPs) and time-frequency (TF) decomposition. For the ERPs, the EEG signal, after being de-noised from environmental and unintended muscular or ocular activities, is time-locked to the onset of an event, a stimulus presentation or an execution of a response. This relatively simple technique has been used even before computers were available. The very early EEG researchers were able to visually identify and compare large ERP components (Davis, 1939). Later, with the developments of computers, it was possible to average the EEG signal over multiple ERP components. This allowed the examination of ERPs that were small relative to the ongoing EEG signal and comparing them across the experimental conditions or participants.

Another commonly used method for analysing the EEG signal is using TF decomposition. Here the de-noised signal is transformed to the frequency domain, most commonly using a complex Morlet wavelet convolution but other methods such as Fast Fourier Transform (FFT) are also used (M. X. Cohen, 2014). This transformation provides information about the distribution of the power across different frequency bands that together constitute the EEG signal and about how they change over time in the case of complex Morlet wavelet convolution. These activities, also known as EEG oscillations, are usually categorised according to the frequency bands. While the exact boundaries of them are not defined, the commonly referred to frequency bands are the theta (< 4 Hz), alpha (8 – 13 Hz), beta (13 – 30 Hz), and gamma (> 30 Hz). The power of such frequency bands for a given time window or a condition is then compared across conditions or participants. While an increase in power of a frequency band as a result of an event (cognitive or motor) relative to a pre-stimulus time or a different condition is referred to as synchronisation, a decrease in power is referred to as a desynchronisation.

The main advantage of this method over the ERPs is that it captures the “non-phase-locked” or induced activity. These are activities within the same frequency band that do not have the same phase. These activities reach their peaks at different times across different trials relative to the onset of the trial. For this reason, these activities, when averaged across trials using ERPs will cancel each other out. While in the TF, as the power is computed before averaging there is no such loss in data.

While these are the most used methods for analysing the EEG signal, there are others. For example in cross-frequency coupling analysis, the interaction between different features of oscillations (amplitude or phase) across different regions are measured and correlated in order to infer which regions may communicate with each other (Aru et al., 2015; Canolty & Knight, 2010). In the study of microstates, the pattern and topography of small transient states of the EEG signal that last between milliseconds and seconds are identified and analysed in respect to different condition or participants groups (Michel & Koenig, 2018). In dynamic causal modelling (DCM) a causal relationship between regions of the brain is estimated based on the EEG signal (Kiebel et al., 2009).

1.3.2 Using EEG to examine Memory Retrieval

A wide range of studies has used the EEG to examine the cognitive neuroscience of memory, particularly the encoding and the retrieval of information (Mecklinger et al., 2016; Rugg & Curran, 2007; Wilding & Ranganath, 2011). Most of these studies have used recognition memory paradigms. Broadly, these paradigms have a study phase and a test phase. During the study phase, participants are given some material to learn. During the test phase, participants are presented with the studied items (old items) as well as items they have not studied (new items) and are asked to respond indicating which items they think they have previously studied and which are new. Usually, the EEG signal after the presentation of correctly identified old items (hits) is contrasted with correctly identified new items (correct rejections) (Wilding & Ranganath, 2011).

The first such study was performed by Sanquist, Rohrbaugh, Syndulko, and Lindsley (1980). They were interested in seeing whether processing the semantic content of the words in comparison to their phonemic (how they sound) or orthographic (its writing style) content would influence the EEG signal during the recognition of these items. To examine this, they asked participants to make a similarity rating based on these criteria on a set of nouns. Their results showed an ERP, recorded over the left-parietal electrodes, which was more positive for hit conditions relative to correct rejections. Furthermore, this difference was larger for the items studied in the semantic condition relative to those studied in the phonemic or orthographic condition.

This old-new ERP effect also known as the late positive component (LPC) has been replicated by other studies, it is most prominent over left-parietal electrodes and it reaches its peak 600 ms after stimulus presentation (Curran, 2000). It is also modulated depending on participants judgment about the source of the items (Senkfor & Van Petten, 1998; Wilding & Rugg, 1996) and is therefore taken to reflect the recollection of contextual information (Rugg & Curran, 2007). Another set of studies have identified a different old-new ERP, this is known as the FN400 or the frontal familiarity based old-new effect which peaks approximately 300 ms after the stimulus presentation (Friedman & Johnson, 2000; Rugg & Curran, 2007). This ERP is sensitive to familiarity-based memory judgments, which is when participants recollect the studied items based on a sense of knowing without necessarily recollecting any specific information about the context in which the items were studied. This ERP is sensitive to participants sense of familiarity and is also sometimes elicited by items that are similar to the studies items (Mecklinger, 2006; Rugg & Curran, 2007). An exploratory study using simultaneous EEG and fMRI recording during a recognition task has shown higher activity in the right dorsolateral prefrontal cortex and right intraparietal sulcus associated with the frontal old-new effect (350 - 550 ms), and higher activity in right posterior hippocampus, parahippocampal cortex, and retrosplenial cortex associated with the LPC (580 - 750 ms) (Hoppstädter et al., 2015). Finally, another old-new ERP, late posterior negativity (LPN) has been examined (Mecklinger et al., 2016). This is functionally similar to the LPC but reaches its peak after a memory judgment has been made.

Moreover, studies using TF methods have identified changes in gamma and theta oscillations in relation to the retrieval of memories (For reviews, see Düzel et al., 2010; Nyhus & Curran, 2010). These studies, similar to the aforementioned ERP studies, have used recognition tasks in order to examine the EEG oscillations associated with the retrieval of memories. One study has shown a modulation in the oscillatory activity based on participants' subjective memory states, recollection and familiarity using a word recognition task (Burgess & Ali, 2002). The results showed synchronisation in the gamma band (25 – 100 Hz) activity over the frontal and parietal sites after the presentation of words which were followed by recollect responses compared to the familiar responses. In another study, participants were asked to perform an old-new recognition judgment on previously seen and new items, as well as recalling their location on the screen on which these items had appeared during the study phase (Gruber et al., 2008). The results showed a synchronisation in the gamma band (35 – 80 Hz) over parieto-occipital electrodes for correctly recognised old items compared to new items, as well as an increase in the theta band (4-7.5 Hz) over fronto-central electrodes for items followed by correct source judgments relative to items followed by incorrect source judgments. The functional role of oscillatory activity has been further studied by exploring the relationship between activities in different frequency bands recorded from different regions of the brain. Using a pictorial recognition task, a phase-amplitude coupling has been demonstrated where the amplitude of gamma band (30-100 Hz) oscillation recorded from parietal electrodes was modulated by the phase of theta (3-6 Hz) band oscillation recorded from frontal electrodes (Köster et al., 2014).

Overall, these studies, using recognition paradigms, have provided useful information about the neurophysiological underpinning of episodic memory retrieval. However, they have mostly used laboratory-based stimuli such as words and pictures. While this has provided a very well controlled environment to study the retrieval of memories, the findings may not be representative of real-world memories such as episodic autobiographical memories. In order to overcome this weakness, a number of studies have used different paradigms in which they have aimed to capture the retrieval of autobiographical memories, though they too have limitations (Conway et al., 2003; Knyazev et al., 2015; Park & Donaldson, 2019; Renoult et al., 2016).

In the first such study, at the beginning of every trial participants were instructed to either remember a real event or imagine one in response to an upcoming verbal cue (Conway et al., 2003). Participants would either use the cue to recall an autobiographical memory or imagine an event related to that cue. The researchers used an EEG recording technique which examined the slow cortical changes. The generation of both imagined and real events was associated with a negative component over the left compared to the right frontal electrodes. This was more negative for imagined events relative to real events. The results were interpreted to indicate that imagining events and remembering experienced events likely share processes that mediate the construction of memory. The main limitation of this type of paradigm is that it is not possible to control the accuracy of recollection of autobiographical memories compared to imagined ones.

Knyazev et al. (2015) use a similar paradigm to Conway et al. (2003) in order to explore the brain oscillations in response to the retrieval of autobiographical memory. In this study, participants were instructed to sit still and remember personally experienced events as vividly as possible. They were instructed to press a button when they had started remembering the memories. This process was repeated 60 times, with a distractor task in between each trial. There was no control condition. The results showed an increase in alpha and beta bands relative to a time before the button press. Since alpha and beta band activities are associated with the activity of the default mode network (DNM) - a highly interconnected large scale brain network, this result was interpreted to suggest an overlap between the retrieval of autobiographical memories with the activity of the DNM. The limitation of this design is that authors did not include a control condition and it is not possible to know whether participants were remembering autobiographical memories or were simply sitting quietly. Since DNM is thought to be activated when no particular attention is being paid to a task and because there is no way to know if participants were actually remembering memories, the activity recorded may indeed come from DNM.

In a different study, the researchers were interested in the neurophysiological response to the retrieval of autobiographical facts, generic semantic knowledge, and episodic memories (Renoult et al., 2016). Participants were instructed to answer yes-no to a series of questions. The questions were grouped in four conditions, probing autobiographical facts, general facts (semantic memory), and unique as well as repeated events (episodic memories). The EEG signal recorded immediately after the participants were presented with a question was thought to reflect the retrieval of memories corresponding to that question. The results showed that questions probing general facts were associated with an increase in the FN400, those probing for unique events were associated with an increase LPC. Both FN400 and LPC ERPs were different between personal semantic conditions (autobiographical facts and repeated events) and semantic memory. The authors interpret these results to suggest that personal semantics (autobiographical facts and repeated events) are distinguishable from episodic and semantic memory. However, there are some limitations to this design. Like Conway et al.'s (2003) study, it is not possible to verify the accuracy of participants judgments. Additionally, the time it would take to find the answers for the questions would vary between trials and between participants making the results noisy and less reliable.

A more recent study has used a recognition task in a more real-world setting (Park & Donaldson, 2019). In this study, participants were taken on a tour in the university building while observing a set of images of objects on a table. By doing so, participants created associations between the images and the physical locations they observed them in. For the recognition task, participants were taken on the tour again and observed the studied objects and new objects in either their original location or a different location. A mobile EEG recording device was used to record participants EEG during this second tour. Comparing the EEG signal between the old and the new images of the objects, the FN400 and the LPC were observed. Furthermore, only the FN400 was sensitive to whether the images were observed in the original location or not, this suggested that only the FN400 was associated with the retrieval of contextual information. While this study provides an interesting take on using EEG in the real world, it does not, in fact, examine real-world memories as the study described uses laboratory-based and not real stimuli, albeit in a real-world context.

In summary, EEG can provide helpful insight into the neurophysiological mechanisms associated with the retrieval of memories. Studies using recognition task paradigms with laboratory-based stimuli have provided a wealth of knowledge about the functional role of different EEG signatures. However, the main drawback of these studies is that the stimuli they have used do not have the characteristics of real-world memories. While there have been attempts to study real-world memories, most of these studies do have quite major methodological limitations.

1.4 Summary and Thesis Overview

In summary, this thesis investigates memory improvements strategies in the context of real-world autobiographical memories. While doing so, EEG is used to explore the neurophysiological mechanisms underlying the retrieval of such memories and to understand how they are influenced by memory improvement strategies.

Wearable cameras have gained popularity as a means of memory improvement (Silva et al., 2016). The sequential presentation of wearable camera photos is thought to act as a powerful memory cue which successfully aids the recollection of personally experienced memories (Loveday & Conway, 2011). This photo review process is also thought to enhance future recollection of those memories (Finley et al., 2011). However, little is known about how this photo review process aids memory or what its central features are. In addition to theoretical importance, such information is very important in the development of more optimal strategies using these cameras to aid memory (Barnard et al., 2011).

In chapter 2, a real-world memory paradigm is used in order to explore the effect of the sequential presentation of the wearable camera photos as memory cues. Participants were taken on a city tour while wearing the camera. One week later they performed a recognition task which included photos from their tour along with control photos. In addition to behavioural measures, EEG was used during the recognition task in order to examine how the neural signatures of recognition memory were modulated as a result of the sequential presentation of the photos.

In chapter 3, the effect of the sequential presentation of wearable camera photos is studied in a person with memory impairment. A similar paradigm to that of chapter 2 was used, however, this time the participant was tested on several occasions. Once on the same day after several hours, once a week later, and finally a week later while this time they were able to use review the photos before the final recognition task. Here the sequence effect was explored along with how it was modulated, depending on the retention time or the presence of a review session during the retention period.

In chapter 4, the long-term effect of wearable camera photo review is contrasted with another memory enhancement strategy, retrieval practice. Retrieval practice refers to improvement in memory as a result of having practised retrieval of the learned material in contrast to a having restudied that material (Karpicke et al., 2017). Here participants were taken on a predefined museum tour while wearing the wearable cameras. After this tour, they either practised retrieving the museum exhibits they had observed or reviewed the wearable camera photos of them. One week later they performed a recognition and a free recall task. In chapter 5, the EEG data collected during the recognition task is presented, both ERP and TF analysis of this data contributes to the current understanding of the neurophysiology of real-world autobiographical memories.

Finally, the results are discussed in light of current theoretical approaches to memory improvement. Based on the findings of this thesis suggestions for potential memory improvement strategies are suggested.

Chapter 2: Behavioural and ERP investigation of the wearable camera photo review

Wearable camera photo review has successfully been used to enhance memory, yet, very little is known about the underlying mechanisms. Here, the sequential presentation of wearable camera photos - a key feature of wearable camera photo review - is examined using behavioural and EEG measures. Twelve female participants were taken on a walking tour, stopping at a series of predefined targets, while wearing a camera that captured photographs of these targets automatically. One week later, a recognition task was administered, in which participants were presented with short photo-sequences depicting either the pre-defined targets or foils from a different walking tour. A sequence of four photos leading to these targets was selected and together with control photos were used in a recognition task one week later. Participants' recognition performance improved with the sequence of photos (measured in hit rates, correct rejections, & sensitivity), revealing for the first time, a positive effect of the sequence of photos in wearable camera photo review. This has important implications for understanding the sequential and cumulative effects of cues on episodic remembering. An old-new ERP effect was also observed over visual regions for hits vs. correct rejections, highlighting the importance of visual processing not only for perception but also for the location of activated memory representations. However, this effect was not modulated by the sequence of photos.

2.1 Introduction

Wearable cameras are small lifelogging devices that have been shown to enhance autobiographical memory retrieval in patients with memory impairments and cognitively healthy individuals (see Chow & Rissman, 2017, for a detailed review). These devices are small digital cameras, first developed by Microsoft in 2003, that are worn around the neck and designed to automatically capture low-resolution, wide-angle photographs from the wearer's perspective. A key feature of these cameras is that the picture capture is influenced by in-built sensors, which detect salient environmental factors, such as movement, light, temperature and direction.

With typical use, the cameras take approximately one image every 10-15s, and sequences of consecutive images can later be reviewed in the form of a time-lapse "movie" at either a predetermined or self-regulated pace. This provides an efficient way of showing many photos in a short time, which can create the experience of an intense "flood" of recollection, termed by Loveday and Conway (2011) as a "Proustian moment".

Although there is now a growing number of studies that show the beneficial effects of the wearable camera photo review (Chow & Rissman, 2017; Mair et al., 2017; Sellen et al., 2007; Silva et al., 2016), an important question is how and why this technology offers such a powerful memory aid. What is it about this type of photograph or the way they are reviewed that makes them so effective in triggering episodic remembering? Explanations include the idea that visual cues are more effective than verbal ones (Maisto & Queen, 1992), or that the sequence of photos provides additional temporal information which supports retrieval through contextual reinstatement (Barnard et al., 2011). Mair et al., (2017) recently showed that the presentation of photos in their natural (i.e. sequential) order is more beneficial than random presentation. A more convincing suggestion is that the photographs produced by these cameras share a number of overlapping features with normal human memory (Hodges et al., 2011). For example, wearable camera-generated stimuli are visual, passively captured, have a "field" (as opposed to "observer") perspective, are time-compressed, and are sequentially ordered.

A key challenge with identifying the underlying mechanism of wearable camera photo review is that there are many variations in how wearable cameras are used, both in experimental studies and everyday life. This makes it difficult to make direct comparisons and draw conclusions. In particular, there is a lack of consistency in whether photos are presented: singly or as a collection; in temporal order, reverse order, or randomly; once or more than once; within hours, weeks or months; or at a pre-determined or self-regulated pace. Studies that have evaluated the value of the camera as a memory aid have not yet systematically explored these factors, nor have they explored the neural correlates associated with these factors. There are now several studies that have used functional Magnetic Resonance Imaging (fMRI) to assess brain activity in people who are reviewing images taken with a wearable camera, but in all these cases the focus is on the neural mechanisms underlying recall of naturalistic autobiographical stimuli (Rissman et al., 2016; St. Jacques et al., 2011, 2015), rather than neural mechanisms underlying how the technology aids the recollection of memories.

An important feature of the wearable camera is the sequential way in which photos are captured, which allows them to be presented and reviewed in the same pattern but at a faster pace. No study to date has explored the behavioural dynamics or neural correlates of this process. An effective way to investigate the fine temporal structure of an underlying processes is by using electroencephalography (EEG) to measure event-related potentials (ERPs). While EEG and ERPs have not been used with wearable cameras, there is however a large body of work that uses this approach to explore the neurophysiology of recognition memory under laboratory conditions. A well-established finding is that correctly identified old words compared to new words elicit an ERP with a higher amplitude over parietal electrodes (Sanquist et al., 1980; Wilding & Ranganath, 2011). When recording from lateral electrodes, this old-new effect is largest over the left-parietal electrodes 500 to 800 milliseconds after stimuli presentation, thus it is termed the left-parietal old-new ERP effect (Friedman & Johnson, 2000; Rugg, 1994). It has been shown that this signature specifically indexes recollection (Mecklinger et al., 2016), whereas the familiarity is characterized by a mid-frontal old-new ERP effect (Mecklinger & Jäger, 2009). Familiarity here refers to participants ability to recognise old stimuli based on their feeling of 'knowing' from somewhere without necessarily recollecting specific information about the context in which the item was studied or experienced. Furthermore, using coloured clip-art stimuli it has been shown that when participants are tested on different study-test time intervals the parietal old-new (recollection) effect attenuates after one week and fades after four weeks, whereas the familiarity old-new effect remains consistent over this time (Roberts et al., 2013; Tsivilis et al., 2015). It is not clear whether these effects will be observed for recognition of real-world memories, which differ from laboratory-based memories in several ways. For example, the study of memory in laboratory conditions usually involves simple stimuli (e.g. words, shapes, generic pictures) encountered within a relatively impoverished and unchanging environment. In contrast, real-world memories consist of complex stimuli encoded within rich, dynamic, and multisensory environments, and involve novel combinations of often familiar items (e.g. people, places, objects). As such, real-world memories are more likely to be personally relevant, emotionally salient, goal-directed, and intrinsically motivated. Moreover, recognition memory in the laboratory involves the presentation of precisely the same stimuli presented within the same context both at study and at test, but outside the laboratory, objects, people, and places are recognised in contexts that differ from the original encoding context, and usually, only partial cues are available.

The current experiment is the first to use EEG to explore the behavioural and neurophysiological mechanisms underlying wearable camera use in a real-world context. Participants were taken on a guided walking tour where they saw a series of targets while they were wearing a wearable camera. The targets included urban artefacts such as a building’s facades, sculptures, and other salient objects in the city. The camera produced multiple photos for each target from the participants perspective as they walked their way towards them. One week later, participants performed a recognition task that included these photos along with control photos taken in a similar manner. During this task, a sequence of four photos per target was shown in their natural order. Participants used a response box and indicated their memory response for each of these photos using three types of responses including ‘don’t remember’, ‘familiar’, & ‘recollect’. This paradigm allowed us to measure behavioural and neurophysiological changes associated with observing a sequence of photos. Firstly, this study investigates whether the typical ‘old-new’ ERP effects found with simple stimuli are also elicited by complex wearable camera images depicting a recently experienced event. Secondly, it examines the ERP amplitude changes across the sequence of photos, in order to identify the timing and location of cortical activation that occurs during a sequenced image review. If memory success is influenced by the sequential presentation of related images, then it will be expected that over the course of the presented sequence, participants’ recognition memory would increase, and the corresponding modulation in amplitude would be observed in recognition-related ERPs. On the other hand, if the sequence is unimportant for memory success then no consistent relationship between the serial position of the image within the sequence and measures of recognition sensitivity and the corresponding ERP amplitude would expect.

2.2 Methods

2.2.1 Participants

Participants were 13 females, ranging in age from 45-56 (*M=51.12*, *SD=3.76*). One participant was excluded as they had confused the responses during the experiment. They were recruited by an advertisement on City University London's participant recruitment website and word of mouth. None of the participants reported any history of brain injury or serious mental health condition at the time of the study and all had a normal or corrected vision. All participants signed an informed consent form. The study was approved by the Psychology Department Ethics Committee of City, University of London.

2.2.2 Wearable Camera

The wearable camera Autographer was used in this study (OMG PLC, http://www.autographer.com). Autographer is a small camera that is worn around the neck and captures photos from the perspective of the person wearing it. It is equipped with a set of sensors reacting to changes in colour, brightness, temperature, perceived direction, and motion. The information from these sensors is then used to detect and take a photo at a "good" moment. In this study, Autographer cameras were set on a setting that took a photo on average every 10 seconds, with variance depending on the information from the sensors.

2.2.3 Stimuli

Fifty-eight predefined 'targets' – urban artefacts are seen during the walking tour, such as a unique building facet, an old police post, a church entry, and sculptures – were used to create the experimental stimuli. For each participant, photos of these predefined targets were selected from the full set of photos captured on their

Autographer during the tour, along with a sequence of three preceding photos. All other photos were discarded. After rejecting sequences with photos containing a recognisable object (e.g. the experimenter, participants' hand), the number of targets ranged from 48 to 56 for participants.

As a control for the sequences of 'tour photo', a set of 'new photo' sequences were constructed from Autographer photos captured on a different walk in a different location by the experimenter. For each participant, the number of new (control) sequences was adjusted to be equal to the number of tour (old) photos. Photos were shown on a CRT screen (resolution: 1264 x 790) with a large 30° * 40° visual angle.

2.2.4 Design and Procedure

The experiment consisted of two parts, a guided walking tour, followed by a recognition test with EEG a week later. Pairs of participants were taken on the guided walking tour while wearing the camera. The experimenter acted as the guide and ensured that the participants encountered each of the targets long enough for it to be captured on the Autographer. They were told to walk naturally as if they were exploring the area and their attention was not specifically drawn to the targets. Participants could talk and take a short break during the tour. All participants followed the same route and observed the same targets. The walking tour took place in the London Borough of Islington and City of London, London, UK, it was 3 miles long and took participants approximately 90 minutes to complete.

The recognition and EEG recording session took place after a one-week interval. For each condition (tour vs new photos), there were between 48 and 56 sequences of 4 photos, compiling on average 207 photos per condition. During the recognition task, the sequences of tour and new photos were presented in a random order, but photos within each sequence were kept in the correct temporal order (see Figure 2.1 for task design). Participants were instructed to use a response box and respond to each photo by pressing one of three buttons: ‘Don’t remember’, when they did not recognise the photo as one from the guided walking tour; ‘Familiar’, when they were sure that they remembered the photo from the tour but had no specific recollection of the context (what they were thinking, saying or doing); and ‘Recollection’, when in addition to remembering the photo from the tour they also recalled what they were experiencing during that time, such as what they were talking or thinking about. Photos were presented until participants responded, with 500 milliseconds inter-trial interval. The main responses were: ‘hit-recollect ‘– correctly recollected photos; ‘hit-familiar’ – correctly familiar photos; ‘miss’ – incorrect ‘don’t remember’ responses. ‘correct rejection’ – correct ‘don’t remember’ responses; and ‘false alarm’ – incorrectly recollected or familiar responses.

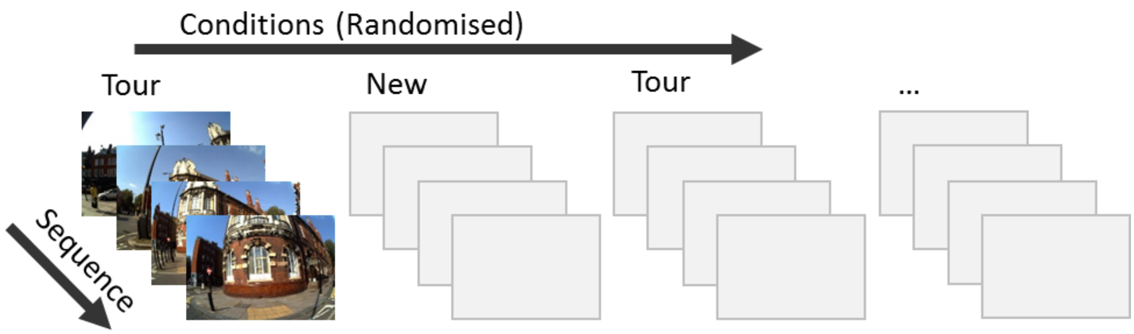

Figure 2.1: The design of the study: Four photos for each target on the walking tour were presented in the order in which they were captured. The order of targets and conditions within the experimental session was randomised. Participants had to respond to every photo they saw with no time limit, with 500 milliseconds inter-trial interval.

2.2.5 EEG Acquisition and Pre-processing

EEG was recorded using a 64-channel, BrainVision BrainAmp series amplifier (Brain Products, Herrsching, Germany) with a 1000 Hz sampling rate. The data were recorded with respect to FCz electrode reference and later re-referenced to the average signal of TP9 and TP10 electrodes. Ocular activity was recorded with an electrode placed underneath the left eye. Pre-processing steps were conducted using BrainVision Analyzer (Brain Products, Herrsching, Germany). A high pass filter of 0.5 Hz was applied along with an automatic ocular correction using the ocular independent component analysis. The data were then segmented from 200 ms prior to 800 ms after stimulus presentation. After a low pass filter of 20 Hz, automatic artefact rejection was applied excluding segments with a slope of 200 µV/ms and min-max difference of 200 µV in 200 ms interval. Baseline correction was applied to the 200 ms interval preceding the stimulus. After pre-processing, the mean amplitude for the given time window for every trial was exported from BrainVision Analyzer for statistical analysis to MatLab (Mathworks Inc, Natick, MA) and grand averages were computed in BrainVision Analyzer for visual inspection of ERPs.

2.2.6 Behavioural Analysis

This study was interested in how participants' hit rate, recollection rate, sensitivity (d'), and response bias changed across the sequence of four photos. For this reason, all these measures were computed 4 times, corresponding to each serial position in the sequence. The hit rate was measured as the proportion of hit responses (both hit-familiar and hit-recollected) to all responses to the tour photos (hits and misses) and the recollection rate as the proportion of correctly recollected responses (hit-recollect) to all hit responses (hit-recollect and hit-familiar). Additionally, for the analysis of sensitivity (d') and response bias, the false alarm rate was computed as the proportion of false alarms to all responses to the control photos (false alarms and correct rejections).

The sensitivity (*d'*) and the response bias (c) were computed from participants' hit and false alarm rates (Stanislaw & Todorov, 1999). The sensitivity provides information about participants' ability to discriminate between old and new photos and response bias provides information about participants' inclination to say 'remember' or 'don't remember'. The hit and false alarm rates used for this analysis were log-transformed to avoid undefined sensitivity values for extreme cases; hit rate of one, and false alarm rate of zero (Hautus, 1995).

To examine how these changed with the sequence, a one-way repeated ANOVA was used in which only the linear effect of the sequence was included. In order to explore where these effects lied within the sequence, post-hoc t-tests were used and their p values were adjusted with Bonferroni correction. These tests compared every step in the sequence with its neighbouring step (i.e. 1^{st} vs 2^{nd}, 2^{nd} vs 3^{rd}, & 3^{rd} vs 4^{th}).

To examine changes in participants' reaction times (RT) across conditions, responses, and the sequences, a 3 (response: familiar, recollect, & don't remember) by 2 (condition: tour & control) by 4 (sequence: first, second, third, & fourth photo) repeated measures ANOVA was used.

2.2.7 ERP Analysis

Based on the grand averages across hits and correct rejection, the mean amplitude between 135 to 450 milliseconds post-stimulus was examined in five regions of interest: (ROI) frontal (F1, F2, Fz), central (C1, C2, Cz), parietal (P1, P2, Pz), parieto-occipital (PO3, PO4, POz), and occipital (O1, O2, Oz) electrodes. Given that five ROIs were being examined, False Discovery Rate (FDR) correction was used for the p values obtained from these comparisons (Benjamini & Hochberg, 1995).

Two separate analyses were conducted to examine the mean amplitude of ERP differences between hits and correct rejections ('old-new effect'), and between hits-recollect and hits-familiar ('familiarity-recollect effect'). In both analyses, the effect of the sequence was examined. For these analyses, linear mixed-effects models were used (LME; Barr et al., 2013). This analysis considers participant-specific variability and accommodates the repeated measures study design. The fixed part of the model included the response, i.e. hit or correct rejection, when looking at the old-new effect, and hit-familiar or hit-recollect when looking at the familiarity-recollect effect. Additionally, electrodes within the ROI and the linear effect of the sequence as fixed factors were included. As random effects, an intercept, slope for the response, sequence, and the electrodes were all included for each participant, the interindividual variability in EEG amplitude was accounted for, and this, therefore, represented a "baseline" for each participant. The significance of fixed effects were computed by comparing a model with the fixed effect of interest with a model without it.

Unlike conventional ANOVA methods where epochs are first averaged across each condition for each participant, LME takes each epoch data (Barr et al., 2013). Doing so is advantageous as the models in this method consider that different conditions may have different variances and number of data points – a crucial weakness in ERP studies that is being improved by using linear mixed effect models (Koerner & Zhang, 2017; Tibon & Levy, 2015). Maximum likelihoods were used to estimate the parameters and Likelihood Ratio tests were used to attain significance levels (Bolker et al., 2009). Finally, the Benjamini-Hochberg method to correct for false discovery rate of multiple comparisons on different ROIs was performed (Benjamini & Hochberg, 1995).

2.3 Results

2.3.1 Behavioural Results

Participants' hit rates and recollection rates for different sequences are presented in Figure 2.2. The overall hit rate was 82.75%. There was a significant linear effect of sequence on participants hit rate $\left(F_{3,11} = 10.75,\ p = .007\right)$ as well as recollection rate $\left(F_{3,11} = 39.39,\ p < .0001\right)$. For the hit rate, post-hoc tests failed to depict a significant difference between any of the neighbouring steps in the sequences. For recollection rate, post-hoc tests showed a significant effect between sequence 1 and 2 $(t(11) = 3.9183,\ p = .007)$ as well as between sequence 2 and 3 $(t(11) = 3.2968,\ p = .02)$. This suggests a steady increase in participants hit responses and correct recollect responses with the sequence.

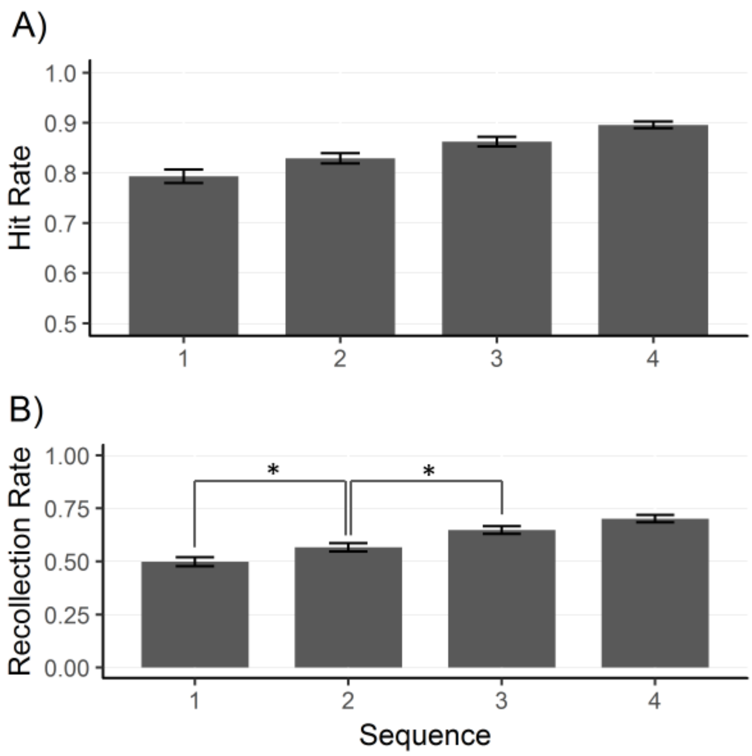

Figure 2.2: Hit and recollection rates: (A) Hit rate – the proportion of correctly remembered photos to all tour photos – across the sequence of photos (B) Recollection rate – the proportion of recollect responses to all hit responses – across the sequence of photos. Error bars represent standard error of the mean.

Participants' sensitivity (d') and response bias (c) are presented in Figure 2.3. There was a significant linear effect of sequence on sensitivity ($F_{1,11} = 30.10$, $p < .001$) but not on response bias ($F_{1,11} = 0.3$, $p > .05$). For sensitivity, post-hoc tests show that only the difference between sequence 3 and sequence 4 was significant ($t(11) = 3.155$, $p = .027$). This suggests a steady increase in participants' sensitivity with the later photos in the sequence.

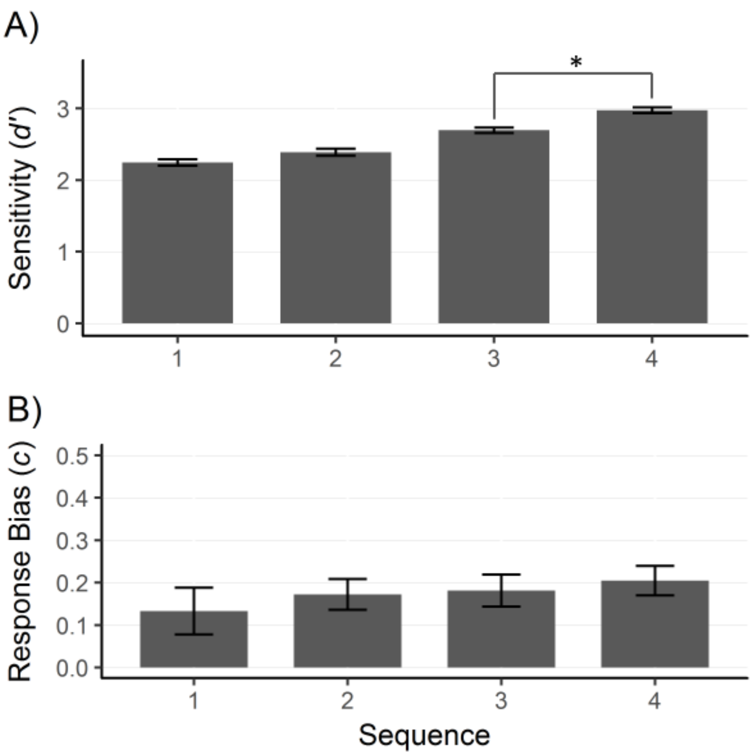

Figure 2.3: Sensitivity and Response Bias: (A) Sensitivity and (B) response bias for the pictures of the target in the sequence of photos. Error bars represent standard error of the mean.

Participants' RT for different conditions (tour/new) are presented in Figure 2.4. Participants took longer to respond to new photos in comparison to tour photos ($F_{1,11} = 15.68$, $p = .002$). There was an effect of sequence ($F_{3,11} =$

$12.14,\ p < .001)$ on RT, with participants taking longer to respond to the first compared to the later photos in a sequence. Three post-hoc t-tests with Bonferroni correction for multiple comparisons were performed to examine where the difference in RT lies within the sequence. Only the difference between sequence 1 and sequence 2 was significant $(t(11) = 3.475,\ p = .02)$. Finally, there was an effect of response type, i.e. 'Don't remember', 'Familiar', or 'Recollect' $(F_{2,11} = 16.91,\ p < .001)$. Post-hoc tests with Bonferroni correction on response showed no difference between don't remember and familiar $(F_{1,11} = .49,\ p > .05)$, but that 'recollect' responses were significantly faster than 'don't remember' responses $(F_{1,11} = 11.00,\ p < .01)$ and 'familiar' responses $(F_{1,11} = 32.62,\ p < .001)$. There were no interactions between response type, conditions, and sequence.

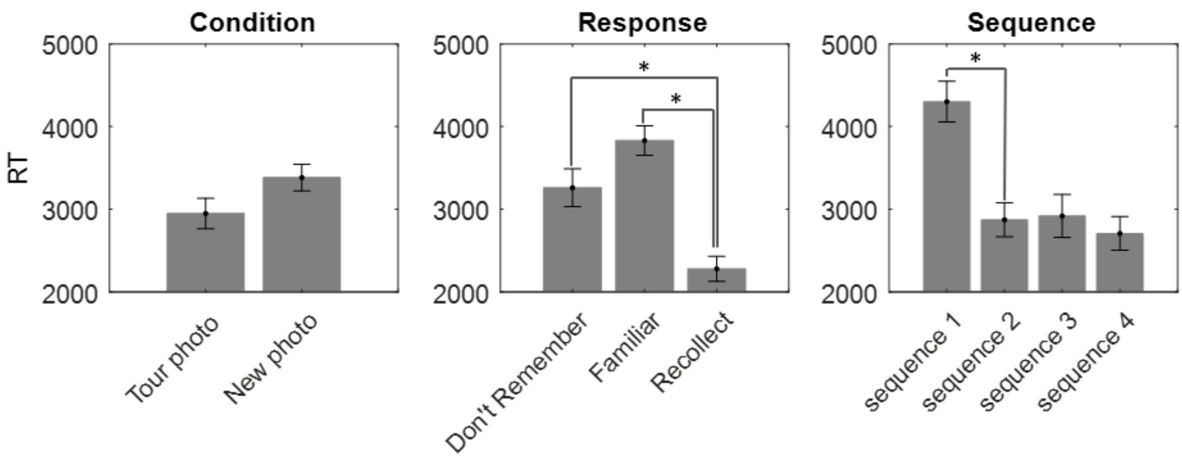

Figure 2.4: RT for different responses and conditions: (Left) RT for different conditions, (middle) responses, and (right) sequence. Error bars represent standard error of the mean

2.3.2 ERP Results

No differences between the hit-familiar and hit-recollect responses across any of the regions were found. The mean positive amplitude between 135 to 450 ms after stimuli presentation was significantly lower in response to hit conditions (hereafter old) compared to correct rejection (hereafter new) conditions at occipital electrodes ($X^2(1) = 12.02,\ p = .003$), parieto-occipital ($X^2(1) = 9.59,\ p = .005$), and that effect was also evident at parietal electrodes ($X^2(1) = 5.76,\ p = .027$). Figure 2.5 shows the old-new effects at occipital, parieto-occipital, parietal and frontal electrodes. There was no effect of sequence.

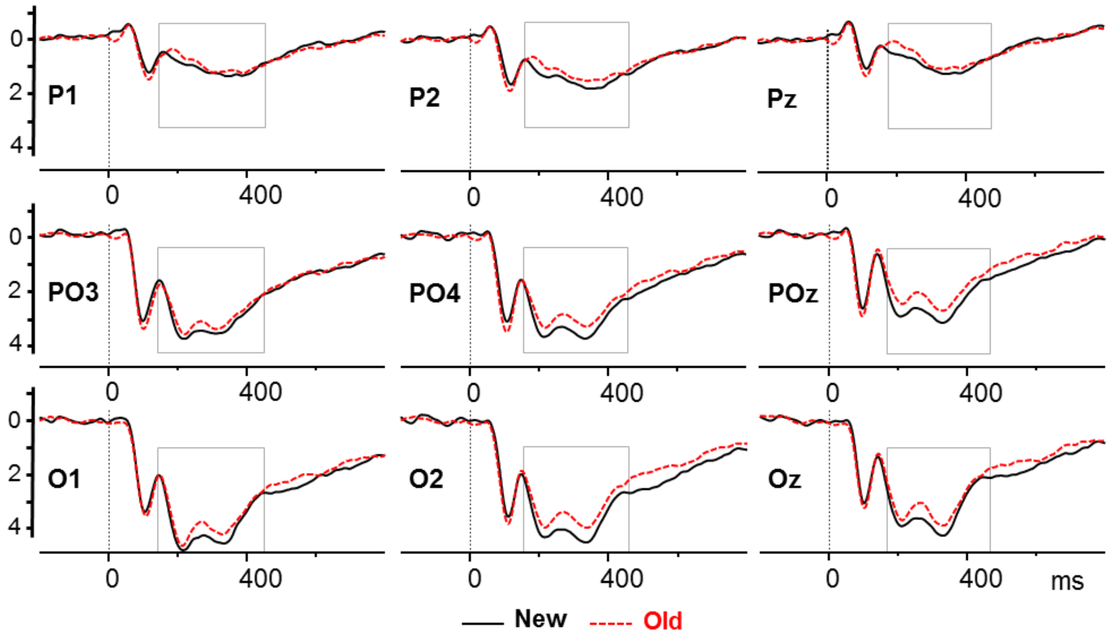

Figure 2.5: Old-new ERP components: ERP components after the presentation of the stimuli for central (C1, C2, Cz), parietal (P1, P2, Pz), parieto-occipital (PO3, PO4, POz), and occipital (O1, O2, Oz) electrodes. New (solid lines) after the presentation of stimuli participants correctly recognised as new (correct rejection). Old (dashed lines) after the presentation of stimuli participants correctly remembered (familiar and recollect hits). Time windows where the two ERP components are significantly different are depicted with shaded boxes.

2.4 Discussion

This study explored the behavioural and neural mechanisms underlying the wearable camera photo review by investigating the recognition of real-world events across sequences of photos, captured during a walking tour. It demonstrated that recognition performance improved across the sequence of four photos, with incremental increases in recollection and sensitivity. Analysis of brain activity using ERPs, revealed an old-new effect over frontal and occipital electrodes but showed that these were not modulated across the sequence of four photos.

Even though there are numerous studies demonstrating the benefits of wearable cameras (Chow & Rissman, 2017), the underlying mechanism of this enhancement has not been examined. A key feature of the wearable camera in its day-to-day use is that photos are captured and reviewed in sequential form, providing multiple exposures to temporally organised cues. This study specifically explored the relevance of this, by isolating sequences of four photos that led up to specific targets and using these to create a recognition task. Participants hit rates, along with their subjective feeling of recollection increased for later photos in the sequence. Importantly, this pattern was also true for sensitivity. Given that an everyday experience will typically generate a sequence with many hundreds of photos, this experimental study offers limited insight into the full potential of viewing photos in sequence, nevertheless, it is quite striking that this effect can be seen with just four photos. These results emphasise the benefit of seeing a sequence of related photos, which is a key feature of wearable camera photo review.

Since sequences of photos in random order were not included in this study, no inferences about the order of photos in the sequence can be made. However, a recent study has shown that sequences of photos in their natural order lead to a stronger final recollection of the events compared to randomly presented photos (Mair et al., 2017). One possibility is that there is an additive effect of the number of cues across the sequence. Since every photo in the sequence has a different perspective, each will contain its own unique combination of cues for the main memory event. Thus, each new photo in the sequence increases the possibility of providing a cue that is personally or environmentally salient.

A second possible explanation for the sequence effect is that a subthreshold reactivation of memories during the miss trials make the target memory more accessible in the next trial of that sequence. Each time a photo from the tour is presented, it has the capacity to act as a memory cue that reactivates the target memory. If this effect is strong enough, a recollection of the event occurs (i.e. hit trials). However, where the cue is not strong enough to trigger explicit episodic remembering (i.e. some miss trials), there may nevertheless be increased activation (see Conway & Loveday, 2015), which makes the target memory more accessible in the next trial of a sequence.

If the sequence does indeed lead to greater activation of the memory trace, then the neural basis remains elusive as there were no corresponding effects in the EEG analysis. This may, of course, reflect a lack of power, or it may be because this methodology is not able to detect these particular neural correlates, for example, if the changes occur at a more sub-cortical level. Nevertheless, there were important overall findings regarding neural activity: a positive old-new ERP component was observed over the visual electrodes from 135 to 450 milliseconds after the photo presentation onset, and the mean peak amplitude was larger in response to the presentation of photos correctly identified as new (correct rejections) compared to photos correctly identified as old (hits).

This ERP effect is different from that observed in other episodic memory ERP literature (Friedman & Johnson, 2000; Mecklinger et al., 2016; Mecklinger & Jäger, 2009; Rugg, 1994; Wilding & Ranganath, 2011). Usually, the old new effects found over the parietal regions have a higher amplitude for old compared to new items, whereas here this effect was reversed. However, this is somewhat expected and reflects the major differences between the paradigm used here and those used in most other ERP studies, namely the complex visual nature of stimuli and the longer retention time. While the laboratory-based episodic memory tasks typically use words or pictures as stimuli, here the stimuli were photos produced by wearable cameras. The visual information in wearable camera photos is more complex than lab-based stimuli; they have a wider visual angle, contain depth, typically have more items per target item, and contain autobiographical information. Due to this complex visual nature of wearable camera photos, it seems plausible that the visual old-new ERP effect reported here reflects the greater contribution of visual regions in recognition of these memories.

Furthermore, the retention interval of one week in this study has likely allowed for offline processes to consolidate the memories further in contrast to other ERP studies with short retention intervals of minutes. If successful, these processes will have changed how memories are stored and retrieved, making them rely less on hippocampus and more on cortical structures (Nieuwenhuis & Takashima, 2011; Squire et al., 2004). This may explain why this study failed to observe a typical parietal old-new effect here and why others have documented attenuated or no parietal old-new ERP effect after long retention intervals of one or four weeks (Roberts et al., 2013; Tsivilis et al., 2015). In addition, since the cortical structures responsible for the visual content of the memories are likely the visual regions, it seems sensible that as a result of consolidation processes the visual regions are contributing to the recognition of these memories. Consequently, as a result of the consolidation processes that have occurred during the one-week retention interval and the visual nature of the stimuli, it is likely that the visual old-new ERP reflects the contribution of the visual regions in recognition of real-world memories.

No differences in the ERPs between the subjective experience of familiarity vs recollection responses was observed. This suggests that participants responses on whether they had recollected contextual information was not reflected in our observed ERP components. One explanation for this finding is that in our study both the new and old photos looked very similar (both were urban areas of London, UK) hence participants recognition memory in order to differentiate between the photos had to rely more on recollection mechanisms than familiarity-based mechanisms. This is also reflected in the increase in recollection with the sequence. Therefore, it may not be surprising that no effect of familiarity was observed. An alternative explanation would be that ERPs are not sensitive enough, in which case, analysing the underlying oscillatory activity might be more sensitive. This is because during ERP analysis a large amount of the EEG signal, the non-phase locked activity, is lost.

There are several factors that future studies should consider in order to achieve a better understanding of how wearable cameras help memory and eventually create better memory enhancement strategies. One important consideration is the *frequency* at which the camera takes the photos, since this establishes how many images are available for review and may also impact on the overlap and variation in cues. Another important factor is the *number* of photos used. In an everyday setting, the user can view long sequences of hundreds or even thousands of images, but this is not practical in studies that are assessing the mechanisms. Ideally, sequences should be short enough to allow convenient organisation and management of images, but long enough to allow the “Proustian moment” to occur (Loveday & Conway, 2011). Although four photos seemed sufficient to detect a sequence effect, it is unclear at which point, if at all, this effect plateaus. This will be crucial in deciding an optimal number of photos for memory enhancement paradigms.

This novel paradigm has allowed us to observe the positive influence of sequence during wearable camera photo-review, but it is essential that future research explores whether this effect is maintained in people with clinical impairments of memory. This not only has important practical implications but may also shed more light on the underlying neural mechanisms. While no ERP correlates of the sequence effect were found in this study, an old-new effect over the visual electrodes was observed that has not been previously seen. This may suggest that for long retention intervals these areas store some of the memories. Furthermore, this likely emphasises the role of visual cortices in recognition of episodic autobiographical memory and highlights the importance of using ecologically valid methods to explore autobiographical remembering.

Chapter 3: Aiding Autobiographical Memory Performance, A Case Study

Changes in the neuroanatomical structure of the brain can result in memory impairments. There is a growing number of case studies of people with memory impairments that use wearable cameras to aid the recollection of everyday events. Wearable cameras are small devices which automatically take a series of photos from the perspective of the wearer. These photos are later used as memory cues to retrieve the original events. The beneficial effect of the photo review seems to be attributed to its sequential nature, argued to induce an intense burst of recollection, referred to as a "Proustian moment" (Loveday & Conway, 2011). While there are a number of case studies supporting this effect (Silva et al., 2016), the underlying mechanism of this process is not well understood. To explore the sequence effect in a more quantitative manner, CR, a woman with memory impairment caused by encephalitis along with 12 healthy controls were taken on a predefined walking tour while wearing a wearable camera. Sequences of photos from the tour were taken along with control photos and used in a recognition task. CR performed the paradigm in three different conditions, once with a 3 hours retention interval, once with a one-week retention interval, and once with a one-week retention interval, where she had the opportunity to review the photos on the first and second day from the walking tour. Healthy participants were only tested with a one-week retention interval, without viewing the photos. For healthy individuals, and CR when tested on the same day, the sequential presentation of photos improved memory performance. However, when CR was tested with a one-week retention interval, with or without reviewing the photos during the retention interval, her overall memory performance was lower and the sequential presentation led to more false 'remember' responses. These results emphasise the role of sequential presentation of photos in improving the recollection of memories. However, they also point to an effect of sequence leading to more false positives. This suggests that wearable camera photo review should be studied in quantitative ways to better understand the optimal condition under which it can work as a good memory cues without leading to more false alarms.

3.1 Introduction

Changes in neuroanatomical structures of the brain sometimes hinder the storage, retention, and recollection of memories resulting in memory impairments (O'Connor & Verfaellie, 2002). These changes sometimes develop over long periods of time such as many years in the case of Alzheimer's disease (Becker & Overman, 2002) or short periods of time such as in the case of head injury, or viral infections (Caine & Watson, 2000). While there are a few cases in which memory damage is temporary, such as in transient global amnesia, where memory functions are restored after the onset of the condition (Goldenberg, 2002), memory impairments are generally permanent and gradually worsen over time (O'Connor & Verfaellie, 2002). Therefore, they can significantly impair patients' social and occupational life. In addition to the direct effect of memory impairment, the emotional distress from these conditions can negatively influence the quality of life of people with memory impairments (Lyketsos et al., 2003).

External memory aids have successfully been used to improve the lives of people with memory impairments (see Kapur et al., 2002 for a review). Most of these devices help prospective memory, that is, they help the person to remember to perform an activity in future, such as taking medication or attending a meeting. These include but are not limited to diaries, calendars, post-it notes, and timers; cases studies have shown that they improve the independence of people with memory impairments (Kime et al., 1996; Oddy & Cogan, 2004). In addition to these prospective memory aids, other devices have been devised to aid the memories of previously occurred personally experienced events. One such device is the wearable camera. These cameras take photos from the perspective of the wearer, also known as a lifelogging technology they "log" the visual experience of an event as it unfolds from the perspective of the wearer. Remembering personally experienced events are important as they contribute to the sense of self. As proposed by Conway and Pleydell-Pearce (Conway, 2005; Conway & Pleydell-Pearce, 2000) through their Self-Memory System (SMS), memory and self are interconnected. As episodic memories contribute to a knowledge base about one's self, this knowledge base then acts as a "data base of the self" (Conway, 2005). For this reason, aiding the recollection of autobiographical memories can contribute to the preservation of a coherent sense of self as well as supporting the recollection of personally experienced events.

Several case studies have used wearable cameras as a means to aid the recollection of personally experienced events in people with memory impairments. For example, Berry et al. (2007) have shown that Mrs B, a 63 years old person with memory impairment as a result of limbic encephalitis, recollects more personally experienced events after reviewing wearable camera photos in contrast to reviewing written diaries. In this study, Mrs B was taken on a number of different interesting and non-routine activities while wearing a wearable camera. One day after the activities Mrs B was asked to recall information about the events. During this, her husband rated Mrs B memories in percentages of information remembered from the events. After this recall task, Mrs B with the assistance of her husband either reviewed wearable camera photos or her written diaries. This process was repeated every two days for 7 times, then after a month, and three months. There was also a baseline condition in which no memory aid was used. After reviewing the photos Mrs B was able to recall 80% of the details of the memories, for a retention interval of a three month. This was in contrast to the diary review condition in which Mrs B was able to recall 50% of memories for a retention interval of 14 days. This study was the first to demonstrate the beneficial effects of the wearable camera in a person with memory impairment, by showing that wearable camera photos can act as memory cues that are able to retrieve memories that are otherwise inaccessible.

Loveday and Conway (2011) examined the beneficial effects of the wearable camera for CR, a 54-year-old person with memory impairment as a result of herpes simplex viral encephalitis. CR was instructed to use the wearable camera and write diary entries for an event, every day for four weeks while naming the events. During the weekends, CRs husband performed a memory recall task with CR, in which CR was initially told the name of the events in order to remember the details of these events. After this initial recall, CR either reviewed the wearable camera photos or her written diary entries. Overall, CRs recalled information was more detailed and more specific following the photo review exercise compared to reading her written diary entries. Loveday and Conway (2011) suggested that the photo review induces a “Proustian moment”, a moment in which an intense recollection is experienced as images of the past flood into consciousness.

Another study has examined the use of wearable camera photo review in helping Mr A, a person with memory impairment as a result of a brain injury (Brindley et al., 2011). For a set of events, Mr A was assigned to one of three conditions. In the first condition, he used the wearable camera, in the second condition he wrote down his memories using a conventional psychotherapy aid called automatic thought record sheets, and finally, in a control condition, he did not use any aid strategies. There was one event per condition. He then performed a recall task similar to that of Berry et al. (2007) and Loveday & Conway (2011) one week after as well as twice every week for the next three weeks. Mr A remembered twice as many details when he reviewed the wearable camera photos compared to the other conditions.

In addition, to studies exploring the positive effect of wearable camera photo review in people with memory impairments, several studies have explored it in healthy individuals. For instance, in a study by Mair, Poirer, and Conway (2017) young and older adults with no memory impairments wore the camera during approximately 15 events across a one-week interval, each of the events taking between 30 minutes to an hour. They also generated titles for these events. After two weeks, participants were given one of three different types of cues and were asked to recall as much information as they could. These cues were either participants' generated titles of the events, these self-generated titles along with the wearable camera photos in a forward sequence, or the self-generated titles along with the wearable camera photos in a random sequence. Participants' recalled information was then rated. The recollection was more detailed in the conditions where self-generated titles were accompanied by wearable camera photos. Furthermore, self-generated titles with a forward sequence of photos led to a slightly better recollection relative to self-generated titles with a random sequence of photos. In another study by Sellen et al. (2007), participants performed a recall task before and after reviewing wearable camera photos at different retention intervals of 3 days, 10 days, and 4 months. In all retention intervals, recall increased after the photo review.

In addition to using wearable camera photo review as a memory cue, there is some evidence for the use of it in enhancing future memory performance. In one study, participants were asked to use the cameras during their daily activities for five days. On two of these days, they were told to review the photos in the evening (Finley et al., 2011). A number of memory tests were performed after 1, 3, and 8 weeks. Participants recognition test performance was higher for the days they had reviewed the photos. In another study, the long-term enhancement effect of the wearable camera photos has been explored in relation to how the photo review takes place (St. Jacques & Schacter, 2013). Here participants were taken on a museum tour while wearing the wearable camera, they performed a photo review two days after the tour, and a recognition task two days after that. During the photo review session, in the 'perspective match' condition photos taken with participants cameras were shown, while in the 'perspective mismatch' condition photos taken from a different perspective by the experimenter were shown. Additionally, photos were either presented in the natural order, 'temporal order match' or in a random order 'temporal order mismatch'. During the recognition task, both match conditions resulted in a higher hit rate, however, they also led to an increase in participants' false alarm rate.

Overall, while case studies, as well as studies with healthy individuals, have demonstrated the beneficial use of wearable camera photo review as a means to recollect memories that are otherwise lost (see Chow & Rissman, 2017; & Silva et al., 2016 for reviews) the underlying mechanism of this process is not clear. One reason is that these studies have used a diverse set of paradigms for encoding and test phases. For instance, some use the camera to capture non-routine special events while others use it to capture everyday events. Despite these differences, a common feature of wearable camera photo review is that photos of the events are presented one after another in a sequential manner. It has been shown that sequences of photos that are in their natural order lead to a better recollection of memories compared to sequences of photos in random order (Mair et al., 2017). Furthermore, when using wearable camera photos as a means to enhance future recollection of memories, sequences in their natural order appear to influence the memories more than sequences of photos in random order (St. Jacques & Schacter, 2013). And finally, as presented in chapter 2, the sequential presentation of wearable camera photos improves the recognition performance in people with no memory impairment. While the sequential presentation is possibly a central feature of the wearable camera photo review, its role in aiding the recollection of memories in people with memory impairments has received little attention.

The aim of this case study was to explore whether the sequential presentation of photos has a positive impact on the recognition of memories in a person with memory impairment. Furthermore, it explored how the effect of the sequential presentation of photos on recognition memory was modulated depending on the retention intervals as well as the presence of a photo review session. EEG was also used to examine how the memory-related ERPs are modulated for CR during the sequential presentation of the photos (see chapter 2 for more information). However, since there was difference in the controls participant's memory related ERP's over the sequence this analysis was not conducted for CR. To examine this, CR, a 54 years old woman with amnesia as a result of encephalitis and healthy age-matched control participants with no memory impairments were taken on a predefined walking tour. The data from control participants are presented in chapter 2. During this tour, participants observed a set of predefined targets while wearing the camera. Additional photos were taken by the researcher from targets participants had not seen (new photos). Four photos leading to each target were selected and used in recognition tasks. CR performed the task on three occasions, once with 3 hours retention interval between the tour and the recognition task, once with one-week retention interval, and once with one-week retention interval where she had the opportunity to review the photos during the retention interval in the first and the second day. Control participants only performed the task with a one-week interval with no photo review during the retention interval. This design allowed the examination of the sequential presentation of photos in the recognition of memories. Furthermore, the long-term effects of the wearable camera photo were examined. Due to the nature of case studies, no specific hypotheses are made. However, this study has two main aims; to examine the impact of sequential presentation of wearable camera photos as a means to aid the recollection of personally experienced events: and the impact of reviewing the wearable camera photos during the retention interval as a means to enhance the final recognition performance in a person with memory impairment.

3.2 Methods

3.2.1 Participants

Case: CR is a 54-year-old female with acquired amnesia due to herpes simplex viral encephalitis contracted nine years previously. She has significant cortical damage to the right side of her brain, including a large portion of the medial temporal lobe extending to the fusiform gyrus, basal ganglia, the insula, and the inferior frontal lobe. She has severe retrograde amnesia, with very few episodic memories between the age of 20 and the time of her illness (age 45). Earlier memories do have some recollective qualities but are sparse, patchy and largely inflexible. CR also has significant levels of anterograde amnesia, with few memories that are more than a day or two old. CR’s rapid forgetting can be seen as a form of accelerated long-term forgetting (ALF), whereby she is able to form memories but they are soon forgotten (Elliott et al., 2014). See table 3.1 for a brief overview of her neuropsychological assessments.

Table 3.1: Summary of CR's neuropsychological assessments.

Cognitive domain (test)	Performance
Estimated premorbid IQ (NART)	High Average
Verbal immediate recall (Hopkins Immediate recall)	Average
Verbal Learning (Hopkins learning)	Average
Delayed Verbal Recall (Hopkins delayed recall)	Low Average
Working Memory (Letter-Number Sequencing)	Scaled Score = High Average
Verbal Fluency (Verbal Fluency)	Average
Semantic Fluency (Semantic Fluency)	Average
Autobiographical Memory (ATM)	Very poor

Control participants: Twelve females were recruited to provide control data. Their ages ranged from 45 to 55 ($M = 51.12, SD = 3.76$), they came from a range of professional backgrounds, and they reported no neurological or psychiatric history.

Control participants received £32 monitory compensation for their effort, CR received monetary compensation and transport costs to reach London. The study was approved by the Psychology Department Ethics Committee of City, University of London.

3.2.2 Procedure & Design

Methods for this study are similar to that of chapter 2. The experiment consisted of two parts, a guided walking tour, followed by a recognition test after a retention interval. Participants were taken on the guided walking tour while wearing a wearable camera called Autographer. While control participants performed the task once with one-week retention interval between the tour and the recognition task, CR's performed the task three times. First, she performed the task with a one-week retention interval. Two months later, she performed the task with a three hours retention interval. Finally, after another two months, she performed the task with a one-week retention interval but this she had the opportunity to go through the photos in the first and second day in her own pace. Additional walking tours were created for different conditions in which CR took part so that she was not taken on the same tour more than once.

The general structure of the walking tour was as follows. The experimenter acted as the guide and ensured that the participants encountered each of the targets for long enough for it to be captured on the wearable camera. They were told to walk as if they would if they were exploring the area and their attention was not specifically drawn to the targets. Participants could talk and take a short break during the tour.

The tour that was used for control participants and CR when her memory was tested with one-week retention interval took in the London Boroughs of Islington and the City of London, London, UK, it was 3 miles long and took participants approximately 90 minutes to complete. It started from City, University of London and ended in St. Pauls cathedral. There were between 48 and 56 and targets for the control participants and 60 for CR in this condition. A second tour was created for CR to be tested in the recognition task on the same day, this was from Kings Cross station to City, University of London. There were 55 targets for CR in this tour. Finally, a third tour was created for CR to be tested in the recognition task one week later but in which she would review the photos on the first and the second day of the following week, this was also from Kings Cross station to City, University of London but through a different route relative to the second tour.

During the recognition task, sequences of four tour photos along with sequences of four photos participants had not seen (new photos) were presented. Each sequence contained the photos in their natural order, however, the sequences themselves were presented in a random order (see Figure 3.1 for task design). Participants were instructed to use a response box and respond to the photo by pressing one of three buttons: ‘Don’t remember’, when they did not recognise the photo as one from the guided walking tour; ‘Familiar’, when they were sure that they remembered the photo from the tour but had no specific recollection of the context (what they were thinking, saying or doing); and ‘Recollection’, when in addition to remembering the photo from the tour they also recalled what they were experiencing during that time, such as what they were talking or thinking about. Photos were presented until participants responded, with 500 milliseconds inter-trial interval. The key conditions explored were: ‘hit-recollect ‘– correct recollect; ‘hit-familiar’ – correct familiar; ‘hits’ – total correct familiar and recollect; ‘correct rejection’ – correct don’t remember; and ‘false alarm’ – incorrect recollect or familiar responses.

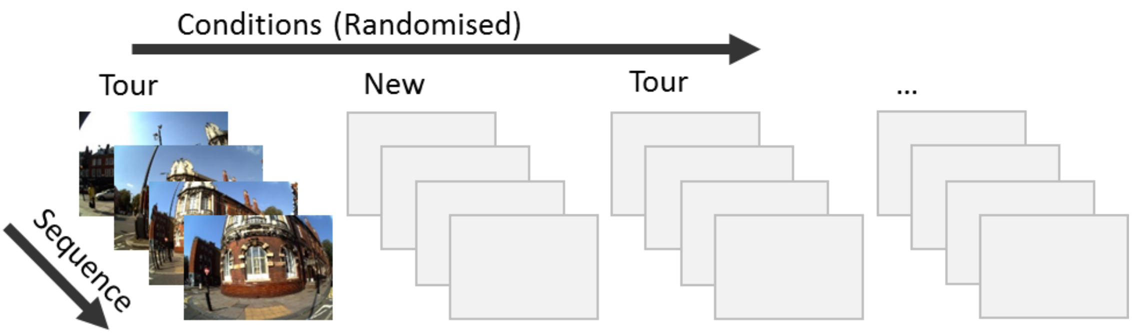

Figure 3.1: The design of the study: Four photos for each target on the walking tour were presented in the order in which they were captured. The order of targets and conditions within the experimental session was randomised. Participants had to respond to every photo they saw with no time limit, with 500 milliseconds inter-trial interval.

3.2.3 Stimuli

Predefined ‘targets’ – urban artefacts seen during the walking tour, such as a unique building facet, an old police post, a church entry, and sculptures –

were used to create the final experimental stimuli. For each participant, photos of these predefined targets were selected from the full set of photos captured on their Autographer during the tour, along with a sequence of three preceding photos. All other photos were discarded. After rejecting sequences with photos containing a recognisable object (e.g. the experimenter, participants' hand), there were 55 items in day condition of CR, 60 in week condition, and 50 in the week with photo review condition. For controls, there were 48 and 56 items in the tour.

As a control for the sequences of 'tour photos', a set of 'new photo' sequences was constructed from Autographer photos captured on a different walk in a different location by the experimenter. This process was repeated for CRs additional conditions. For each participant, the number of new (control) sequences was adjusted to be equal to the number of tour (old) photos. Photos were shown on a CRT screen (resolution: 1264 x 790) with a large 30° * 40° visual angle.

3.2.4 Data Analysis & Statistics

Overall. To examine changes in participants' subjective feeling of recollection over the sequence of photos, the proportion of correct recollect responses to all hit responses (recollect and familiar) were computed for each of the photos for the sequence. This is referred to as the recollection rate. For objective measures, hit rates were computed as the proportion of correctly identified old items ('familiar' or 'recollect') to all old items and correct rejection rates was computed as the proportion of correctly identified new items ('don't remember') to all new items. Sensitivity (*d'*) and response bias (*c*) were calculated as measures for participants' ability to distinguish between old and new and their tendency to use one or the other response (Stanislaw & Todorov, 1999). Higher sensitivity scores suggest better differentiation between the old and the new items. Larger response bias suggests a tendency to answer with 'remember' and a lower response bias suggests a tendency to answer with a 'don't remember' response while higher response bias suggests a tendency to answer using a 'remember' response. Modified t-tests were used to compare the overall CRs performance to controls (Crawford & Howell, 1998).

Across the sequence. Performance across the sequence was plotted for visual observation. Since there was only one data point from CR for each sequence, no statistical test was performed in order to examine the effect of sequence on CRs performance, instead, these data were visually inspected and interpreted. Furthermore, changes in recognition task related to the sequence were not statistically compared across the conditions of CR and control participants, these were only described by visual observation of the data.

3.2.5 EEG acquisition and analysis

The EEG set up was identical to that presented in chapter 2. The aim of this study was to explore how the memory-related ERP effects are modulated depending on the sequential presentation of the photos. However, as shown in chapter 2, this effect was not found in control participants and therefore was not examined for CR either. Instead, the old-new ERP effect which was found in control participants (135 - 450 ms, parieto-occipital electrodes) was compared to that of CR's. This was done by first computing the difference waves between the correct rejection and hit conditions and then comparing this difference waves between control participants and CR. Since old-new ERPs are modulated depending on the retention interval (Roberts et al., 2013; Tsivilis et al., 2015) and control participants performed the task with one-week retention interval, CR's data from the condition with three hours retention interval was not used in this analysis. The mean amplitude for the difference wave from 135 to 450 ms after the presentation of the photos was compared between CR and control participants for parieto-occipital electrodes because this was the region where a significant effect was found in the control participants (see chapter 2).

3.3 Results

3.3.1 Overall Recognition Performance

Recollection rate, hit rate, and correct rejection rate for CR in different conditions relative to controls performance is shown in Figure 3.2. Sensitivity and response bias for CR in different conditions relative to controls performance is shown in Figure 3.3.

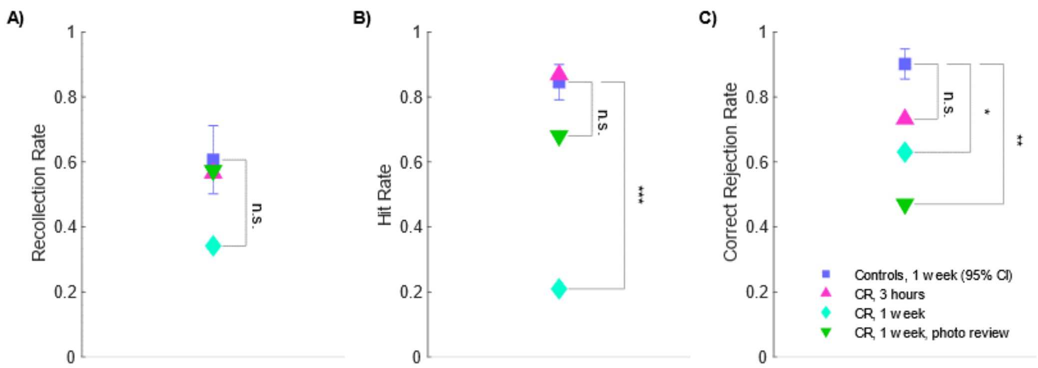

Figure 3.2: Recollection rate, Hit rate, & Correct Rejection rate: A) Depicts recollection rates for CR in different conditions and controls mean hit rate with its 95% confidence interval. B) Depicts hit rates for CR in different conditions and controls mean hit rate with its 95% confidence interval. C) Depicts correct rejection for CR in different conditions and controls mean hit rate with its 95% confidence interval. Asterix indicates significance levels of the modified t-test comparing CRs results to controls (* p<.05, ** p<.01, *** p<.001).

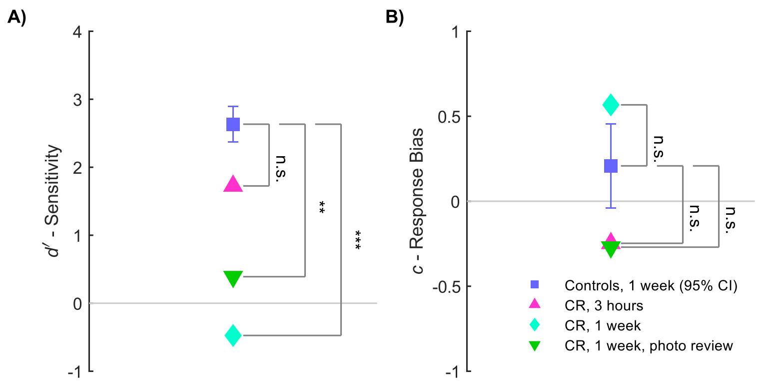

Figure 3.3: Sensitivity and Response Bias: A) Depicts sensitivity for CR in different conditions and controls mean sensitivity with its 95% confidence interval. B) Depicts response bias for CR in different conditions and controls mean response bias with its 95% confidence interval. Asterix indicates significance levels of the modified t-test comparing CRs results to controls (* p<.05, ** p<.01, *** p<.001).

Table 3.2 shows the scores for these measures for CR tested in different conditions relative to the mean scores for control participants. This table also shows the results of the modified t-test comparing the scores of CR to controls. The key findings here are that CR's sensitivity in the condition with one-week retention interval, with photo review (0.39) or without (-0.47) was significantly lower than the sensitivity for control participants $(M = 2.63,\ smallest\ difference\ \ t(11) = \ 3.943,\ p = .002)$. However, CR's sensitivity in the condition with 3 hours retention interval (1.73) was not significantly different from control participants sensitivity with one-week retention interval $(M = 2.63,\ t(11) = \ 0.844,\ p > .05)$.

Table 3.2: Recognition Performance Control vs CR: This table depicts the score for CR as well as the mean and SD for different measures of the recognition task and the modified t-test comparison between CRs data with controls.

	Controls; week interval		**CR; 1-week interval, with photo review**			**CR; 1-week interval**			**CR; 3 hours interval**		
	Mean	SD	score	*t* (df=11)	p	score	*t* (df=11)	p	score	*t* (df=11)	p
Recollection rate	0.61	0.22	0.57	0.144	> .05	0.34	1.154	> .05	0.57	0.179	> .05
Hit rate	0.85	0.11	0.68	1.394	> .05	0.21	5.364	<.001	0.87	0.193	> .05
Correct Rejection rate	0.9	0.1	0.47	4.251	.001	0.63	2.674	.021	0.73	1.67	> .05
***d'* - Sensitivity**	2.63	0.55	0.39	3.943	.002	-0.47	5.462	<.001	1.73	1.596	> .05
***c* - Response Bias**	0.21	0.52	-0.27	0.886	> .05	0.57	0.665	> .05	-0.25	0.844	> .05

3.3.2 Recognition Performance Over the Sequence of Photos

Across the sequence. Changes in the recollection rate, hit rate, and correct rejection rates across the sequence are presented in Figure 3.4 and changes in the sensitivity and response bias across the sequence are presented in Figure 3.5. There was a significant linear effect of sequence on control participants' recollection rate $\left(F_{3,11} = 39.39,\ p < .0001\right)$, hit rate $\left(F_{3,11} = 10.75,\ p = .007\right)$, as well as correct rejection $\left(F_{3,11} = 8.48,\ p = .014\right)$, but not on response bias $(F_{1,11} = 0.3,\ p > .05)$.

When CR was tested with three hours retention interval her recollection rate, hit rate, correct rejection, and sensitivity followed a pattern similar to that of controls, while her response bias slightly lowered with the sequence. When CR was tested with one-week interval her recollection rate and hit rate increased with the sequence, however her correct rejection decrease. Furthermore, while her sensitivity did not change across the sequence her response bias decreased. Finally, when CR was tested with a one-week interval during which she reviewed the photos, her recollection rate and hit rate increased with the sequence and her correct rejection rate decreased. In this condition, her sensitivity or response bias did not change over the sequence.

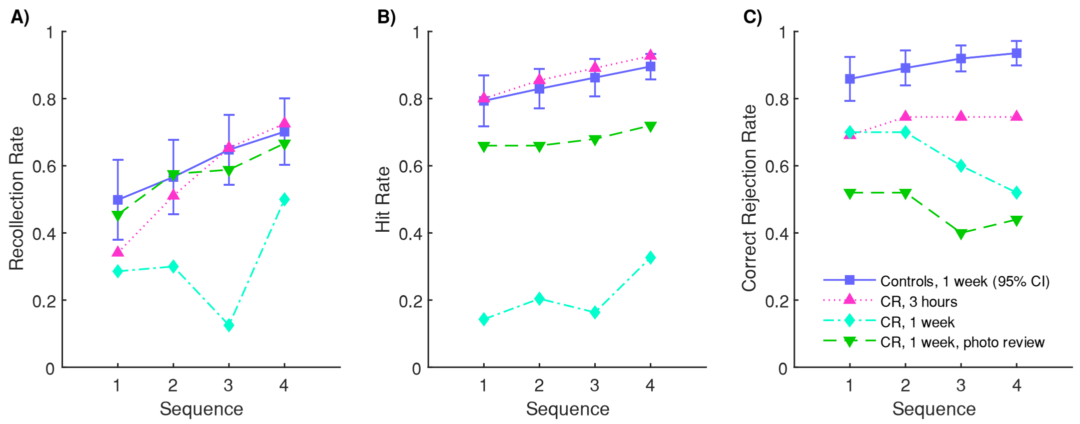

Figure 3.4: Recollection rate, Hit rate, & Correct Rejection rate over the sequence: A) Depicts recollection rates for CR in different conditions and controls mean hit rate with its 95% confidence interval across the sequence. B) Depicts hit rates for CR in different conditions and controls mean hit rate with its 95% confidence interval across the sequence. C) Depicts correct rejection for CR in different conditions and controls mean hit rate with its 95% confidence interval across the sequence.

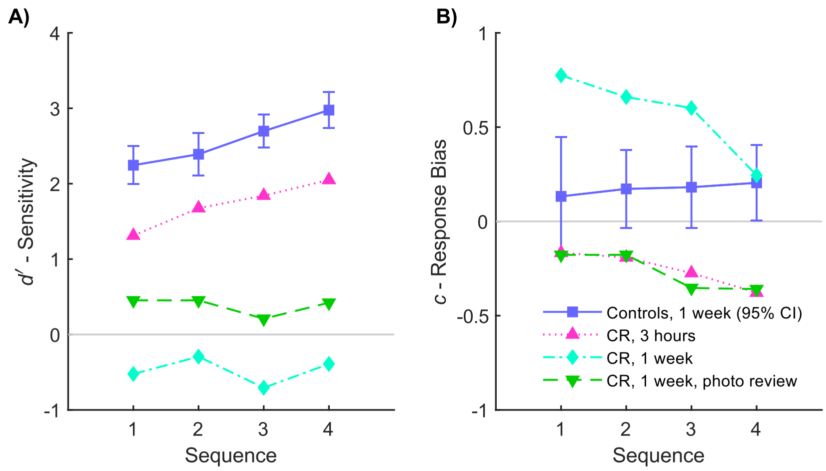

Figure 3.5: Sensitivity and Response Bias across the sequence: A) Depicts sensitivity for CR in different conditions and controls mean sensitivity with its 95% confidence interval across the sequence. B) Depicts response bias for CR in different conditions and controls mean response bias with its 95% confidence interval across the sequence.

3.3.3 EEG

Figure 3.6 compares the difference wave (correct rejection minus hit) between CR and control participants. The mean amplitude for CR's difference ERP when she was tested with one-week retention interval (0.51) and when tested with week retention interval during which she also reviewed the photos (0.36) were no different from that of controls ($M = 0.11, SD = 0.31;\ t(11) = 0.808, p > .05;\ t(11) = 1.268, p > .05$). This suggests that the old-new ERP effect for CR was not significantly different to that of Controls.

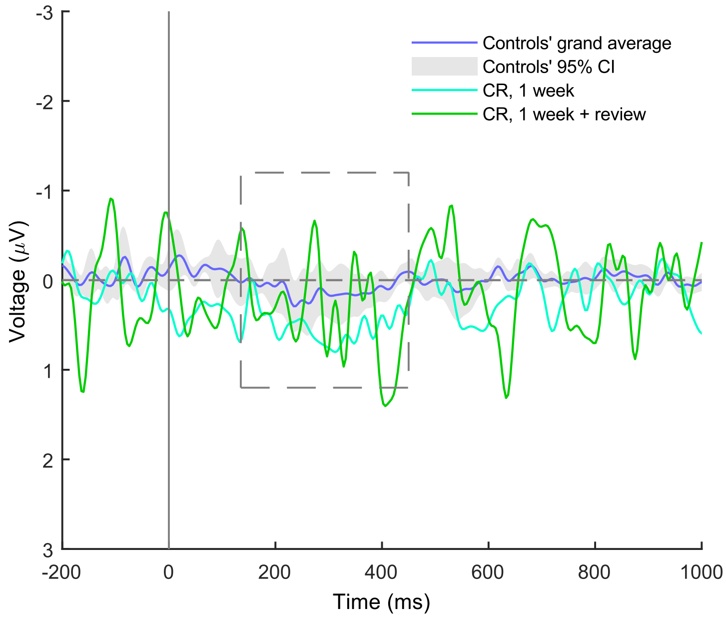

Figure 3.6: ERPs CR vs Controls: The ERPs for the difference wave between correct rejection and hit conditions are plotted for CR in the conditions with one-week retention interval and control participants.

3.4 Discussion

In this study, the effect of the sequential presentation of wearable camera photos in recognition of personally experienced events was examined in a person with memory impairment along with age-matched controls. For the retention interval of one-week, control participants had a high hit rate as well as sensitivity, and the sequential presentation of the photos improved these measures (see chapter 2). CR in the condition with a one-week retention interval had a near chance level sensitivity. The sequential presentation of photos lowered her response bias, making her more likely to use a remember response. However, when CR was tested with a three hours retention interval her performance was not significantly different from the control participants' performance when tested with one-week retention interval. She had a high hit rate as well as sensitivity and these measures improved with the sequential presentation of the photos. Finally, when CR was tested with one-week retention interval while reviewing the wearable camera photos during the first and the second days of retention interval, her performance did not improve much relative to the condition with a one-week retention interval but no photo review. Her sensitivity was still close to chance level but her response bias was lower. That is, reviewing the photos as a means to enhance her memories did not improve her memories but made her use a remember response more often. While it was planned to use the EEG to explore CR's memory related ERP's in response to the sequential presentation of the photos, this analysis was not performed since as discussed in chapter 2 no such effect was present in the control participants. However, the old-new ERP effect that was observed in control participants was compared with CR's. This analysis showed no difference between CR's and Controls' ERPs. While this would suggest that neurophysiological mechanisms for CR's are not different from control participants, it is more likely that these ERP comparisons are not a reliable measure of the neurophysiological mechanisms employed by CR. This is because EEG for one person is quite noisy and therefore very difficult to interpret.

It is suggested that the sequential presentation of the wearable camera photos induces a "Proustian moment", an intense recollection of episodic details from the original event in people with memory impairments (Berry et al., 2007; Loveday & Conway, 2011). The results of this study showed that when CR had a high recognition performance, that is in the condition with three hours retention interval, the sequential presentation of photos improved her subjective feeling of recollection, the recollection rate, as well as the objective measures of the task, the hit rate, correct rejection rate, and sensitivity. This supports the notion that the sequential presentation of the photos can improve the recollection of the memories (Berry et al., 2007; Brindley et al., 2011; Loveday & Conway, 2011). However, it is important to note that, as discussed in chapter 2, the behavioural changes associated with the sequential presentation of photos may not necessarily depend on the photos being presented in their natural temporal order. That is sequential presentation of randomly ordered photos may also induce similar behavioural effects.

Interestedly, the results of this study also point to potential negative effects of sequential presentation of photos when the overall memory performance is poor, i.e. recognition performance is near chance level. For instance, when CR was tested with a one-week retention interval, her recognition performance was close to being to chance level. In this condition, her ability to distinguish new and old photos as measured with sensitivity did not improve with the sequential presentation of photos while her tendency to respond using a ‘remember’ response increased. In other words, the sequential presentation of photos caused CR to use a ‘remember’ response more often but it did not help her differentiate between old and new photos. An important notion to consider regarding this finding is that studies using wearable cameras to aid the recollection of memories almost never measure false recollection (Silva et al., 2016). While in real life, no false photos would be appended to one’s wearable camera photo collection, the sequential presentation of photos can still lead to false recollections of memories which do not correspond to the actual events that were captured with the wearable camera. Overall, the sequential presentation of wearable camera photos seems to only be useful when the overall recognition memory is high, otherwise, it leads participants to use more ‘remember’ responses without actually improving their ability to distinguish between old and new items.

Wearable camera photos reviews have been shown to improve future recollection of memories (Finley et al., 2011). This notion was examined by comparing CR’s memory performance in a condition where she reviewed the photos during the retention interval with a condition where she did not. Both conditions had a one-week retention interval. When CR reviewed the photos during the retention interval, her recognition did not improve, her sensitivity was still close to a chance level. However, her tendency to use a ‘remember’ response increased. It is possible that reviewing the photos had a short-lasting impact that was not captured after one week. That is, had she, for example, performed the recognition task on day four maybe there would have been an improvement in her recognition performance. This increase in the false recollection as a result of having reviewed the wearable camera photos is similar to the finding of St. Jacques & Schacter (2013). In their study reviewing wearable camera photos taken from participants perspective in their natural order increased the hit rate but also the false recollection rates compared to the condition where photos were taken from a different perspective and presented in random order. The results presented in this paragraph and the findings of St. Jacques & Schacter suggests that reviewing wearable camera photos leads to an increase in the tendency to use a remember response, which may or may not be accompanied with an increase in participants recognition performance.

The main limitation of this study is that only two different retention intervals were used. For this reason, it was not clear at which point did CR’s memories faded. Furthermore, while the sequential presentation of photos was beneficial for CR after 3 hours, it was not after one week. Unfortunately, it was not clear at which point does the sequential presentation of photos stop producing a beneficial effect and only impact the response bias in CRs responses. This limitation can be overcome by testing CR on smaller retention intervals of two days and four days. Doing so would also allow potential short-lasting effects of the photo review processes to be detected.

While the sequential presentation of photos is beneficial when the overall memory is good, it produces unwanted effects when memories are poor. This has important implications for the use of wearable cameras photo review as a means to recollect personally experienced events. Because, so far, the majority of studies interested in this effect have been interested in the positive effects of wearable camera photo review (e.g. studies reviewed by Silva et al., 2016). It is therefore very important for future studies to explore the link between the overall memory performance and the impact of the sequential presentation of wearable camera photos. One way this can be achieved is by adjusting the retention interval across different conditions.

Overall, this study successfully examined the effect of the sequential presentation of wearable camera photos in a person with memory impairment and age-matched control participants. It showed that while the sequential presentation of photos has a beneficial effect when CR recognition memory was not very poor, i.e. after three hours of retention interval, it had a negative impact when CRs memories were poor. It increased the tendency for CR to use the ‘remember’ responses. This emphasises the need for measuring false recollections in studies that are interested in the role of wearable camera photo review as a means to aid recollection of autobiographical memories.

Chapter 4: Enhancing Future Autobiographical Memory Performance

Retrieving recently encoded memories has a positive effect on future memory performance, a phenomenon known as 'retrieval effect' or 'testing effect' (Karpicke et al., 2017). Retrieval practice studies have predominantly used educational material (passages, lectures, basic visual symbols) and for this reason, their impact on autobiographical memory is not known. In a different line of research, the wearable camera has been used as an autobiographical memory aid (Silva et al., 2016). It is shown that reviewing the wearable camera photos aids the recollection, in addition, this process is also described to enhance the performance in a future memory task. The aim of this study is therefore to examine the relative positive impact of retrieval practice and wearable camera photo review on real-world autobiographical memories. Twenty-nine participants were taken on a predefined guided tour at the British Museum while they wore a wearable camera. Participants in the retrieval practice condition verbally recalled the content of the tour and those in the photo review condition looked at the photos taken by the camera. One week later, all participants performed a recognition and a recall task. Recall performance was higher in the retrieval practice condition compared to the photo review condition. In contrast, recognition performance was higher in the reactivation condition compared to the retrieval practice condition. Since in the real-world recognition tasks are rarely used, retrieval practice can provide a more useful memory enhancement strategy relative to wearable camera photo review.

4.1 Introduction

Exploring what improves memories is important as it has implications in developing memory enhancement strategies in educational and clinical settings and helps us understand the nature of memory processes. Several procedures have been examined as a means to improve the retrieval of memories. For instance, it has been shown that simply asking participants to retrieve studied material benefits future retrieval of that material more than simply re-exposing them to it; this is known as the retrieval practice or testing effect (see Karpicke et al., 2017, for a review). In retrieval practice studies, participants are typically divided into two groups. Those in the retrieval practice group are taught and then asked to perform a memory test on some material while those in the control group are taught the same material twice. After a delay interval, at the final test, the retrieval practice group outperforms the control group in a number of memory tasks (i.e. recognition, recall).

Different variations of retrieval practice paradigms have been examined in order to understand its underlying mechanisms. For instance, when using cued recall during the retrieval practice, more cues lead to a smaller retrieval effect while fewer cues lead to a larger effect (Carpenter & DeLosh, 2006; Rowland, 2014). These results show that effort plays an important role in retrieval practice. That is, the more effort participants make during the initial memory test, the stronger the retrieval practice effect. This might suggest that the more difficult the retrieval practice exercise, the larger its memory enhancement effect. But, since retrieval practice only works if the contents of the memory are successfully retrieved, making the retrieval practice exercise more difficult may lead to failure of retrieval and therefore an absence of memory enhancement. However, effort does not explain why retrieval practice happens; the higher effort simply means more retrieval has happened.

In addition to effort, the role of retention intervals in retrieval practice has also been examined. While some studies show that the effect of retrieval practice is only present after long retention intervals such as a few days or a week (Roediger & Karpicke, 2006a), some studies have shown the presence of retrieval practices in as short as 20 minutes intervals (Rowl & DeLosh, 2014). Overall, a meta-analysis has shown that longer retention intervals are associated with a longer retrieval practice effect such as days or a week (Rowland, 2014).

Recently, the retrieval practice effect has been explained within the framework of neural theories of memory formation. Antony has recently proposed that reactivation could be seen as a “fast consolidation” process (Antony & Paller, 2017; see also Ferreira et al., 2019). They proposed that retrieval practice may improve the integration of the memories with stored neocortical knowledge. As a consequence of this, memories would become less hippocampus-dependent. Therefore, it is suggested that retrieval practice enables a fast route to (hippocampus-independent) consolidation (Antony et al., 2017; Ferreira et al., 2019).

Since the majority of retrieval practice studies have taken place in educational settings with the aim of improving students’ learning outcomes, they have predominantly used stimuli that are most relevant in the educational setting. These range from lists of words to educational texts with some visual and spatial material (Karpicke et al., 2017). The retrieval effect has also been studied with regard to non-verbal stimuli using visual stimuli (Kang, 2010; Tse et al., 2010; Wheeler & Roediger, 1992) as well as video lecture presentations (Butler & Roediger, 2007; Johnson & Mayer, 2009) and spatial memory in a three-dimensional virtual space (Carpenter & Kelly, 2012). However, the effect of photo review with real-world material, such as episodic autobiographical memory, has not yet been examined.

In a different line of research, in order to aid real-world memories, wearable cameras have been employed (see Chow & Rissman, 2017 for a review). These are small and lightweight cameras that are worn around the neck or clipped to clothing and automatically take photographs from the perspective of the wearer. Reviewing photos taken with these cameras have been used for aiding autobiographical memories. For instance, Berry et al. (2007), as well as Loveday and Conway (2011), have used wearable cameras to improve recollection of autobiographical memories in people with amnesia as a result of encephalitis. In these studies, the persons with amnesia wore the camera during several non-mundane events while also writing diary entries for them. After some delay, they were able to recollect more information after reviewing the photos (also referred to as SenseCam review) compared to reviewing the written diary entries (Berry et al., 2007; Loveday & Conway, 2011).

A similar pattern is also observed in people with no memory impairment. For instance, in a study by Mair, Poirier, and Conway (2017) both young and older participants were taken on a set of events and asked to generate names for these events while wearing the camera. In a cued-recall task two weeks later, participants recalled significantly more semantic and episodic details when the cues were the self-generated event names together with wearable camera photos compared to when the cues only included the event names. Similarly, Sellen et al. (2007) have shown that participants remember more event details (who, what, where, & when) after wearable camera photo review three and ten days as well as four months after the initial events.

Hodges, Berry, and Wood (2011) provide two possible explanations for why photo review is such a strong cue for remembering memories. First, since the cameras capture a large number of photos, at least one of them will have captured a moment at which the memory was encoded. Therefore, once this photo which had captured the moment of encoding from the wearer's perspective is observed, recall is triggered. The second explanation is that reviewing photos allows recollection because the collection of photos closely resembles how the episodic memories are stored. That is, they represent short time slices of experiences, temporally ordered, have strong visual content, and have the perspective of the wearer. Overall, the wearable camera photo review seems to be a good cue that helps recollection of personally experienced events.

In addition to wearable camera photo reviews' short-term effects of being used as memory cues, their long-term effects as a means to enhance future memory performance have also been documented. In one such study by Finley, Brewer, and Benjamin (2011), participants used the wearable cameras during five consecutive days. On two of these days, participants reviewed the photos in the evening. When participants were tested approximately 1, 3, and 8 weeks later, they had a better cued-recall and recognition memory performance for events from the review days compared to no review days.

In another study, St. Jacques and Schacter (2013) have shown that the way wearable camera photos are reviewed influences how much they enhance future memory performance. Here, participants reviewed wearable camera photos of a museum tour two days after and performed a recognition task two days later. During the reviewing phase, the temporal order and the perspective of the photos were manipulated. In the 'temporal order match' conditions photos of the targets were shown in the same temporal order that they were taken and in the 'temporal order mismatch' condition this order was randomly shuffled. For the 'perspective match' condition, photos taken from the perspective of the participants were shown, and for the 'perspective mismatch' condition photos of the targets were taken from different angles. Both match conditions produced higher hit rates in the recognition task relative to the mismatch conditions, suggesting the closer the photo review processes were to their natural order and perspective the stronger the effect of wearable camera photo review. However, participants false alarm rates also increased for the match conditions. Overall, while there seems to be robust evidence in favour of the wearable camera photos as a powerful means to aid the recollection of memories, the evidence for their use as a means to enhance the future recollection of memories is less clear.

Long-term effects of wearable camera photo review on episodic autobiographical memory have only been compared to a written diary review or no review condition (Finley et al., 2011), while retrieval practice has predominantly been studied using education material (Karpicke et al., 2017). Therefore, there is no information regarding the relative benefit of wearable camera photo review and retrieval practice. For this reason, in this study, the effect of these two strategies in aiding the retrieval of autobiographical memories are compared. After participants were taken on the guided museum tour observing a set of predefined exhibits, they were allocated to one of two enhancement conditions, either a retrieval practice or a photo review condition. In the photo review condition, they reviewed wearable camera photos that were taken during their tour. For the retrieval practice condition, participants were asked to verbally recall what they remembered from the museum tour. One week later, all participants performed a recognition task followed by a recall task. During the recall task participants recalled the exhibits they had seen and during the recognition task, participants observed their wearable camera photos along with photos of exhibits from places they had not been (control photos) and responded using 'remember' and 'don't remember' responses. In the recognition memory task, participants were also asked about their confidence levels for every response, this allowed us to measure their metacognitive abilities regarding their recognition memory performance. These metacognitive abilities in the context of memory, also known as 'metamemory', broadly refer to the knowledge about how well one is aware of their memory performance and the processes that allow memory self-monitoring (Pannu & Kaszniak, 2005). These are crucial in allowing one to recognise and take appropriate action regarding their memory performance (e.g. refer to a diary if they are not sure if they have met a friend). While they have not been studied in the context of memory enhancement, they have been included in this design to explore how they react to different enhancement strategies.

This paradigm allowed the effect of two forms of retrieval practice on both recall and recognition memory for a real-world autobiographical memory to be examined. If photo review resembles restudying then based on the retrieval practice literature, retrieval practice will lead to a better overall memory performance compared to photo review. However, if photo review involves a process beyond simply restudying the content, and has beneficial effects more than retrieval practice then photo review will lead to a better memory performance compared to retrieval practice.

4.2 Methods

4.2.1 Participants

Twenty-nine participants (seven males) took part in this study (age; range = 18-55, M = 29.04, SD = 10.62). Participants either received course credit or £ 32 as reimbursement for their efforts to take a part in this experiment. Undergraduate students who received course credits were recruited through the university portal, others were recruited by word of mouth or had emailed the research unit for participation in psychology studies. All participants read and signed an informed consent form before the study began and the study was approved by City, University of London's psychology ethics committee.

4.2.2 Procedure & Design

The experiment consisted of three parts; a study, an enhancement, and a test phase. The study and the enhancement phase took place on the first day at the British Museum, London. The test phase took part one week later at the laboratory at City, University of London. Participants were alternatingly allocated to retrieval practice and photo review conditions. The enhancement phase differed across participants depending on the condition (retrieval practice and photo review) the participants were in. The study and test phase remained the same for all.

For the study phase, participants were taken on a predefined guided tour at the British Museum while wearing the wearable camera around their neck. They were guided by the experimenter who gave instructions on the route, pointed them to the exhibits, and gave information regarding the exhibits. The information given was controlled across participants by having the experimenter read the same information to all participants. The tour included 91 exhibits. However, on a few occasions, some of the exhibits were either temporarily removed or were in a section that was temporarily closed. The photos were exported from the wearable camera and only those of the 91 exhibits were kept while the rest were set aside. Photos of exhibits that accidentally captured the experimenter, or had a very low quality were excluded. These photos were then used for the enhancement phase - in the photo review condition - and the test phase – in the recognition task.

The enhancement phase took part after the tour, inside the museum in a quiet area. For the retrieval practice condition, participants were asked to perform a free recall task. They were instructed to verbally recall as many exhibits as they remembered for 15 minutes. For the photo review condition, participants were shown the photos of the tour taken with the wearable camera on a laptop screen and each photo was presented for 10 seconds. If the photos of all 91 exhibits were presented, this process lasted up to 15 minutes. It lasted less if any of the exhibits were unavailable or their photos were rejected.

One week later, participants came to one of the EEG laboratories at City, University of London where they first performed a recognition task and then a recall task (See the next chapter for the EEG results). This order was chosen to reduce the interference effect of the memory tasks on each other. If the recall task had come first, it could have produced an additional retrieval practice effect, impacting the performance in the recognition task. However, recognition task is expected to have some interference on the recall task, but this is much smaller than the interference effect caused by the recall task on recognition task. For the recognition task, participants responded to the photos from their tour and control photos that were taken by the experimenter from parts of the museum participants had not been. Participants were shown on average 88.17 photos from the tour and an equal number of control photos in the recognition task. There was no time limit on how long participants could take until responding to the photos, however, the recognition task lasted between 20 and 30 minutes. They indicated whether they remembered the photos from the tour or not, by pressing one of two buttons on a response box. They were asked to press a green button if they remembered the photo from the tour and a red button if they did not remember the photo from the tour. After responding to each photo, they were asked to indicate how confident they were in their judgment. They used the 7 buttons on the response box to indicate their confidence on a scale of 7, i.e. the left-most button was used to indicate the least confidence, the right-most button was used to indicate the most confidence, and middle buttons were used according to their positions.

The recall task involved participants verbally remembering the content of the tour within 15 minutes. Participants were asked to describe the exhibits, descriptions were deemed sufficient and counted as one correct recall as long as they could be used to identify the exhibit in the museum.

Participants were blind to the nature of the study and were unaware of the other condition until they were debriefed after the last stage of the experiment.

4.2.3 Data analysis

Recognition task. For the recognition memory task, hit rates were computed as the proportion of correctly identified old items to all old items and correct rejection rates was computed as the proportion of correctly identified new items to all new items. Sensitivity (*d'*) and Bias (*c*) were calculated as measures for participants' ability to distinguish between old and new and their tendency to use one or the other response (Stanislaw & Todorov, 1999).

Two measures of metacognition were computed from participants confidence ratings on their memory judgments in the recognition task. Metacognitive efficiency was used to measure participants ability to monitor their task performance and metacognitive bias was used to measure how confidence participants were overall (Fleming & Lau, 2014; Maniscalco & Lau, 2012). Metacognitive efficiency is computed as Meta-*d'* normalised by participants performance, the recognition sensitivity - *d'* (Baird et al., 2013; McCurdy et al., 2013). For metacognitive bias, participants average confidence rating was computed.

Recall task. The recall performance was measured by counting the number of exhibits correctly remembered from the tour and dividing them by the number of exhibits participants saw during their tour.

4.2.4 Statistical Analysis

Group comparisons for recall rate, sensitivity, response bias, metacognitive efficiency, and metacognitive bias were performed using an independent t-test and Cohen's *d* was used as a measure of effect size.

Additionally, an equivalence test was performed to examine whether participants in the retrieval practice condition remembered the same amount of information during the retrieval practice session and the final recall task (Lakens et al., 2018). Assuming a meaningful effect exists, this test examines whether it is surprisingly small. It is commonly used in pharmacokinetics, examining whether a new treatment, which may have fewer side effects or be cheaper is as effective as an older alternative (Sharon & Hauck, 1983) and it is now also applied in psychological studies (Goertzen & Cribbie, 2010). This test involves performing two one-sided t-tests for the upper and lower bounds of the smaller effect size of interest, an effect size so small that any effect size smaller than that can be deemed not meaningful (see, Lakens et al., 2018 for an overview). An effect size of .2 (lower and upper bounds of - .2 and 2) that is usually considered to be weak (J. Cohen, 2013) was chosen as an effects size that would be considered surprisingly small.

4.3 Results

4.3.1 Recognition task

Hit & Correct Rejection Rates. Participants hit rates were higher in the photo review condition ($M = 0.88, SD = 0.9$) compared to the retrieval practice condition ($M = 0.81, SD = 0.11$). However, this difference was not significant ($t(27) = -1.846, p = .08, Cohen's\ d = 0.67,$ figure 4.1.A). Correct rejection rates were also higher in the photo review conditions ($M = 0.92, SD = 0.05$) compared to retrieval practice condition ($M = 0.87, SD = 0.07$). However, this difference was also not significant ($t(27) = -1.937, p = .06, Cohen's\ d = 0.72$, figure 4.1.B).

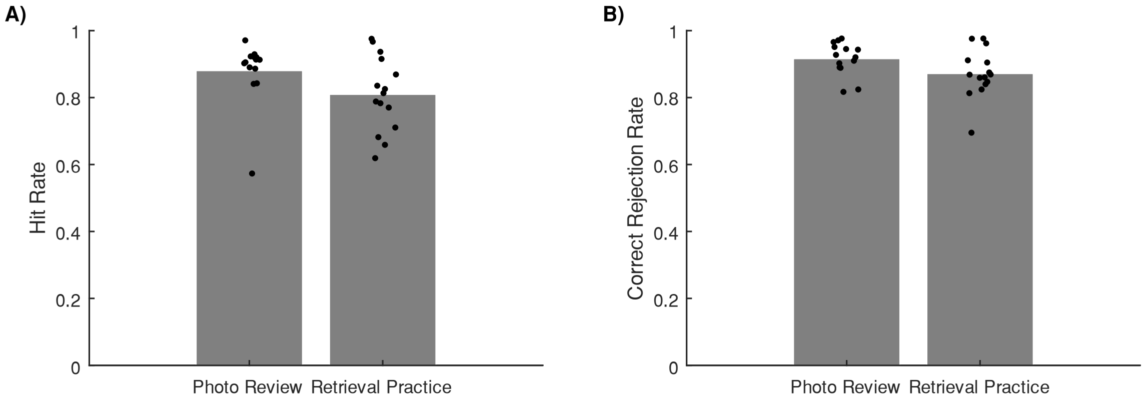

Figure 4.1: Hit and correct rejection Rates: A) Hit rates across different conditions measured by the proportion of correctly identified old targets out of all old targets. B) Correct Rejection rates across different conditions measured by the proportion of correctly identified new targets out of all new targets. The dots represent performance for each participant.

Sensitivity and Response bias. Participants' sensitivity as measured by d' was significantly lower in the retrieval practice condition ($M = 2.20, SD = 0.52$) compared to the photo review condition ($M = 2.71, SD = 0.57;\ t(27) = -2.491, p = .019, Cohen's\ d = 0.93$, figure 4.2.A). This suggests that participants in the photo review condition were better at distinguishing between the photos of seen targets and unseen targets compared to those in the retrieval condition. Participants' response bias as measured by *c* did not differ between photo review ($M = 0.10, SD = 0.21$) condition and retrieval practice condition ($M = 0.12, SD = 0.38;\ t(27) = -1.937, p = .06, Cohen's\ d = 0.72$, figure 4.2.B).

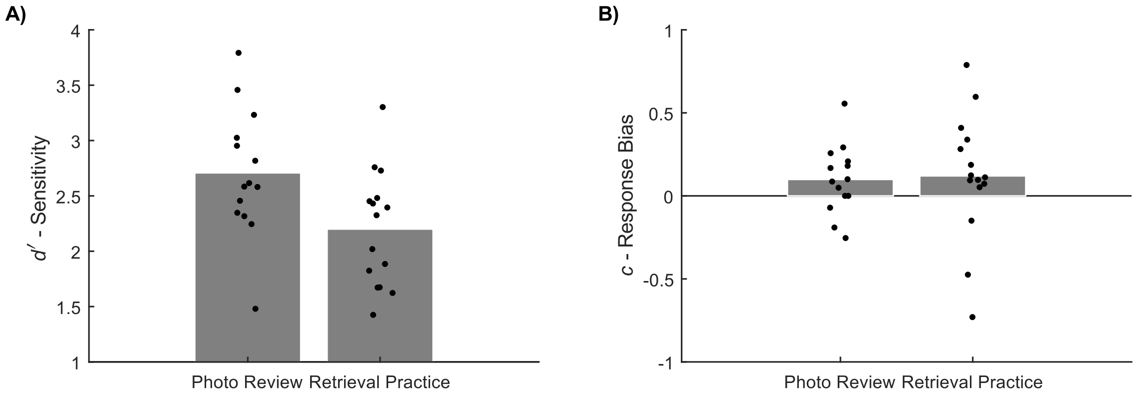

Figure 4.2: Sensitivity and Response Bias: A) Mean sensitivity in the recognition task across different conditions measured using d'. B) Mean Response Bias in the recognition task across different conditions measured using c. The dots represent performance for each participant.

Metacognitive efficacy and bias. Participants' metacognitive efficiency was not different across retrieval practice ($M = 1.17, SD = 0.36$) and photo review conditions ($M = 0.91, SD = 0.64;\ t(27) = 1.365, p = .18, Cohen's\ d = 0.50$, figure 4.3.A). However, their metacognitive bias was significantly higher in photo review ($M = 6.16, SD = 0.35$) compared to retrieval practice condition ($M = 5.65, SD = 0.48;\ t(27) = 3.230, p = .003, Cohen's\ d = 1.21$, figure 4.3.B).

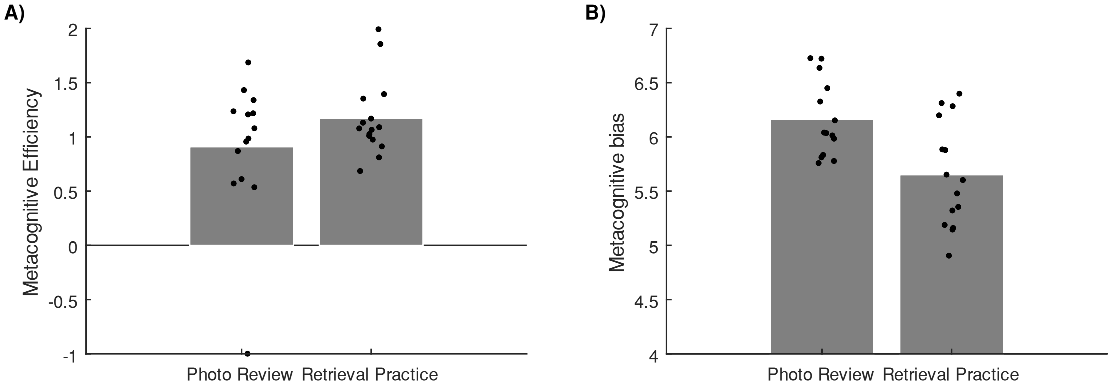

Figure 4.3: Metacognitive efficiency and bias: A) Mean metacognitive efficiency measured by meta d' normalised by d' in the recognition task across different conditions. B) Mean metacognitive bias measured by the average confidence rating in the recognition task across different conditions. The dots represent performance for each participant.

4.3.2 Recall task

The proportion of recalled items was significantly higher in the retrieval practice ($M = 0.36, SD = 0.08$) compared to the photo review condition ($M = 0.28, SD = 0.08$; $t(27) = 2.519, p = .018, Cohen's\ d = -0.94$, $M = 0.36, SD = 0.08$, figure 4.4). This suggests that participants in the retrieval condition performed better than those in the photo review condition in the recall condition.

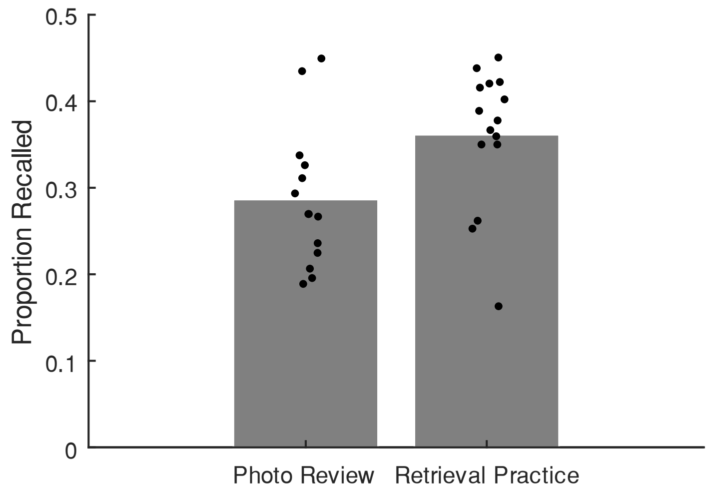

Figure 4.4: Recall rate: Mean proportion of items recalled across different conditions measured by the proportion of items recalled. The dots represent performance for each participant.

Recall within retrieval practice condition. Participants who were in the retrieval practice condition performed the final recall task ($M = 0.36, SD = 0.08$) equally well compared to the recall task during the enhancement task ($M = 0.38, SD = 0.08$, Figure 4.5). This procedure indicated that the observed effect size ($d = .36$) was significantly within the equivalent bounds of the -0.2 and 0.2 scale points $t(14) = -11.83, p < .001$. this suggests that recall during the enhancement and final test phase was statistically equivalent.

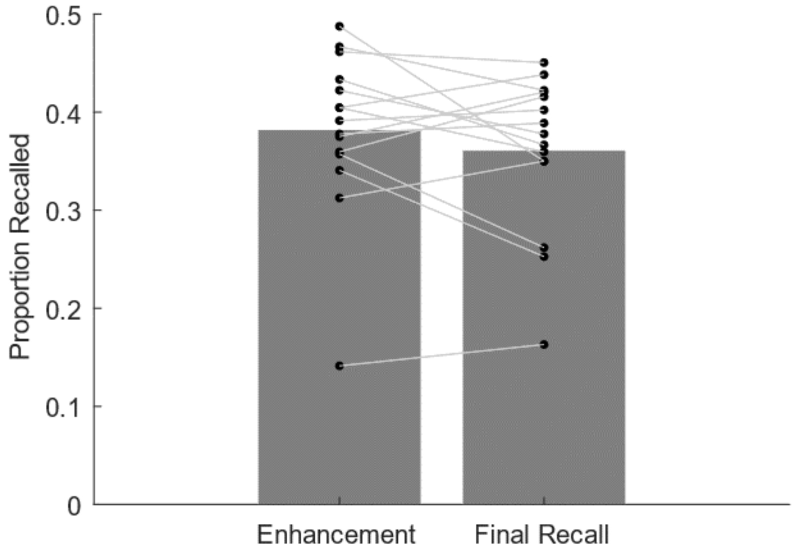

Figure 4.5: Recall Within Retrieval Practice: Recall performance measured by the proportion of items recalled within the retrieval condition during the enhancement phase and the final test phase. The lines represent performance for each participant.

4.4 Discussion

In this study, the benefits of the wearable camera photo review and retrieval practice in aiding autobiographical memories were compared. Participants' recall performance, as measured by the proportion of correctly remembered items, was better in the retrieval practice condition compared to the photo review condition. In contrast, participants' recognition performance, as measured by recognition sensitivity, was better in the photo review condition compared to retrieval practice condition. There was no difference between hit, correct rejection rates, and response bias. While participants' metacognitive efficiency was not different across the conditions, their metacognitive bias was higher in the photo review condition compared to the retrieval practice condition. This suggests that while participants in the photo review condition were no better at monitoring their performance than those in the retrieval practice condition, they were on average more confident about their memory judgments. Furthermore, for the participants in the retrieval practice condition, the recall performance during the enhancement phase and final test were significantly equivalent. This suggests that participants in this condition recalled about the same number of items as they did during the initial enhancement phase.

The increase in participants' performance in the recognition task is in line with studies of long-term effects of the wearable camera (Finley et al., 2011; St. Jacques & Schacter, 2013). While Finley, Brewer, and Benjamin (2011) have demonstrated the long term beneficial effect of the wearable camera photo review in contrast to a no review condition, here the beneficial effect of photo review in contrast to another enhancement strategy, retrieval practice, was explored. In this study, wearable camera photo review led to a better performance in a final recognition task, relative to the retrieval practice. One explanation for this pattern of results is that by reviewing the photos in the museum, participants would reactivate the visual aspects of the memories more than those in the retrieval practice condition. This reactivation, immediately after the museum tour, would stabilise the visual content of the memories as shown by St. Jacques and Schacter (2013) allowing better performance on the recognition task as it relies on this type of information. However, while in St. Jacques and Schacter's study the final memory task took place two days after the photo review, in this study it took place one week after the photo review, suggesting a longer effect of photo review.

Participants in the photo review condition had a higher metacognitive bias; on average they were more confident in their judgments than those in the retrieval practice condition. High metacognitive bias may be caused by participants having a sense of familiarity to watching photos as they had done during the photo review condition. But there was no difference in metacognitive efficiency across conditions; participants' ability to assign confidence levels to their judgments that would reflect on these judgments' average accuracy was not different across the conditions. One explanation for this is that that metacognitive efficacy is not modulated by enhancement strategies and are instead learned during a longer duration in one's lifetime, while metacognitive bias may be influenced with participants experience of having watched the photos earlier.

Regarding the recall task, results show a strong effect of retrieval practice. One explanation is that retrieval practice has tagged memories such that they are stabilised during later consolidation processes, for example during sleep, through a cascade of activities. However, this is unlikely since evidence suggests that retrieved content receives less consolidation during sleep than restudied content (Bäuml et al., 2014). Alternatively, this finding can be explained by "fast consolidation" effect of retrieval practice as argued by Antony, Ferreira, Norman, & Wimber (2017). That is, the retrieval of the semantic and episodic content of the tour aided them to undergo a fast consolidation process leading to more stable memory performance in the recall task one week later. This notion is also supported by the finding that participants in the retrieval condition retrieved the same amount of information during the retrieval practice and the final recall task, suggesting that no noticeable forgetting had occurred during the week in this group. Another explanation of this finding is that performing memory recall for retrieval practice requires more effort than watching the photos in the photo review condition (Karpicke et al., 2017). However, the higher effort simply suggests a greater amount memory has been retrieved and does not explain why retrieval practice enhances the recall performance.

Overall, it appears that the reason different memory tasks are differently influenced by different enhancement strategies is that each task relies mostly on certain aspects of the memories. While the recognition task relies on visual content, recall task relies on semantic and episodic content of the memories. And, as the recognition task benefits from photo review as a result of the strengthening of the visual content, recall task benefits from retrieval practice as a result of it strengthening of the episodic and semantic content of the memories.

There are a number of points that future studies should consider in order to find out what an optimal memory enhancement strategy would be. Retrieval practice and photo review enhancement exercises were performed only once, each taking 15 minutes. It is unclear how their relative benefit may change if they were performed on multiple occasions with longer time allowed for each. Future studies should explore the different frequency of enhancement strategies with varying time allowed for each over the retention interval for a better understanding of enhancement strategies. Although retrieval practice and photo review were explored as means of memory enhancement in the context of real-world autobiographical memories, there may well be other types of retrieval practice exercises that could provide an even stronger enhancement effect on the recall task. For instance, considering retrieval practice only works if memory items are successfully recalled and that the more effort participants make during the initial memory retrieval the higher the influence of retrieval practice, a potential strategy would be to combine photo review and retrieval practice to create a cued retrieval. In this case, using partially covered photos in the cued retrieval would be expected to create an even stronger enhancement effect relative to a retrieval practice with no cues. Similar to the findings of Carpenter and Delosh (2006), these partially covered photos might act as weak cues, while allowing a high number of retrieval, they would require more effort relative to uncovered photos. While this has been shown using words (Rowland, 2014), it is likely to produce a similar effect for autobiographical memories.

Finally, metacognitive abilities play an important role in how we daily use memory. They allow us to identify the times when we might need to refer to more reliable sources of information than to rely on our memories (e.g. asking a friend, checking calendar entries or diary notes). A degree of memory loss may not be as life impairing if we are aware of it. For this reason, being able to enhance metacognition of memory would also be a crucial step in helping people with memory impairments.

Overall, in this study, the effect of wearable camera photo review and retrieval practice was contrasted. While the final recall performance was better for the retrieval practice condition relative to photo review condition, the opposite pattern was observed for the recognition task. This was explained in terms of the two memory tasks relying on different content of memories, and that these different contents are differently strengthened during the different enhancement conditions. Since real-life memories are more often recalled than recognised, retrieval practice may be considered as a better memory enhancement strategy compared to photo review. While these results shed light on important memory enhancement strategies for real-world autobiographical memories, it is important to replicate these patterns of enhancement in people with memory impairment, to whom such enhancement strategies are most valuable.

Chapter 5: Brain Oscillations during real-world autobiographical memory retrieval

Electroencephalograph (EEG) has been widely used to understand the neural mechanisms underlying recognition memory. Studies using event-related potentials have outlined the role of the parietal old-new effect as a signature for recollection processes and frontal old-new effect as a signature for familiarity related processes (Mecklinger, 2006; Rugg & Curran, 2007). In addition, studies using time-frequency decomposition methods have shown the role of synchronisation in gamma (25-100 Hz) and theta (4-7.5 Hz) bands (Gruber et al., 2008) in the reinstatement of episodic details (Nyhus & Curran, 2010). Furthermore, desynchronization in alpha (10-13 Hz) and beta (13-18 Hz) bands (Hanslmayr et al., 2012) has been observed which is argued to play a role in information transfer for the recollection of memories (Hanslmayr et al., 2016). While these studies shed light on the different neurophysiological mechanisms of recognition of episodic memory, they have used laboratory-based stimuli such as words and pictures, leaving the mechanisms for the real-world autobiographical memories unexplored. Therefore, the aim of this study is to examine these EEG signatures in the context of real-world autobiographical memories. Using wearable cameras cues from participants' (N=29) real-world autobiographical memories were captured and used in a recognition task one week later while their EEG was being recorded. Participants were assigned to one of two enhancement exercises. Retrieval practice – recalling the content of the tour, which is thought to stabilise the semantic content of the memories. And, photo review – reviewing the wearable camera photos, which is thought to stabilise the visual content of the memories. Event-related potentials and time-frequency analysis were employed in this study to examine the EEG signatures for the retrieval of real-wold memories. More specifically, the impact of different memory enhancement strategies on these EEG signatures was examined. A parietal old-new effect in the photo review condition was observed, suggesting that it is influenced by the sensory information. Furthermore, there were desynchronizations in the gamma frequency band in the photo review condition over the frontal and parietal electrodes which may indicate the role of gamma in sensory information transfer. The lack of old-new EEG effects in the retrieval practice condition suggests that the use of semantic information during the retrieval of real-world memories may not be associated with the known EEG signatures for recognition memory.

5.1 Introduction

Episodic autobiographical memories refer to the recollection of personally experienced events often along with recollection of contextual details associated with those events, such as the where or with whom those events took place (Tulving, 1985). The electrophysiological mechanisms underlying recognition of episodic memories have been extensively studied in highly controlled laboratory settings using words and pictures (for a review, see Wilding & Ranganath, 2011), yet not much is known about the mechanisms for real-world episodic autobiographical memories, which differ from the laboratory-based episodic memories in at least two main aspects. First, the content of real-world episodic autobiographical memories tends to contain information in different modalities (visual, auditory, olfactory). Second, the time interval between learning and remembering of real-world episodic autobiographical memories is much longer than that of most laboratory-based studies. The development of wearable cameras has allowed episodic autobiographical memories to be studied in an ecologically valid setting yet in systematic and controlled manner (Chow & Rissman, 2017).

In order to advance neurophysiological theories on recognition memory, a wide range of studies has used the electroencephalogram (EEG) (Burgess & Ali, 2002; Gruber et al., 2008; Mecklinger, 2006; Mecklinger et al., 2016; Rugg & Curran, 2007). Studies using EEG to explore recognition of episodic memory use recognition tasks during which participants are presented with items they have previously seen (old items) as well as items they have not previously seen (new items). After the presentation of each item, participants then indicate whether or not they remember that item, often using a ‘remember’ or a ‘don’t remember’ button (Wilding & Ranganath, 2011). Other responses include but are not limited to ‘familiar’ vs ‘recollect’ or ‘remember’ vs ‘know’. Comparing the EEG signal between different responses highlights the EEG signal associated with memory mechanisms that are thought to be present during one response but not the other. For instance, a mechanism related to the successful recognition would be present in responses that participants correctly identified old items but would be absent in conditions in which the participant correctly identified a new item. Comparing these conditions would then shed light on the timing and topographical location of the electrophysiological mechanism associated with successful recognition of the memories.

In order to analyse the EEG data, many studies have employed event-related potentials (ERPs). This involves averaging the EEG signal over the trials of different conditions and then comparing them with each other. This process identifies different ERP components, typically referred to by their temporal and spatial information as well as by the memory mechanism they are associated with. One such ERP component is the frontal old-new effect, also referred to as the FN400 effect (Mecklinger, 2006; Rugg & Curran, 2007). This ERP is observed over the frontal and sometimes central electrodes between 300 to 400 ms after stimulus presentation and is associated with the participants' sense of familiarity. Familiarity is typically thought to reflect a sense of 'knowing' the item from somewhere, but without recollection of contextual information (Rugg & Curran, 2007) and can be induced by items participants have not seen but are very similar to those they have seen. This ERP component has a higher amplitude for old and for new items that seem familiar to participants, compared to novel items. Another ERP effect, the late parietal old-new ERP effect or the late positive component (LPC) is observed over the parietal electrodes 400 to 500 ms after stimulus presentation (see, Rugg & Curran, 2007 for a review). This ERP component is associated with correct recollection of contextual information such as for example correctly recognising the location on the screen in which the item was presented. This ERP has a more positive amplitude for correctly identified old items that are recognised along with contextual information about them compared to new items. Some have explored how these ERP components change over time. For example, in one study participants learned a set of coloured pictures either one week or five minutes before the recognition task (Roberts et al., 2013). During the recognition task, the parietal old-new effect was decreased for items learned one week earlier compared to items learn 5 minutes before the task. Using a similar paradigm it has been shown that the parietal old-new effect completely fades after 4 weeks compared to 5 minutes (Tsivilis et al., 2015). These changes are thought to reflect consolidation processes, during which the way memories are stored as well as retrieved are modified (Alvarez & Squire, 1994).

Finally, a late posterior negative (LPN) ERP component is observed over parietal and occipital locations (see, Mecklinger et al., 2016 for a review). This ERP effect is observed when contrasting the EEG signal after the presentation of old items with new items, and similar to the parietal old-new effect, this component is also associated with the successful recognition of the contextual information. However, unlike other recognition related ERP components, this component peaks after a response has been made, although it begins before it. This ERP component has a larger amplitude for new items compared to old items for which a correct source judgment has been made.

In addition to using ERPs for analysing the EEG signal, time-frequency (TF) decomposition methods have been used. These methods are advantageous since they explore neural activities not evident in ERPs. This is because during the averaging process for ERPs, the parts of brain oscillations in the EEG signal that are not *in phase* across the trials are lost. This part of the signal, also known as the *non-phase-locked* or induced activity, reaches its maximum and minimum amplitudes at different times across different trials and when averaged across the trials it is largely cancelled out. For this reason, the final ERP only contains the *phase-locked* or evoked activity, the part of the signal that reaches its maximum and minimum at the same time across the trials. One method for exploring the non-phase-locked activity in the EEG signal is the Fast Furrier Transformation (FFT). FFT provides the distribution of power across different frequency oscillations which together form the EEG signal within a predefined time-window for each trial. This distribution of power across different frequencies is then averaged across conditions and is used to infer how ‘strong’ or synchronised certain frequency band oscillations (e.g. those between 4 and 7.5 Hz also known as theta) are across conditions or participants. An increase in the power suggests a synchronisation in a given frequency band and a decrease suggests a desynchronization. However, FFT provides information about the power of the different frequency oscillations across the entire duration the signal that is analysed, without providing information about the timing of these activities, e.g. when a synchronisation in certain frequency may start or end. Complex Morlet’s Wavelet Convolution, on the other hand, provides information about changes in the power and the phase of different frequency oscillations over time in the signal analysed (M. X. Cohen, 2014). Studies using time-frequency analysis of the EEG data have paradigms similar to ERP studies, where participants make memory judgments for items previously seen and new items while their EEG signal is being recorded (Burgess & Ali, 2002; Gruber et al., 2008).

Using a word recognition task Burgess and Ali (2002) have shown synchronisation in the gamma frequency band (25-100 Hz) 300 to 500 ms after presentation of items that were followed by a “recollect” response compared to a “familiar” responses over parietal and frontal electrodes. In this study, participants were not explicitly instructed on how to use the ‘recollect’ or the ‘familiar’ responses and used their own interpretation of what they meant. Additionally, Burgess and Ali (2002)have found greater coherence between gamma oscillations recorded from frontal and parietal electrodes for "recollect" responses compared to "familiar" responses. This meant that oscillations in the gamma band over frontal and parietal electrodes were reaching their peaks at the same time. This suggests that oscillations in the gamma band play a role in enabling communication across parietal and frontal regions that allows recollection of episodic memories. Further evidence regarding the role of gamma and theta band oscillations in recognition memory comes from a study during which participants performed a recognition task using pictorial stimuli. Here, in addition to making old-new responses, participants had to remember where on the screen the pictures were shown (Gruber et al., 2008). In this study, synchronisation in gamma (35-80 Hz) band oscillations over the parieto-occipital electrodes was observed 210 to 330 ms after correctly recognised old items compared to correctly identified new items. Furthermore, synchronisation in theta (4-7.5 Hz) band was also recorded from fronto-central electrodes 600 to 1200 ms after stimuli presentation of correct compared to incorrect location judgments.

Although EEG is typically unable to record neurophysiological activity from deep brain regions, some studies instead of placing the EEG electrodes over the scalp, have placed them inside the scalp directly on the different regions of the brain. This type of EEG, also known as intracranial EEG, is only performed on patients that are to undergo brain surgery and provides a higher topographical resolution than the conventional EEG. In one such study, using a memory recognition task in patients with epilepsy, synchronisation in gamma activity was observed in the hippocampus and adjacent regions for successful retrieval of old items relative to new items (Staresina et al., 2012). These results emphasize the role of gamma synchronisation in supporting the neural mechanisms for reinstatement or re-experiencing of the memories (Nyhus & Curran, 2010). Furthermore, theta oscillations are thought to reflect top-down processes from frontal regions to hippocampus, modulating the encoding and retrieval of the memories (Nyhus & Curran, 2010). Evidence for this comes from retrieval-induced forgetting paradigms. In these paradigms, retrieval of an item inhibits the memory of competing items, items that are learned in a similar context. The increase in power of theta (4 –7 Hz) band activity when contrasting the old with new items is stronger when the old items are competitive – related to other items learned in a similar context, compared to when they are not. (Hanslmayr et al., 2010; Staudigl et al., 2010). These findings suggest that theta-band activity is associated with the rise and resolution of the interferences caused by the competing items.

In addition to synchronisation in gamma and theta band activity to the retrieval of episodic memories, desynchronizations in oscillatory activity have also been documented. In a study by Burgess and Gruzelier (2000) faces and words were shown in a recognition task. The results showed desynchronization in upper alpha & lower beta frequency ranges (∼10–13 Hz) for old compared to new items. Furthermore, this was laterally modulated, depending on the type of stimuli. There was a stronger desynchronization for words over left parietal regions, and stronger desynchronization over right parietal regions for faces (Burgess & Gruzelier, 2000). This result is taken to indicate that these desynchronizations in ∼10–13 Hz frequency bands are associated with reactivation of the sensory information of the memories. Khader and Rösler (2011) have complemented this notion by showing that alpha and beta desynchronization vary depending on the number of items retrieved. They have shown that the higher the number of items retrieved in a recognition task the stronger the desynchronization in alpha and beta. Moreover, the association between desynchronization in alpha and beta and the reactivation of sensory information is also supported by a proposal that these desynchronizations allow these oscillations to carry more information relative to a state where they are synchronised (Hanslmayr et al., 2012, 2016). Hanslmayr et al. have shown by applying mathematical models of information theory that desynchronization is positively related to the richness of information represented in the brain.

Overall, the ERP and the TF studies have provided important insights into different frequency band oscillations and memory mechanisms. However, they have relied only on laboratory-based material such as words and pictures and have left real-world memories with longer retention intervals unexplored. In order to address this, this study uses a real-world recognition paradigm to explore ERP and TF of real-world episodic memory signatures. Participants are taken on a museum tour while photos from their perspective are recorded using wearable cameras. After the museum tour, participants perform one of two enhancement exercises, photo review or retrieval practice. In the photo review condition, participants reviewed the photos of the museum. This condition has been suggested to stabilise the visual content of the memories (St. Jacques & Schacter, 2013). In the retrieval practice condition, participants were asked to verbally recall the content of memories from the museum tour. In this condition, it is suggested that the semantic content of the memories is stabilised (Karpicke et al., 2017). Wearable camera photos taken during the museum tour, along with control photos, are used in a recognition task one week later while participants EEG is being recorded. This design allows examination of memory contents and processes that are reflected in each of the EEG signatures of recognition memory such as the ERP or TF old-new effects. In particular, if an old-new effect is present in the photo review condition but not in the retrieval practice condition, it likely reflects the involvement of sensory information during recognition. Alternatively, if an old-new effect is present in the retrieval practice condition but not in the photo review condition, it likely reflects the involvement of semantic information during recognition.

Based on the previous literature the following regions were examined for the ERP and TF effects. For the ERPs, the parietal electrodes were examined for the recollection based parietal old-new effect (Rugg & Curran, 2007) and, fronto-central electrodes for the familiarity based frontal old-new effect (Mecklinger, 2006). For the theta frequency band oscillation, frontal electrodes were be examined (Gruber et al., 2008). For gamma band activity, the parieto-occipital and frontal electrodes will be examined (Burgess & Ali, 2002; Gruber et al., 2008). And finally, for alpha and beta frequency bands lateral (left & right) parietal electrodes were be examined (Burgess & Gruzelier, 2000).

5.2 Methods

5.2.1 Participants

Twenty-nine participants (6 males) took part in this study (age; range = 18-55, M = 29.04, SD = 10.62). These were the same participants who took part in the experiment reported in the previous chapter. Furthermore, one of the participants had very fluffy hair and the EEG cap did not fit their head. For this reason, data from twenty-eight participants were used in the ERP analysis. No further EEG data from other participants were rejected. However, for the TF analysis only data from sixteen participants (5 males) were used (age; range = 18-53, M = 27.31, SD = 9.78). This was due to an unintentional online high cut off filter (30Hz, 24 dB/oct) being applied during the EEG acquisition which made the EEG data from the first 15 participants unusable for this analysis.

Participants were recruited by word of mouth and via online advertisements on City, University of London's participant recruitment website. Participants did not report any history of brain injury or current mental health condition. They all signed an informed consent form before the study, undergraduate students received course credits and others received £32 upon completion of the study for their efforts. The study was approved by City, University of London's Psychology Department Ethics committee.

5.2.2 Procedure & Design

The experiment consisted of three parts: a study, an enhancement, and a test phase. The study and the enhancement phase took place on the first day at the British Museum, London, UK. The test phase took part one week later at one of the EEG laboratories at City, University of London. Participants were alternatingly allocated to retrieval practice or photo review conditions. The enhancement phase differed across participants depending on the conditions of retrieval practice or photo review. The study and test phase remained the same for all.

For the study phase, participants were taken on a predefined guided tour at the British Museum while wearing the wearable camera around their neck. They were guided by the experimenter who gave instructions on the route, pointed them to the exhibits, and gave information regarding the exhibits. The information given was controlled across participants by having the experimenter read the same information to all participants. The tour included 91 exhibits. However, on a few occasions, some of the exhibits were either temporarily removed or were in a section that was temporarily closed. After the tour, the photos were exported from the wearable camera and only those of the 91 exhibits were kept while the rest were set aside. These photos were then used for the enhancement phase - in the photo review condition - and the test phase – in the recognition task.

The enhancement phase took part after the tour. For the retrieval practice condition, participants were asked to perform a free recall task. They were instructed to recall as many exhibits as they remembered for 15 minutes. For the photo review condition, participants were shown the photos of the tour taken with the wearable camera on a laptop screen and each photo was presented for 10 seconds.

One week later, participants came to the laboratory at City, University of London where they first performed a recognition task and then a recall task. For the recognition task, participants responded to the photos from their tour and control photos that were taken by the experimenter from parts of the museum participants had not been. Participants were shown on average 88.17 photos from the tour and an equal number of control photos in the recognition task. They indicated whether they remembered the photos from the tour or not, by pressing one of two buttons on a response box. They were asked to press a green button if they remembered the photo from the tour and a red button if they did not remember the photo from the tour. The recall task, again, involved participants remembering the content of the tour within 15 minutes. Participants were blind to the nature of the study and were unaware of the other condition until they were debriefed after the last stage of the experiment.

5.2.3 Behavioural Data analysis and statistics

The proportion of correctly remembered old items (hit rate) and the proportion of correctly identified new items (correct rejection) were computed. Furthermore, sensitivity (*d'*) and response bias (*c*) were calculated as measures for participants' ability to distinguish between old and new items and their tendency to use one or the other response (Stanislaw & Todorov, 1999). Independent t-tests were used to compare participants' performance across the two different conditions of enhancement.

5.2.4 EEG Acquisition and Pre-processing

Electroencephalogram (EEG) was recorded using a 64 channel ActiCap system with a 1000 Hz sampling rate (Brain Products, Herrsching, Germany). Blinks were recorded using an electrooculogram electrode placed underneath the left eye.

EEGlab was used for pre-processing of the EEG data. Pre-processing involved a high bandpass filter (0.1 Hz), removing flatline electrodes, automatic source reconstruction (ASR) for recovering the unusual activities in the signal, and independent component analysis (ICA) procedure for ocular correction (Delorme & Makeig, 2004). The removed channels were interpolated and the data were re-referenced to the average signal. To obtain the epochs, the data were segmented from 1000 milliseconds prior to 2000 milliseconds after the presentation of the photos. At this stage, data for each participant was visually inspected and epochs were rejected if they still contained artefacts that had passed through pre-processing.

5.2.5 Data Analysis: ERPs - Phase-locked Activity

For the ERP analysis, a low pass filter of 30 was used and the epochs were baseline corrected based on intervals 200 ms preceding the stimulus onset. The signal was then averaged for different conditions. Based on previous literature two groups of electrodes for this analysis were chosen; Fronto-central – FC1, FC2, & Fz electrodes (Mecklinger, 2006), and Parietal – P1, P2, & Pz (Rugg & Curran, 2007).

Due to differences between the current paradigm and previous studies, no predefined time-windows were chosen for examining the old-new ERP effects, instead, a cluster-size permutation test was used to find significant ($p < .05$) clusters from 100 ms to 700 ms after the stimulus presentation (M. X. Cohen, 2014). In this analysis, the ERP signals for the two conditions are compared using a t-test on every time point. The significant time points that have neighbouring significant time points are identified as “clusters”. In order to correct for multiple comparisons, a permutation test is performed. For this, a null distribution of cluster sizes is estimated, which is then used to estimate the probability of a cluster based on its size to appear just by chance if there are no differences between the two conditions. This distribution is estimated by randomly shuffling the data for the two signals multiple times (i.e. 10,000), capturing the sizes of all clusters that appear, and estimating the distribution of these clusters. Finally, the size of each cluster that is found by comparing the two signals from the two conditions is compared against the null distribution. This process provides a p-value for that cluster, saying how unlikely is it to find such a cluster of activity if there were no difference between the two signals. This analysis was conducted on data collected from each condition of enhancement.

5.2.6 Data Analysis: TF - Non-phase Locked Activity

Changes in the induced activity were analysed by means of complex Morlet wavelet convolution (M. X. Cohen, 2014). Similar to Gruber et al. (2008), separate TF decomposition analyses were performed using different wavelet parameters for the high and low frequency bands. For high frequency bands activity (30 – 100 Hz), a wavelet with a width of 10 cycles was used. For low frequency band activity (2 – 30 Hz), a wavelet that had a width of 2 cycles but logarithmically increased to 10 for the highest frequency in this band was used. The spectral activity was baseline corrected;

baseline was chosen from 500 to 100 ms prior to stimulus onset. Finally, as we were interested in the induced response, we subtracted the phase-locked activity (the ERP) from each trial. This analysis was implemented in MatLab, based on protocols provided by Cohen (2014).

Based on previous literature the following groups of electrodes were chosen: F1, F2, and Fz for frontal theta and gamma (Gruber et al., 2008); PO3, PO4, and POz for parieto-occipital gamma (Burgess & Ali, 2002; Gruber et al., 2008); P3, P5, and P7 for left parietal as well as P2, P4, and P6 for right parietal alpha or beta (Burgess & Gruzelier, 2000).

Due to major differences between the current study design and those in the literature as well as the variability in time and frequency areas that are different across the hit and the correct rejection responses, instead of comparing predefined time-frequency regions the entire time-frequency spectrum was examined. For this, nonparametric cluster-based permutations tests were used (M. X. Cohen, 2014; Maris & Oostenveld, 2007). This analysis finds regions within the time-frequency space that are different between hit and correct rejection responses while controlling for multiple comparison tests.

5.3 Results

5.3.1 Behavioural Results

Participants in the photo review condition had a higher sensitivity than those in the retrieval practice condition (see table 5.1). Participants hit rates and sensitivity (d') were significantly better in the photo review conditions. While correct rejection was also much higher in the photo review condition, this was not significant at a p-value of .05. This result is also presented in chapter 4 and discussed in more details.

Table 5.1: Recognition task results: This table shows means and standard deviations for hit rate, correct rejection (CR) rate, d' – sensitivity, and c – response bias for the two conditions of enhancement and t-test comparing them across the conditions.

	Overall		Retrieval practice		Photo review		t-test		
	mean	SD	mean	SD	mean	SD	t (27)	p	Cohen's d
Hit rate	0.84	0.11	0.81	0.11	0.88	0.09	-1.85	0.08	0.688
CR rate	0.89	0.06	0.87	0.07	0.92	0.05	-1.94	0.06	0.725
d'	2.44	0.6	2.2	0.52	2.71	0.57	-2.49	0.02	0.924
c	0.11	0.3	0.12	0.38	0.1	0.21	0.19	0.85	-0.07

5.3.2 ERP Results

Figure 5.1 shows the ERPs averaged across fronto-central electrodes for correct rejection and hit responses for retrieval practice and photo review conditions. As indicated in the bottom right section of this figure, an old-new effect can be seen 460 ms to 640 ms from stimulus presentation in the photo review condition, where hits have a higher amplitude than correct rejection.

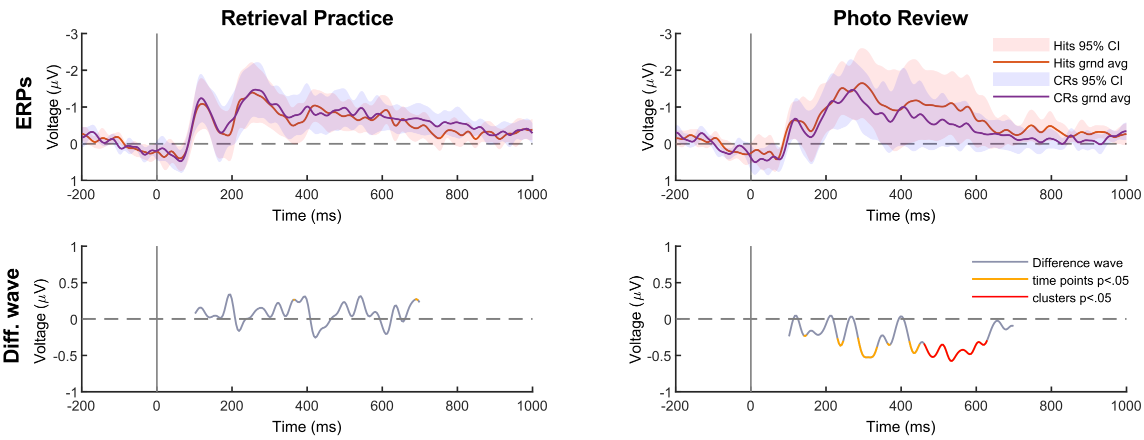

Figure 5.1: Hit vs CR, fronto-central electrodes: Top figures shows the ERPs for hit and correct rejection trials along with their confidence intervals for the retrieval practice condition (left) and photo review condition (right) for fronto-central electrodes (FC1, FC2, & Fz). Bottom plots show the difference waves between hit and correct rejection from 100 to 700 ms after the presentation of the photos. The red regions indicate areas that are significantly different across the hits and correct rejection after multiple comparison correction.

Figure 5.2 shows the ERPs averaged across parietal electrodes for correct rejection and hit responses for retrieval practice and photo review conditions. As indicated in the bottom right section of this figure, an old-new effect can be seen 250 ms to 320 ms from stimulus presentation in the photo review condition, where hits have a higher amplitude than correct rejection. No old-new effect is found in the retrieval practice condition.

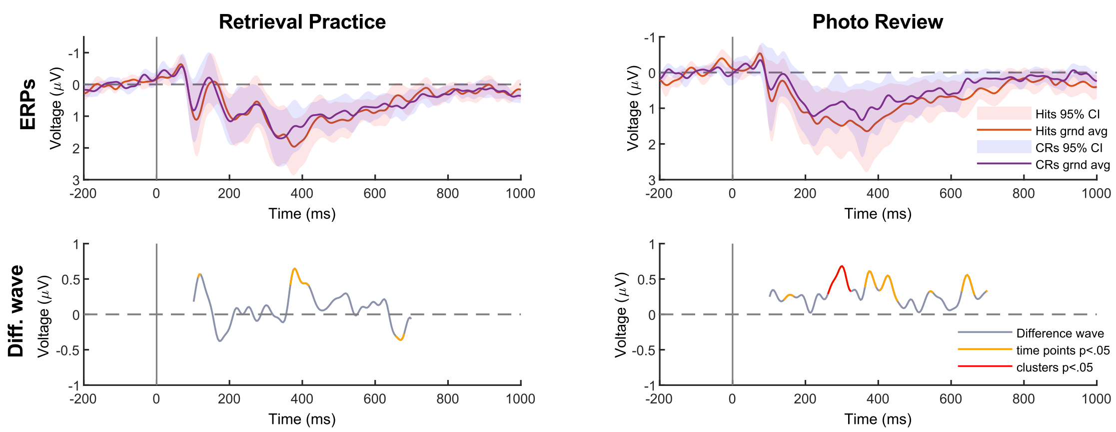

Figure 5.2: Hit vs CR, parietal electrodes: Top figures shows the ERPs for hit and correct rejection trials along with their confidence intervals for the retrieval practice condition (left) and photo review condition (right) for fronto-central electrodes (P1, Pz, & P2). Bottom plots show the difference waves between hit and correct rejection from 100 to 700 ms after the presentation of the photos. The red regions indicate areas that are significantly different across the hits and correct rejection after multiple comparison correction.

5.3.3 TF Results

The time-frequency difference maps (correct rejection minus hits) for the retrieval practice and photo review condition for the frontal gamma and parieto-occipital were plotted. Figure 5.3 shows a decrease in gamma band power from 200 ms to 850 ms post-stimulus over the frontal electrodes in the photo review conditions. Figure 5.4 shows a decrease in gamma band power between 800 ms post-stimulus over the parieto-occipital electrodes in the photo review conditions. There were no significant clusters in low (3-30 Hz) frequency bands over frontal or parieto-occipital electrodes.

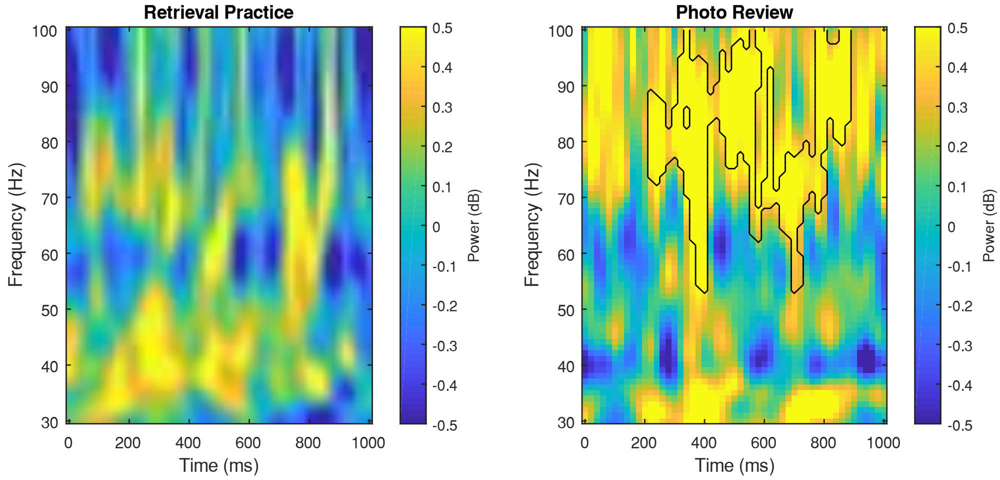

Figure 5.3: Frontal gamma: TF difference map for averaged frontal electrodes (F1, F2, & Fz). Correct rejection minus hit conditions, higher powers on this difference indicates desynchronization in hit trials. These show the difference in power of different frequency bands activities between hit and correct rejection responses. Significant clusters that pass the multiple comparison threshold are outlined with a black line.

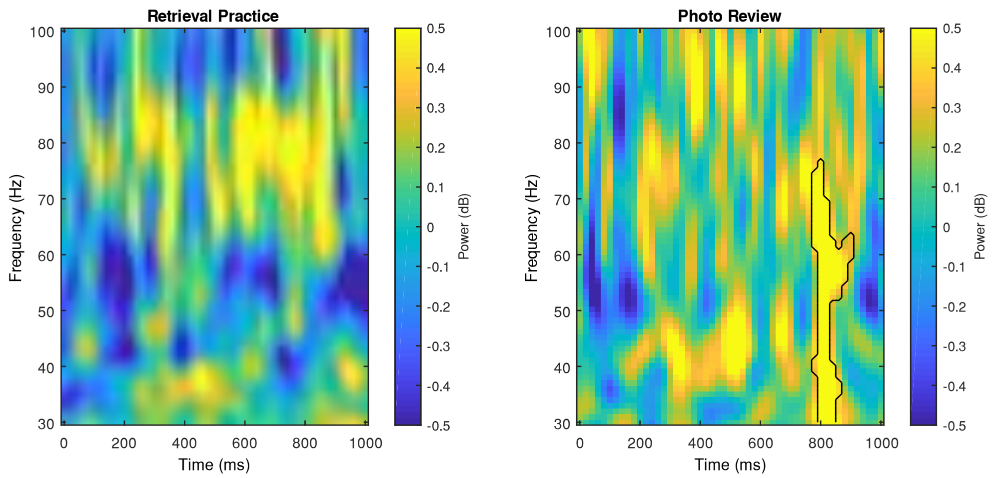

Figure 5.4: Parieto-occipital gamma: TF difference map for averaged parieto-occipital electrodes (PO3, PO4, & POz). Correct rejection minus hit conditions, higher powers on this difference indicates desynchronisation in hit trials. These show the difference in power of different frequency bands activities between hit and correct rejection responses. Significant clusters that pass the multiple comparison threshold are outlined with a black line.

5.4 *Discussion*

Episodic autobiographical memory recognition was examined in relation to memory enhancement strategies using ERP and time-frequency analysis. As discussed in the previous chapter, participants in the photo review condition performed better in the recognition task compared to those in the retrieval practice condition, they had higher sensitivity while their hit rate, correct rejection rate, and response bias were not different across the conditions. Old-new EEG effects were only observed in the photo review condition. For the ERPs, there was a negative old-new effect (410 - 490 ms) over the fronto-central electrodes, with lower amplitude for hits compared to correct rejection responses and a positive old-new ERP (360 – 420 ms) over the parietal electrodes with higher amplitude for hits compared to correct rejections. For the TF results, a desynchronization in the gamma band was observed over frontal electrodes (50 – 100 Hz, 200-850 ms) and over parieto-occipital electrodes (30 – 80 Hz, ~ 800ms).

A parietal old-new ERP effect over parietal electrodes 360 ms to 420 post photo presentation was observed. This ERP component is thought to reflect mechanisms that are responsible for the recollection of specific details of the memories, such as the source of it (Rugg & Curran, 2007). It appears that this ERP component reflects the recollection related processes in this study as well. This is because familiarity-based processes likely would not be able to distinguish between the old and the new items in the current paradigm. The new items were taken from a similar context to the new items and there was a high similarity between them. This similarity between the old and the new items would make familiarity-based processes ineffective in distinguishing between them. Therefore, recollection mechanisms would be required in order to correctly distinguish between the old and new items. Furthermore, since this ERP component was only observed in the photo review conditions, it is likely that it reflects the role of sensory information in recognition of the memories. This is based on the assumption that the photo review condition would have stabilised the sensory information of the memories (St. Jacques & Schacter, 2013) which in turn would have made the recognition of these memories rely more on this type of information. For this reason, the parietal old-new ERP component in this study may indicate the use of sensory information during the recognition of memories. Overall, it seems that the parietal old-new effect reported in this study reflects the recollection processes, additionally, since this effect is only present in the condition where the sensory information is thought to be stabilised, this ERP component likely relies on the sensory information of the memories.

A late frontal old-new ERP effect was also observed in this study. This ERP effect is topographically similar to the frontal old-new familiarity ERP component but is likely functionally different from it. The frontal related old-new effect is thought to reflect the familiarity related mechanisms that allow the recognition of old items (Mecklinger, 2006). However, in the current paradigm, familiarity-based mechanisms are unlikely to be helpful in the recognition of the memories. This is because the new photos are similar to the old ones, a sense of familiarity would rise from both, not allowing them to be distinguished. Furthermore, unlike the familiarity related frontal old-new effect (Mecklinger, 2006; Rugg & Curran, 2007), this ERP had a higher amplitude for correct rejection compared to hit responses. Moreover, as explained for the parietal old-new effect earlier, since this effect is only present in the photo review condition, it is likely that it also reflects the use of sensory information during the recognition.

Cluster-size based analysis showed significant desynchronization in the gamma band over the frontal electrodes. Gamma is typically suggested to play a role in synchronising different regions, such as hippocampus with cortical regions (Staresina et al., 2012). However, while previous studies have shown an increase in gamma band for hit compared to correct rejection response (Burgess & Ali, 2002; Gruber et al., 2008) in the current study there was a decrease in gamma band activity for hits compared to correct rejections in the photo review condition. As desynchronizations in a frequency band can allow for more information transfer (Hanslmayr et al., 2016), one explanation for this result is that gamma also plays a role in transferring information, aiding the reinstatement of sensory information.

Both ERPs and TF results in this study show differences between hit and correct rejection in the photo condition but not in the retrieval practice condition. One possible explanation for this may be that TF and ERP signatures of memory rely on sensory information while in the retrieval practice condition participants rely less of sensory information and more on semantic information. This is because performing retrieval practice may have facilitated participants' 'retrieval strategies', allowing them to augment the memories with semantic information and therefore rely less on their sensory information. Consequently, during the recognition task, participants in this condition would then rely less on the sensory information and more on the semantic information. For example, participants in this condition may recognise an item for its semantic information such as its historic era, and not its sensory information, such as its colour or shape. Therefore, assuming participants in this condition rely less on sensory information and more on semantic information, the results may suggest that semantic processing are not detected using the EEG signatures of memory.

There were no differences across the hit and correct rejection in theta band over frontal electrodes and alpha or beta over left and right parietal regions. These effects have only been observed over very short retention intervals (Burgess & Ali, 2002; Burgess & Gruzelier, 2000; Gruber et al., 2008) and no study has attempted to examine them for longer retention intervals. Therefore, one explanation for not finding a difference in these frequency bands might be because they are less involved in the recognition of one-week-old memories, memories which have passed through some consolidation processes. Since consolidation processes change the way memories are stored and retrieved (Alvarez & Squire, 1994) they likely also change the way different frequencies are involved with the recognition of memories. Another explanation for the lack of old-new effects within these frequency bands may be due to the type of stimuli used in this study. While studies exploring the role of different oscillatory activity use laboratory-based stimuli such as words and pictures presented on a computer screens (Burgess & Ali, 2002; Burgess & Gruzelier, 2000; Gruber et al., 2008), the stimuli used here were much more visually complex and are experienced by participants in real world. It is likely that the neural mechanisms underlying the recognition of the real-world stimuli as used here are different from that of laboratory-based stimuli and are there not associated with frequency bands in the same way that laboratory-based stimuli are.

A limitation of this study is that a condition with no enhancement (a control condition) was not included. The current design allows a comparison between the two enhancement conditions to understand their relative differences. However, including a control condition would have allowed examining the changes related to the enhancement conditions relative to a control condition. Moreover, a technical limitation of this study was that the high frequency band activity from some participants was accidentally filtered. As a result, data from only 16 participants, 8 in each condition of enhancement, was available for the TF analysis, making the TF findings less reliable.

Overall in this study, the EEG of real-world episodic autobiographical memory was analysed. The ERP and TF old-new effects were only present in the photo review condition and not in the retrieval practice condition. The photo review condition is thought to have stabilised the sensory information of the memories while the retrieval practice condition may have stabilised the semantic information of the events. If this is the case, our results emphasise the role of sensory information in the EEG signatures of episodic memory recognition.

Chapter 6: General Discussion

This thesis explored the sequential presentation of wearable cameras photos as a means to aid recollection of autobiographical episodic memories, in healthy individuals and for a person with a memory impairment. It also explored how the process of photo review as a long-term memory enhancement strategy compares with another memory enhancement strategy, retrieval practice. Moreover, EEG was used to explore the neurophysiological mechanisms underlying the retrieval of memories.

In this section the key results and conclusions of the experimental chapters are summarised, their implications in the context of real-world memory improvement are considered, and finally, the limitations and future directions of this line of research are discussed.

6.1 Chapter Summaries

6.1.1 Chapter 2

This chapter explored the underlying mechanism of wearable camera photo review as a memory aid. The use of wearable cameras as a means to aid the recollection of memories are presented and their key features are overviewed. Several studies are discussed in which reviewing the wearable camera photos aids the recollection of personally experienced events (for a review of studies, see Silva et al., 2016). Across the different studies, wearable camera photo review has been used in different ways and for this reason, there is a lack of systematic understanding of how wearable camera photo review influences memory recollection and what its main features are. Despite this, almost always the wearable camera photos are reviewed sequentially. In this study, the sequential presentation of photos is taken as a key feature of wearable camera photo review and is examined in a controlled environment. Moreover, the use of EEG in exploring the neurophysiological mechanisms underlying the recognition memory is discussed. When comparing the EEG signal after the presentation of correctly identified old items with new items, several old-new ERP components are found. For example, an old-new effect that corresponds with participants sense of familiarity is observed over the frontal areas of the brain and an old-new effect which corresponds to recollection about the source of the memories is observed over the parietal sides of the brain (Rugg & Curran, 2007). While EEG can be used to explore whether the underlying mechanism of recognition memory is affected by the sequential presentation of the wearable camera photos, it can also shed light on the overall recognition processes for real-world autobiographical memories.

Participants were taken on a city walking tour while they viewed a set of predefined exhibits. One week later they performed a recognition task in which sequences of four photos from the tour along with control photos were presented while their EEG was being recorded. They responded to the photos based on their subjective feeling of whether specific information from the targets was recollected (‘recollect’ response) or they remembered based on a sense of familiarity (‘familiar’ response), along with a ‘don’t remember’ response for photos they did not remember. This recognition task allowed the examination of participants’ recognition performance across the sequences of photos for each exhibit.

Participants hit rate – the proportion of correct hit (recollect and familiar) responses to all tour photos, increased along the sequence of photos. The same thing happened to their recollection rate – the proportion of correct recollect responses to all remember responses (recollect and familiar). Finally, their ability to distinguish between the tour and control photos as measured by sensitivity d’ also increased over the sequence. Overall, these results indicate the positive effect of the sequential presentation of photo in enhancing participants recognition memory. This improvement in the recognition task as a result of the sequential presentation of the photos is in line with findings of Mair et al. (2017). In their study, participants' recall was more detailed after observing photo in their natural order relative to in random order. No changes related to the sequence were observed in the old-new EEG effects. Finally, factors such as the frequency in which photos are captured as well as presented to participants and the number of photos in the sequence are further discussed. It is suggested that future research would benefit from using this type of paradigms in the examination of optimal conditions for aiding autobiographical memories.

6.1.2 Chapter 3

This chapter explored the effect of the sequential presentation of wearable camera photos in aiding the recollection of autobiographical memories in a person with memory impairment. More specifically, it explored how the effect of sequential presentation is modulated based on the retention interval (same day or a week) and whether the participant reviews the wearable camera photos during the retention interval.

Several neurological conditions (e.g. Alzheimer's disease, viral infections) can produce significant impairment in a person's ability to create, maintain, and recollect memories (Becker & Overman, 2002; O'Connor & Verfaellie, 2002). The resulting memory impairment can have dire consequences on the social and occupational lives of people living with such conditions (Lyketsos et al., 2003). External aids are discussed as a means to improve the lives of people with memory impairment. While many such aids are designed to remind people to perform a task in future (e.g. calendars, diary notes), wearable cameras are described which are designed to aid the recollection of autobiographical memories. Case studies are discussed in which the review of wearable camera photos aids the recollection of memories better relative to reviewing written diary entries (e.g. Berry et al., 2007; Loveday & Conway, 2011). Similar findings are presented for people with no memory impairment (e.g. Mair et al., 2017; Sellen et al., 2007). Finally, the influence of reviewing the wearable camera photos on future retrieval of those memories is reviewed (Finley et al., 2011; St. Jacques & Schacter, 2013).

The participant for this study is CR, a person with memory impairment as a result of limbic encephalitis. Similar to the paradigm presented in chapter 2, CR is taken on a city walking tour observing a set of predefined exhibits while wearing the wearable camera. After some retention interval, sequences of wearable camera photos for each of the exhibits are presented in a recognition task along with control photos. This process is repeated for the three conditions, new material is used for each condition. In the first condition there is a three hours retention interval and in the second condition one week. In the third condition, there is a one-week retention interval, but here, CR reviews the wearable camera photo on the first and the second condition. CR's results are also contrasted with the results of control participants (presented in chapter 2).

In the condition with three hours retention interval, CRs response is very similar to participants, the sequential presentation of the photos has a positive effect on her recognition performance. However, in the condition with one-week retention interval, her recognition performance is poorer, and the sequential presentation does not improve her recognition performance. It also increases her false alarm rates. Finally, in the condition where she had reviewed the photos, the sequential presentation of photos increase her likelihood of using a remember response. There is an increase in hit and false alarm rates, while her ability to distinguish between old and new photos remains poor across the sequence of the photos.

These findings emphasise the role of sequential wearable camera photo presentation in improving the recollection of personally experienced events in a person with memory impairment. However, this is only the case when the overall memory performance is relatively intact. Furthermore, while it has been suggested that reviewing wearable camera photos improves future memory performance, this result is not supported by this study. Indeed, reviewing the photos during the retention interval drastically increases CR's tendency to use a remember response while not meaningfully improving her ability to distinguish between old and new items. This result emphasizes the need for a more controlled examination of wearable camera use; a notion that has also been put forward by Barnard et al. (2011).

The main limitation of this design is that only two retention intervals are used. For this reason, the duration CR can maintain memories is unclear, along with the length of any positive influence reviewing photos may have had on her memories. Overall, while this study shows the beneficial effects of sequential presentation of wearable camera photos for recollecting personally experienced events, it also highlights that this effect is only present when the overall memory is good enough otherwise it has a negative effect of inducing a false sense of remembrance.

6.1.3 Chapter 4

While chapter 2 and 3 examined how wearable cameras can be used to aid the retrieval of memories in healthy individuals and people with memory impairments, in this chapter the effectiveness of different strategies on enhancing future memory performance was examined.

The literature of retrieval practice and the use of wearable camera photo as a means to enhance future memory performance is reviewed. Retrieval practice refers to the memory enhancement effect as a result of testing the learnt material relative to restudying them (Karpicke et al., 2017). The influence of effort is overviewed in this process and it is concluded that retrieval practice may act as a fast consolidation process. While this is a robust finding, it has not been examined in the context of real-world autobiographical memories. In addition, the use of the wearable camera photo review is introduced as a way to improve future memory performance real-world autobiographical memories (Finley et al., 2011; St. Jacques & Schacter, 2013). Reviewing the camera photos is shown to enhance future memory performance of the event.

In order to compare these two strategies, participants were taken on a museum tour while wearing the wearable camera. They performed one of two enhancement exercises right after this tour; those in the retrieval practice condition attempted to recall the exhibits they had seen and those in the photo review condition watched the wearable camera photos of the exhibits. One week later, all participants performed a recognition test followed by a free recall test. During the recognition task, participants also indicated their confidence levels in each response.

The recognition performance was better in the photo review condition, while the free recall performance was better in the retrieval practice condition. This is interpreted to reflect the notion that different enhancement strategies stabilise and strengthen different features of the memories (e.g. Antony et al., 2017; St. Jacques & Schacter, 2013) and therefore different memory tests benefit from different memory enhancement strategies. Visual features enhanced during the photo review lead to a better performance in the recognition task which relies on visual features of the photos. And, semantic and episodic details enhanced during the retrieval practice results in an improvement in a final recall task. It is argued retrieval practice may be a better enhancement strategy that can be used in a real-world setting. This is because in day to day life, memories are rarely tested in a manner similar to a recognition task but are instead usually remembered in a manner similar to a free recall task.

6.1.4 Chapter 5

While the previous chapters presented in this thesis focused on the memory improvements strategies for real-world autobiographical memories, this chapter focused on the neurophysiological mechanisms underlying the recognition of such memories. The use of recognition tasks was described in order to examine the neurophysiological mechanism of memory retrieval. This method essentially involves comparing the electroencephalogram (EEG) signal recorded after the presentation of correctly recognised studied items with correctly recognised new items. The changes between the two signals provide information about the timing and topography of the neurophysiological activity that is associated with the successful retrieval of information.

Event-related potentials (ERPs) and time-frequency analysis (TF), the two main methods of analysing the EEG data were overviewed. Main old-new ERP effects were described; the frontal old-new effect which is functionally associated with participants sense of familiarity and parietal old-new effect which is associated with successful recollection of information about the source of the information (Rugg & Curran, 2007). Additionally, studies using time-frequency analysis have outlined the roles played by synchronisation in gamma band activity, which is associated recollection of sensory information, and theta band activity, which is associated with ‘high’ level memory processing (Burgess & Ali, 2002; Gruber et al., 2008). Finally, desynchronization in alpha and beta bands were mentioned (Burgess & Gruzelier, 2000; Khader & Rösler, 2011) along with a proposal that this desynchronization plays a role in transferring sensory information during the time of memory retrieval (Hanslmayr et al., 2012).

While these past studies provided useful information about the neurophysiological mechanism underlying the recognition of memory, they use stimuli that were much simpler relative to real-world memories and usually have a very short retention interval. In order to explore the neurophysiological mechanisms underlying the retrieval of more real-world episodic autobiographical memories, participants' EEG was recorded during the recognition task described in chapter 4. This enabled the examination of the neurophysiological mechanism underlying the retrieval of real-world autobiographical memories and explore how they were modulated by different enhancement strategies: the retrieval practice or photo review. The ERP results indicated a parietal old-new effect and the TF results indicated a desynchronisation in gamma band over the parietal and frontal electrodes. Both these effects were only observed the in the photo review condition. Since the sensory information is thought to be strengthened in this condition, these results are taken to emphasis the role of sensory information in old-new EEG effects. Moreover, while previously only synchronisation in gamma has been described, the results here show a desynchronization in gamma band activity. This is interpreted to potentially emphasise the role of gamma oscillations in transferring sensory information for the reinstatement of the memories. The lack of finding old-new effects in other frequency bands (e.g. theta, alpha, & beta) were explained as reflecting the differences between the paradigms used in the literature and in the current study.

6.2 Implications

The results of the present thesis can be utilised in developing strategies for aiding autobiographical memories. Such strategies can be employed by people with and without memories impairments in order to aid their autobiographical memories, and potentially have a positive impact on the quality of life (e.g. Browne et al., 2011). The implication of the main findings of this thesis in the development and optimisation of memory enhancement strategies are discussed below.

6.2.1 Aiding Immediate Recollection

The first two studies presented in this thesis emphasised the role of sequential presentation of photos in aiding the recollection of personally experienced events. They revealed that when overall recognition performance was good (i.e. better than chance), showing sequences of photos was beneficial in aiding the recollection of memories. There was a linear increase in the recognition performance associated with the number of photos in the sequence, that is the recognition performance improved as more photos were presented. This was the case for both subjective sense of recollection and also objective measures of recognition (hit rate & sensitivity). Along with findings from previous studies, these results emphasise the importance of the sequential presentation of photos (Loveday & Conway, 2011; Mair et al., 2017). However, when the overall memory performance was poor – recognition performance was near chance, the sequential presentation did not have a beneficial effect. In this situation, the sequential presentation of photos led to participants falsely identifying new items as old items. That is the presentation of further photos of the new items increased the likelihood of these items being falsely recognised as old items.

The increase in the false recognition rate can further lead to the creation of false memories in a manner similar to the negative suggestion effect in the retrieval practice paradigms (Koediger & Marsh, 2005). In these cases, the presentation of false information during the retrieval practice conditions lead to a false memory of these items being presented in the initial learning phase. While this is an important caveat to consider, none of the studies that are interested in wearable cameras as a means to aid memory in people with memory impairment has measured nor discussed it (Barnard et al., 2011). In real life, where there are no control photos placed in the photo review session, the sequential presentation of photos can still lead to memory distortions. This is because the memories which may be constructed during the false recollections would not be representative of the actual memories. For this reason, when using wearable cameras as a means to aid the recollection of memories for people with memory impairments, supervision is necessary to correct the memories of falsely remembered events.

Overall, the sequential presentation of photos appears to be a useful means to allow recollection of memories. When aiming to aid the recollection of memories using the wearable camera or other devices that function in the same way, then the photos should be captured and presented in a sequential manner in order to produce a stronger recollection. However, it is important to consider the overall memory levels and make sure that the sequential presentation of photos is not leading to false recognitions. For people with memory impairments, this can be resolved by having a person (e.g. a carer or a friend) who can point to false recollections and correct them if possible.

It is important to note that since the temporal order of the photos was not manipulated (i.e. photos were only presented in their natural order) it is possible that sequences of randomly ordered photos could also induce similar behavioural effects to that explained in this sections.

6.2.2 Enhancing Future Memory Performance

The fourth chapter contrasted two enhancement strategies for improving the future recollection of autobiographical memories. While reviewing the wearable camera photos improved the recognition performance, practising retrieval improved the free recall performance. As argued in this chapter, since real-life memories are usually recalled in a manner similar to a free recall task, it seems more sensible to use a retrieval practice condition for enhancing future memory for autobiographical memories.

While the relative effects of photo review and retrieval practice seem clear, there are a few additional points to be considered in assessing these two strategies with each other. These are mainly related to the fact that for a photo review session, photos need to be taken. One limitation of using wearable cameras in public places is the privacy considerations of capturing photos of other people. For this reason, some private places may completely ban photography and some places as well as certain countries (e.g. Spain, Switzerland, Japan, & many more) require explicit consent from people who are to be photographed. Another limitation of wearable cameras is that they perform very poorly in low light or during movement. On the plus side, there is now a range of active sports cameras that produce videos which can be converted into sets of photos. And finally, cameras require maintenance in order to be ready for use, for instance, they need to be charged and cleared for new photos. Overall, these are some of the restrictions of using wearable cameras that may make them less desirable depending on the environment and the ability of the person using it.

Integrating the findings of this thesis with that of the retrieval practice literature, a potentially powerful enhancement strategy will be to use a cued retrieval practice. Retrieval practice only produces an effect if the learned material is successfully retrieved and that the more difficult the retrieval practice the stronger its effect (Karpicke et al., 2017; Rowland, 2014). Furthermore, items that are not retrieved during this process will become less likely to be remembered after the retrieval practice (retrieval-induced forgetting; Anderson, 2003). This means that the content of the memories which are not retrieved during the retrieval practice will become less likely to be retrieved after the retrieval practice process. One way to overcome this forgetting effect and increasing the recollection rate, while still allowing the retrieval practice to produce an optimal enhancement effect would be to use a cued recall retrieval practice (e.g. Carpenter & DeLosh, 2006). This method would require wearable cameras to be partially masked and presented in a cued retrieval condition. During this, the participant would be required to recall information about the given events using these partially covered photos. Doing so would increase the number of memories that are retrieved but at the same time having partially covered the wearable camera photos would ensure the retrieval is actively performed by the participants resulting in a strong memory enhancement effect.

6.2.3 Summary

Overall, for aiding the recollection of memories, the sequential presentation of wearable camera photos provides a strong aid., However, this is only the case when the overall memory is relatively good. For enhancing the future recollection of memories, it appears that retrieval practice may be a more superior solution relative to the wearable camera. This is because its effects are more useful for everyday memory (its effect on free recall) and do not suffer the limitation of the wearable camera (e.g. privacy, low-quality photos). A potential enhancement strategy would be to use partially covered wearable camera photos in a cued retrieval practice.

6.3 Limitations and Future Directions

In this section methodological limitations are summarised, and future research directions are discussed.

In chapter 2 and 3, in order to examine the effect of sequential photo presentation as a means to aid recollection of memories, sequences of four photos were used in a recognition task. This allowed the changes in participants over the sequence to be measured. While positive effects of sequential presentation of photos were evident, the results also showed that sequential presentation of the photo can lead to a higher rate false-positives in CR. Furthermore, while having performed a photo review did not improve CRs ability to distinguish between old and the new photos, her overall tendency to use a remember response increased. In these conditions, having metacognitive measures would have provided information about her overall ability to monitor her performance and more importantly about how this is modulated with the photo review session. While control conditions were not necessary in order to understand whether the sequence has any effect at all, including them could provide additional important information. For example, paradigms using longer sequences can provide information about when the sequence effect plateaus, and the optimal number of photos in a sequence for each item that can produce a sequence effect. Paradigms using sequences of photos in random order can provide information about the effectiveness of the temporal order in creating a sequence effect.

Another important consideration for future research should be ways in which the number of wearable camera photos may be reduced. Wearable cameras usually take photos with the same frequency over the duration of an entire event (e.g. Berry et al., 2007; Loveday & Conway, 2011). That is, if a participant is taken on a day trip, the wearable camera will take photos for the entire duration of the trip. This results in photos with an almost equal time interval between them, with small variations due to the camera sensors. It is not known whether these photo collections can be reduced in number but still produce a recollection effect similar to the full photo collections. This is important since a high number of photos require more time to observe, more space to store, and more effort to organise. One way the photo can be reduced is to lower the frequency of photos in between the main memory events. This can be done manually by changing the frequency at which the camera takes photos during the event or setting the camera on the higher frequency but reduce them post hoc. Reducing the frequency of photo for non-important sections would still provide some information from them but would optimise how they are used over the course of the event.

In chapter 4 in order to explore the long-term effects of wearable camera photo review and retrieval practice, a recognition test along with a free recall test was used. However, the recognition task provided much more in-depth information than did the recall task. For the recall task, only correctly remembered items were counted while further information could have been acquired as well. For example, the number of false items participants may have recollected, the degree of details recollected for each of the items, and finally, confidence ratings for metacognitive measures.

It has been shown that in certain cases, photo review leads to an increase in false alarm rates in a recognition task (St. Jacques & Schacter, 2013). While this was not the case here for the recognition task, it is unclear whether participants in the photo review condition falsely recollected more exhibits in the free recall task that those in the retrieval practice condition. Measuring the number of falsely recollected items during the free recall would provide information about this. Another measure that could have provided useful information during the recall is the degree of details participants were able to recollect for each of the exhibits. This would be useful in contrasting the effect of photo review and retrieval practice. Finally, while there were measures of metacognition during the recognition task, no such measures were considered for the free recall task. Although it would have been possible to also take such measures, by asking participants to provide confidence ratings for each recollection and for their overall performance in this task.

As described in the implication section for enhancing future memory performance, a potentially powerful enhancement strategy will be to use a cue retrieval practice. While based on the findings of this study and that of the retrieval practice this strategy can produce, it has not been empirically tested yet and future studies should investigate the effectiveness of this strategy.

6.4 Conclusion

Overall, this thesis evaluated the role of the sequential presentation of photos taken by wearable cameras in aiding the recollection of autobiographical memories. Presenting the photos sequentially led to better memory performance in healthy individuals as well as for a person with a memory impairment. It further showed that this was only the case when the overall memory performance was relatively better than chance, otherwise the sequential presentation of photos led to false recollections. This negative effect, unexplored in wearable camera literature, should be considered in memory research as well as in the development of memory improvement strategies that use cameras. It is important to note that, based on the studies described in this thesis, the sequence of photos may not need to be in a natural temporal order. That is to say that a randomly ordered sequence of photos may create similar effects. Moreover, for long-term enhancement of memories, the best strategy depends on how memories are tested. While reviewing wearable camera photos improves the performance in a future recognition task, retrieval practice improves future recall performance. Since real-life memories are typically remembered in a manner more akin to a recall task than a recognition task, retrieval practice seems to be a better alternative than wearable camera photo review. Finally, the EEG signatures of memory retrieval were examined using both ERP and TF analysis in the recognition task. These were only present in the retrieval practice condition. Based on the assumption that photo review enhances sensory information while retrieval practice enhances semantic information, it would appear that known EEG signatures are related to the processing of sensory information during recognition.

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