The Cognitive and Neural Correlates of Rich and Vivid Memory for Real World Events

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Abstract

Episodic memories are composed of rich, perceptual details, and are re-experienced from a specific visual perspective. The aim of this thesis was to investigate the processes which allow us to remember in a rich and vivid way and the neural underpinnings of rich, successful retrieval. The behavioural studies conducted in Chapters 2 and 3 used a newly created video stimulus set, depicting real-world events. In Chapter 2, these stimuli were used to investigate retrieval differences following the encoding of unisensory (audio, visual), compared to multisensory (audio-visual) versions of the videos. Accuracy, vividness and amount of descriptive details retrieved were not positively affected by the presentation of multisensory stimuli. Chapter 3 compared the effects of encoding the videos from a field or an observer perspective on subsequent retrieval performance. No performance differences were observed when comparing the two perspectives, but observer memories contained a greater amount of sensory details, compared to field ones. Chapter 4 reviewed existing literature on the role of the angular gyrus in episodic memory retrieval and proposed that the angular gyrus is sensitive to the richness of recollected information and amount of details retrieved. This hypothesis was tested in an fMRI study in Chapter 5, focusing on the role of the angular gyrus in the retrieval of autobiographical memories. Results indeed demonstrated a positive relationship between angular gyrus activity and amount of details remembered. This association was seen for the retrieval of both episodic (specific) and semantic (categoric) events. This study also illustrated differential involvement of angular gyrus subregions, PGa and PGp in the retrieval of episodic and semantic memories. Taken together, these chapters outline behavioural processes and neural correlates that support our ability to retrieve memories in a rich and vivid manner, giving us a sense of re-living an event.

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Chapter 4 is a modification of an article in preparation with collaborators Dr Jon Simons (Cambridge University) and Dr Michael Rugg (University of Texas):

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Chapter 1 - Literature Review

1.1 Introduction

Remembering unique past events, termed as ‘episodic memory’ allows us to mentally travel to the past, recreating and re-living our subjective experience of an event (Tulving, 1972). This sense of reliving has been associated with the richness and fidelity of the visual imagery being retrieved (Zaman & Russell, 2022) and can be influenced by the visual perspective adopted when retrieving an event. Our perceptual experiences are multimodal in nature (Sathian & Ramachandran, 2019) and require a perspective from which to visualise the event in our mind’s eye when remembering them (Rubin & Umanath, 2015). These two components seem to be key in understanding how experiences are later retrieved in a rich and vivid way from episodic memory. The aim of this thesis is to investigate and discuss these two components in turn; namely how sensory details and the manipulation of unisensory versus multisensory events can affect the subjective re-experiencing and accuracy of memory retrieval. And secondly, the effect of visual perspective manipulation (‘Field’ versus ‘Observer’) at encoding on these same characteristics of memory.

Finally, recent evidence has demonstrated the importance of the angular gyrus (AG) in the retrieval of episodic memories (Rugg & King, 2018; Simons et al., 2022). Previous findings have associated this region with aspects of subjective recollection, such as vividness and confidence. The evidence associated with the AG and episodic memory will be reviewed and accompanied by the reporting of an fMRI study assessing subjective detail ratings during retrieval of specific and categoric autobiographical memories (AM).

1.2 Episodic Memory

The term ‘Episodic Memory’ and the distinction between episodic and semantic memory was first proposed by Tulving in 1972. Episodic memory was defined as a system storing “*personally experienced unique events*”, while referring to semantic memory as the memory necessary for the understanding of language, for which there is no record of the context in which the memory is acquired (Tulving, 1972). Numerous concepts regarding episodic and semantic memory and their distinction have evolved in the years since the theory was first introduced (such as the focus on language comprehension in semantic memory), but many of the ideas remain relevant to this day, namely the overlap between episodic and semantic memory (for a review of Tulving’s work on the distinction of semantic and episodic memory see Renoult & Rugg, 2020). Key to this thesis is Tulving’s idea that episodic memory involves the retrieval of sensory-perceptual details, and a subjective sense of time, permitting us to re-experience a past event (Tulving, 1985; Wheeler et al., 1997)

Episodic memory is often operationalised in terms of ‘objective’ aspects of retrieval performance, as in the case of judgements of source memory, when contextual details associated with the presentation of study items are queried by the experimenter and the accuracy of retrieved content can be verified. For Tulving, however (Tulving, 1983, 1985; 2002), recollection is necessarily associated with the subjective experience of the self mentally ‘travelling through time’ to re-experience the original event. Subjective aspects of episodic memory can be queried by asking participants to introspect and report details of the phenomenological experience accompanying the recollection of a past event (Simons et al., 2022). In the ‘Remember-Know’ procedure developed by Tulving (1985), a Remember response is considered to be indicative of recollection (for which the context of the memory and when it was encoded is also recalled) and a Know response of familiarity (a sense or 'feeling' of having encountered an item before, in the absence of contextual information; see also Gardiner, 2001). Subjective measures of episodic memory also include asking participants about the vividness of a retrieved memory, typically defined as the richness and clarity of the memory, including the number of sensory details and the sense of re-experiencing the original event (Rubin & Kozin, 1984; Talarico, et al., 2004; Folville et al., 2021); their confidence that an event was previously experienced (e.g., Roediger et al., 2012; for a recent review on subjective measures of recollection, see Zaman & Russell, 2022), and thus to reflect on their own mnemonic operations, a so-called metamemory judgement (e.g. Flavell & Wellman, 1977; Koriat, 2007). There is evidence that subjective and objective measures of episodic memory are correlated. High vividness ratings during study can predict subsequent recall (D'Angiulli et al., 2013; Jackson & Schacter, 2004; Alghamdi & Rugg, 2020), while high vividness ratings during recall were associated with a higher fidelity of memory for the visual details of pictures (Cooper et al., 2019; Richter et al., 2016; Xie & Zhang, 2017). On the other hand, recollection, for example as operationalized as successful source retrieval, has typically been associated with high confidence judgments (Yonelinas, 1994, 2001).

It is not clear however whether various subjective measures (e.g., Remember/Know; confidence; vividness) are equivalent to one another. Dissociations have been reported in ageing studies. For example, older adults tend to rate their memories with similar degrees of vividness as young adults despite having lower objective (source) memory performance (Folville et al., 2020; Gallo et al., 2011). On the other hand, studies using R/K judgements as subjective measure of episodic recollection did not observe any dissociation with objective memory performance (Prull et al., 2006; Koen & Yonelinas, 2014; Alghamdi & Rugg, 2020). One possibility to explain this discrepancy between vividness and R/K ratings, as suggested by Alghamdi & Rugg (2020), is that vividness instructions might allow participants more flexibility in how they interpret instructions, while R/K instructions often require participants to restrict Remember responses to trials where a reportable contextual detail about the study episode was recollected (see also Folville et al., 2021).

1.3 Sensory Modality and Episodic Memory

Our memories seldom consist of singular sensory information, and it is through these different senses that we can recall rich and vivid episodes (Sathian & Ramachandran, 2019). It has been argued that all our perceptual experiences are multimodal in nature and there can be no such thing as a unisensory experience, isolated from any other sensory input (Sathian & Ramachandran, 2019). From an early age, we learn how to group different multisensory information into one single perceptual entity (for a review, see Murray et al., 2016). Nonetheless, research within the perception and memory fields has focused more heavily on assessing behaviour and brain activity evoked by unimodal stimuli (Matusz et al., 2017; Quak et al., 2015). It is necessary to revert the focus on multisensory experiences if we are to represent real-life environments in our experimental paradigms.

Aside from providing higher ecological validity, the use of multisensory stimuli has been shown to be indispensable for many aspects of higher cognitive functioning. For example, learning multisensory, compared to unisensory information, was shown to be faster and more effective (Sathian & Ramachandran, 2019; Shams & Seitz, 2008; Seitz et al., 2006; Yang et al., 2014) and associated with improved memory accuracy and subsequent object recognition (Bonnici et al., 2016; Lehmann & Murray, 2005; Murray et al., 2004; Schroeder & Marian, 2016; Thelen et al., 2014). These findings seem to be consistent only when encoded in a semantically congruent pairing, with semantically incongruent presentations often leading to no memory aid or a hindrance to memory performance (Heikkilä et al., 2015; 2017). For instance, hearing the bark of a dog in conjunction with seeing an image of a dog (rather than hearing a bark and seeing an image of a bird for the incongruent equivalent), at encoding, has been shown to aid retrieval of that visual information (Lehman & Murray, 2005). These findings clearly demonstrate how our perceptual and cognitive functioning is preferentially attuned to multisensory settings (Sathian & Ramachandran, 2019). Shroeder and Marian (2016) demonstrate how these effects are not simply due to participants using auditory cues, such as a dog bark, as confirmation of seeing the image of a dog, but that input of auditory information can strengthen episodic memory for visual information. Using a source memory task, they found participants showed better retrieval for the location of an image on the screen when paired with a location irrelevant, congruent sound (i.e., bark and image of a dog).

Though our retrieval seems to be consistently improved when encoding multisensory information, it should also be noted that retrieval accuracy does not seem to be equal across sensory modalities. Studies have shown how individuals with normal hearing and vision are typically visually oriented (Colavita, 1974; Koppen & Spence, 2007). We seem to be much better at retrieving visual items, above other sensory information and this seems to be key for the retrieval of autobiographical and episodic memories (Rubin et al., 2003). Specifically on the topic of re-living rich and vivid memories, Rubin et al., (2003) showed how highly re-lived AMs were significantly related to strong visual images being retrieved. Numerous studies have supported our notable capacity to retain large amounts of visual information (Brady et al., 2008; Standing, 1973, Shepard, 1967), and demonstrate high fidelity of visual information (Konkle et al., 2010a; 2010b).

Even when presenting semantically related ‘new’ items, findings have shown exceptionally high accuracy for correct rejection judgements of ‘new’ visual items (82% Accuracy, Konkle et al., 2010a), and scenes (Konkle et al., 2010b).

The same capacity and fidelity is not seen for the retrieval of auditory information. When comparing memory accuracy across senses, individuals generally demonstrate less accurate recognition judgements for auditory, compared to visual stimuli (Cohen et al., 2009; 2011), and as suggested by Bigelow and Poremba (2014) also reduced accuracy for tactile information, compared to visual. When looking at the fidelity of memory representations, Gloede and Gregg (2019) found no differences in the accuracy of ‘old/new’ recognition judgements (old items, new related, and new unrelated) for visual information but did find significantly poorer correct rejection accuracy for ‘new related’ judgements of auditory stimuli. Providing an accurate ‘new’ judgement for semantically related items would require a thorough retrieval of perceptual details, demonstrating a difference in fidelity of memory representations between visual and auditory stimuli (Gloede & Gregg, 2019). This distinction may explain these findings demonstrating higher discrimination accuracy for visual compared to auditory information.

While previous studies have assessed differences in retrieval accuracy across sensory modalities and emphasized the importance of multisensory processes in learning and memory, many have relied on simplified and artificial stimuli, such as a simple picture-sound pairing, thereby weakening the argument for high ecological validity and relevance to realistic settings (Sathian & Ramachandran, 2019). To address this limitation, the current research project utilizes a multisensory data set consisting of videos depicting everyday life scenarios, ensuring the experimental paradigm parallels real-life settings and episodic events. Investigating the properties of multisensory memory can provide valuable insights into the vivid nature of memory recollection. As discussed earlier, from a behavioural perspective, memory accuracy was shown to be significantly enhanced following multisensory stimulus presentation compared to unisensory presentation (Bonnici et al., 2016; Murray et al., 2004). Studies have examined this effect using audiovisual pairings, revealing the lowest accuracy for auditory-only presentation and the highest for combined audio-visual presentation (Sathian & Ramachandran, 2019). Further research is necessary to understand the circumstances in which multisensory processing aids memory and to explore the retrieval of each sensory modality individually.

1.4 Perspective and Memory

As discussed above, our episodic memories are composed of rich sensorial and perceptual information (Johnson et al., 1988). Visual imagery seems to be integral when remembering episodic and AMs and is one of the best predictors of the subjective re-experiencing of events and a sense of reliving (Rubin et al., 2003). One often overlooked, but key aspect of visual imagery is the ability to hold a specific viewpoint in one's mind eye when retrieving such sensory information (St. Jacques, 2022). The acknowledgement that individuals can hold multiple viewpoints during retrieval has been noted for some time (Henri & Henri, 1896). Nigro and Neisser (1983) were the first to conduct an empirical study investigating the effects of visual perspective on memory. This study was key for the initial distinction and recognition of two possible perspectives at memory recall, 'Field' (the perspective from one's own eyes or a first-person perspective) and 'Observer' (the perspective of an autobiographical event as seen from an observers' point of view or a third-person perspective). Field perspective is associated with higher emotional valence, self-awareness, and more commonly relies on recent events (Nigro & Neisser, 1983). It is generally acknowledged that events are initially encoded from a field perspective. Through mnemonic change and reconstructive processes, older memories are more likely to be retrieved from an observer perspective (Freud 1950; Nigro & Neisser, 1983; Robinson & Swanson, 1990), supporting numerous findings linking temporal distance with adopting an observer perspective at retrieval (Nigro & Neisser, 1983; Piolino et al., 2006,2007; Pronin & Ross, 2006; Rice, 2010; Robinson & Swanson, 1993; Sutin & Robins, 2008), with the exception of flashbulb memories (Talarico & Rubin, 2003).

Aside from the determinants that lead individuals to use a field or observer perspective when remembering, visual perspective can also influence the phenomenology and characteristics of memories, commonly shown through studies where participants actively shift from a field to an observer perspective. Studies have shown how shifting to an observer perspective leads to a reduction of vividness, sense of reliving and intensity of emotion (Akhtar et al., 2017; Berntsen & Rubin, 2006; Butler et al., 2016; Marcotti & St Jacques, 2018; Robinson & Swanson, 1993; St Jacques, 2022; Williams & Moulds, 2008). Although this could be a phenomenological aspect of observer perspective memories, the fact that observer memories are more likely to be remote might also be an explanation for the reduced vividness shown. The link between temporal distance and observer perspective memories could imply that a reduction in vividness ratings is a by-product of such temporal distance, making it difficult to discern the reasoning behind this mnemonic change (Verhaeghen et al., 2018).

Evidence from shifting effects of newly, experimentally encoded memories, can help shed light on this effect further. Butler et al., (2016) asked participants to walk around campus and perform a series of mini-events. They found that mnemonic changes during repeated retrieval were dependent on the perspective participants adopted. Visual information and sense of recollection (measured through the autobiographical memory questionnaire AMQ) were maintained when individuals repeatedly retrieved memories from a field perspective and were reduced when shifting from a field to an observer perspective. Poor performance also did not revert when individuals were asked to shift back from an observer to a field perspective, suggesting that a shift to an observer perspective leads to permanent mnemonic changes of memory, even when asked to shift back to a field perspective. These findings suggest that maintaining a field perspective can slow the reconstructive effects of memory and that the shifting to an observer perspective leads to a loss of visual information and sense of recollection, suggesting that mnemonic changes witnessed for memories retrieved from an observer perspective are not solely a result of temporal distance. In addition to a reduction in vividness ratings, Akhktar et al., (2017) demonstrated that retrieval from an observer perspective was coupled with a reduction in episodic details being retrieved. Marcotti and St Jacques (2018) also found that reduced vividness ratings when shifting to an observer perspective predicted impairments in retrieval accuracy, linking perspective to the accuracy and fidelity of a memory.

Most of the current focus of research assessing visual perspective and memory has been on the shift from a field to observer perspective at retrieval. However, some evidence from research conducted with PTSD patients does suggest that observer memories for highly emotional and stressful events could be encoded from an observer perspective (McIsaac & Eich, 2004). Few studies have assessed differences in memory retrieval when manipulating perspective at encoding, mostly due to the practical difficulty of manipulating an observer perspective when events are initially experienced from a field perspective. In one study, participants demonstrated better source memory accuracy for word lists when these were encoded from a field perspective (video of an empty chair and computer task), compared to an observer perspective (video displaying the participants themselves in the chair; Leynes et al., 2017). Using virtual reality (VR) scenes, Bergouignan et al., (2014) compared an in-body to an out-of-body condition for a series of life events. Participants were able to recall significantly fewer episodic details for events encoded in the out-of-body condition, compared to the in-body condition.

Similarly, Iriye and St Jacques (2021) used virtual reality environments to assess the effect of observer experiences on the formation of memories. However, this study found no difference in the percentage of correct responses on a free recall test or reported vividness of memories, encoded from either a field or observer perspective. Nonetheless, participants did report a significantly lower ‘sense of presence’ for observer, compared to field environments. The use of ‘sense of presence’ as a subjective rating of experienced events has mostly been used within virtual reality environments (Dinh et al., 1999; Witmer & Singer, 1998). This measure focuses on the extent to which an individual has a feeling of ‘being there’, typically in the context of an immersive virtual environment (Makowski et al., 2017). Research adopting virtual environments for the development of memories has found that a field perspective is associated with a higher sense of presence, compared to an observer perspective (Denisova & Cairns, 2015; Kallinen et al., 2007). A stronger sense of presence at encoding may also result in improved accuracy at recollection (Krokos et al., 2019; Makowski et al., 2017). Makowski et al., (2017) found that participants’ accuracy for factual details (ratio of correct answers to a set of questions about a movie) was higher for movies during which they reported a greater sense of presence.

The limited research conducted on the effect of perspective manipulation at encoding has shown contradicting findings regarding the effect of encoding an event from an observer perspective on the retrieval accuracy of that event. Some studies have shown how being presented with stimuli from an observer, rather than field perspective at encoding can result in impaired accuracy (Bergouignan et al., 2014; Leynes et al., 2017), while others did not find any differences in accuracy or vividness ratings at retrieval when encoding an event from either a field or observer perspective (Iriye & St Jacques, 2021). There is therefore room for this area to be investigated further, using measures and designs used for the mentioned VR experiments as the base on which these investigations can be conducted.

1.5 Brain Regions Involved in Rich and Vivid Re-experiencing of Events

Episodic memory refers to memory of unique events, within a specific spatial-temporal context, associated with autonoetic consciousness which enables a sense of reliving the episode (Tulving, 1983; Moscovitch et al., 2016). The medial temporal lobe (MTL), specifically the hippocampus; the parahippocampal, medial prefrontal (mPFC), posterior cingulate and retrosplenial cortices, as well as left angular gyrus and left middle temporal gyrus have been recognised as key brain regions involved in episodic memory retrieval, forming a ‘core’ recollection network that is engaged when the recollection of a memory is successful (Figure 1.1; Renoult et al., 2019; Rugg & Vilberg, 2013; Rugg et al., 2015).

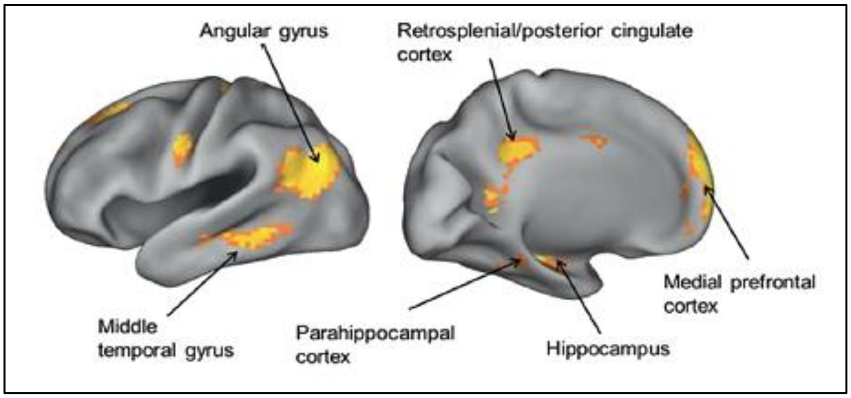

Figure 1.1. The core recollection network is involved in the successful recollection of memories, irrespective of the recollected content, as depicted in Rugg and Vilberg (2013).

Starting with findings from patient studies, such as H.M, where removal of parts of his MTL led to severe anterograde amnesia (Scoville & Milner, 1957), it has been concluded for some time that the MTL is key in the formation and retrieval of declarative memories (Squire, 2009). Since then, the MTL has been associated with the binding of detailed information of an event at encoding (Moscovitch, 2008; Moscovitch et al., 2016; Rubin & Umanath, 2015) and reconstruction of scenes pertaining to such memory at retrieval, allowing for the internal representation of an event (Maguire & Mullally, 2013). The hippocampus in particular seems to play a key role in episodic memory due to its capacity to associate components of an event at encoding and store patterns of cortical activity that are then reinstated at retrieval, following a cue (Rugg et al., 2015). Researchers have also shown how the role of the hippocampus extends beyond episodic memory and encompasses a multitude of cognitive processes, from spatial navigation (Spiers & Maguire, 2006) to imagining future events, by being able to combine elements into a coherent scene (Bird & Burgess, 2008; Maguire & Mullally, 2013).

More recently, the parietal cortex, specifically the angular gyrus (AG) has gained traction as a brain region studied in relation to episodic memory. The AG is situated in the ventral posterior parietal cortex (vPPC), corresponding to Broadman area 39. Positioned at the junction between the occipital and temporal lobes (Seghier, 2013), AG has little or no input from primary sensory regions but is connected to other association regions. The connectivity of the AG thus makes it an ideal candidate for the integration of multimodal information (Simons et al., 2022), suggesting it may act as a convergence zone (Hagmann et al., 2008; Tomasi & Volkow, 2011; Seghier, 2013). Various theories have been proposed explaining the role of the AG on recollection. These will be reviewed and described in detail in Chapter Four.

Looking more closely at findings relating to perspective and memory little research has been conducted to examine the neural underpinnings of visual perspective during memory retrieval. Evidence from first-person perspective tasks demonstrates the involvement of medial cortical regions, (consisting of the anterior medial prefrontal, medial parietal and posterior cingulate cortex) for the ability of individuals to relate to objects in a surrounding environment and inferior parietal cortex for the computation of egocentric reference frames (for a review see, Vogeley & Fink, 2003).

Russell and colleagues (2019) presented participants with a 3D scene of a two-by-two grid pattern with two objects placed in various locations of the grid. They assessed participants' accuracy in correctly recognising the position of the objects on the grid (item shift), as well as the perspective from which the objects were viewed at encoding. This was compared between parietal lobe lesion patients and healthy controls. No differences in accuracy recognition scores were found between patient and control samples when the objects were shifted. However, when participants were provided two photographs, showing different perspectives of the scene, patients demonstrated significantly lower accuracy in recognising the perspective from which they encoded the scene, compared to that from the opposite angle. This study provides evidence in support of the role of the parietal lobe in egocentric spatial perspective. Supporting evidence on the role of the parietal lobe on perspective and retrieval, Bonnici et al., (2016) found reduced retrieval from a field perspective when applying TMS stimulation to the AG, as participants were less likely to retrieve AMs using first-person pronouns, following stimulation.

Studies have also shown a positive correlation between precuneus grey matter volume and holding first-person perspective memories (Freton et al., 2014; Hebscher et al., 2018; St. Jacques, 2019). Contrastingly, fMRI findings have demonstrated increased precuneus activity for retrieval of events from an observer perspective (Grol et al., 2017). St Jacques et al., (2017) suggest the contradiction between the involvement of the precuneus for both field and observer perspectives may be a result of the regions' role in adopting a novel point of view during retrieval, rather than its specialised role for retrieval of one perspective in particular (field or observer). Participants were asked to retrieve AMs and either adopt a novel observer perspective or maintain their natural own eyes perspective. Results showed the involvement of the precuneus in the shifting from a field to observer perspective (St. Jacques 2018). Recruitment of the precuneus is seen irrespective of the direction of the shift, with similar findings shown for a shift from observer to field perspective of AMs (St. Jacques et al., 2018). Bringing evidence for the AG and precuneus together, St Jacques et al., (2017, 2018) found supporting evidence for both the precuneus and AGs' link to perspective during retrieval, finding activation of both regions when individuals actively shift visual perspective, irrespective of the direction of the shift. Suggesting that both brain regions may not be responsible for a specific perspective, but rather the shifting between perspectives.

1.6 Chapters Breakdown.

Chapter Two: Episodic Memory for Unisensory and Multisensory Real-World Events

This first experimental chapter discusses the creation of a new stimulus set consisting of everyday life episodic events, in the form of 10sec long videos. Experiment 1 outlines the creation of the stimulus set, including quality checks, initial findings regarding the impact of multisensory information on retrieval and the selection of videos for Experiment 2.

The second study examines the effect of sensory modality (audio-only, visual-only and audio-visual) on retrieval. Based on the selection determined from the results following Experiment 1, participants were presented with a series of videos either in a unisensory modality (audio-only, visual-only) or multisensory (audio-visual) modality. This study was originally designed for a TMS experiment, whereby participants would be shown three videos for each modality (nine total) in week one, followed by stimulation to the Vertex (control) and another nine videos one week apart, followed by stimulation to the Angular gyrus (AG). The order of stimulation would have been counterbalanced. The TMS experiment was not conducted due to restrictions for COVID-19 which prevented in-person testing. Nonetheless, the behavioural component of the study was conducted as originally planned, with participants being split between two groups, each one was presented with three videos for each modality and took part in an identical task, with the only exception being which videos they saw at encoding.

Taken together, this chapter assesses the effect of multisensory Vs unisensory encoding on rich and vivid retrieval, measured through retrieval accuracy (Hits divided by total number of details that could be recalled), amount of perceptual descriptive details recalled, and subjective measures such as familiarity to the video and sense of presence at encoding, as well as confidence and vividness at recall.

Chapter Three: Visual Perspective Manipulation at Study and Memory Retrieval

The second experimental chapter also investigates components of rich and vivid remembering through retrieval accuracy, familiarity, presence, confidence, and vividness but focuses on the manipulation of visual perspective at encoding instead. Experiments 3 and 4 introduce a new stimulus set of videos filmed either from a ‘Field View’ (1st person perspective) or ‘Observer View’ (3rd person perspective). These videos are similar in style and content to those selected for Chapter 2. These two chapters cover quality checks conducted to assess the suitability of the videos, as well as the selection process of videos used for Experiment 5.

The final experiment (5) assesses the effect of perspective (field vs. observer) at encoding on subsequent retrieval. This experimental task follows the same general procedure as that from Experiment 2, Chapter 2. Participants all viewed the same stimulus set, consisting of six ‘Field’ videos and six ‘Observer’ videos, followed by a free recall task (for which retrieval accuracy data was obtained). The effect of perspective modulation at encoding on retrieval was analysed both for retrieval accuracy, amount of perceptual descriptive details and subjective measures (familiarity, presence, confidence, and vividness).

Chapter Four: Angular Gyrus Function in Episodic Memory Retrieval: An Integrative Account

This chapter reviews the existing literature and theoretical work on the role of the AG in episodic retrieval, focusing specifically on the subjective experience of remembering account, attention to memory model, buffer hypothesis, and cortical binding or relational activity theory. Following the discussion of these theoretical accounts, it is proposed that the role of the AG is more closely related to the richness of recollected memory, referring specifically to the amount of detail and fidelity of the memory and vividness of such recollection.

Chapter Five: The Role of the Angular Gyrus in the Elaboration of Specific and Categoric Memories

The final experimental chapter investigates the role of the angular gyrus in retrieving episodic (specific events) and semantic (categoric) memories. The focus of this chapter is to investigate the role of AG subregions PGa and PGp in the retrieval of AMs, as well as its involvement in both episodic and semantic aspects of memory retrieval. To investigate the idea that the AG is involved in the successful retrieval of memories, rich in content, we ask participants to report the amount of details recalled when thinking of a specific or categoric event. Results from this measure were added to our analysis as a parametric regressor to investigate the relationship between BOLD activity in AG subregions, PGa and PGp, and number of details retrieved.

Chapter 2 - Episodic Memory for Unisensory and Multisensory Real-World Events

2.1 Introduction

Our ability to re-experience rich episodic events relies in part on the amount of information of those memories. We live in a world, rich in multisensory details, as a result, our memories seldom consist of singular sensory information. Can there even be such a thing as a solely unisensory experience, isolated from any other sensory input? (Sathian & Ramachandran, 2019). It could be argued that to investigate the richness, fidelity, and vividness of episodic memory we must consider the impact that multisensory details and their integration has on such a process.

Our ability to retrieve sensory information from memory seems to differ across modalities, with significantly better performance seen when retrieving visual, compared to auditory information (Cohen et al., 2009; 2011). It has been speculated that this performance difference might result from a visual dominance effect (Colavita, 1974; Koppen & Spence, 2007), robustly supported by findings of a failure to correctly respond to auditory components for multimodal targets in speeded discrimination tasks. A propensity to be more attentive to visual items could lead to higher recognition accuracy for visual, compared to auditory information. Not only do individuals demonstrate an extraordinary capacity to retain large amounts of visual information (Brady et al., 2008), but there also seems to be a difference in the fidelity of retrieval between auditory and visual stimuli, whereby auditory information is retrieved in a more gist-like conceptual manner, while visual items are retrieved in a more detailed way (Gloede & Gregg, 2019).

Though differences may be seen in the dominance and retrieval of different types of sensory information when presented separately, research has shown how auditory information can strengthen episodic memory for visual items (Schroeder & Marian, 2016). Presenting multimodal stimuli has been demonstrated to enhance learning effectiveness when compared to single-sensory settings (Sathian & Ramachandran, 2019; Shams & Seitz, 2008; Seitz et al., 2006; Yang et al., 2014). Additionally, it has been shown to enhance single-sensory object recognition (Bonnici et al., 2016; Lehmann & Murray, 2005; Murray et al., 2004; Schroeder & Marian, 2016; Thelen et al., 2014). Using a source memory task, Schroeder and Marian (2016) reported better retrieval for the location of objects on a screen when this was paired with a location irrelevant, congruent sound (i.e., bark sound and image of a dog) at encoding. The benefits of multisensory stimulus presentation seem to mostly occur when image-sound representations are semantically congruent. Studies have consistently shown better memory following multisensory encoding when features are semantically congruent to one another, with no difference in memory accuracy found between unisensory and multisensory incongruent features (Lehmann & Murray., 2005; Murray et al., 2004; Nyberg et al., 2000; Thelen et al., 2012). This integration of congruent, meaningful multisensory features has been referred to as a kind of "deep level of processing", which is typically associated with better memory recall (Craik & Tulving, 1975). It is thus important to consider the influence of pre-existing, multisensory associations based on semantic knowledge when designing studies to look at the process of multisensory recollection in real world environments.

While the aim of many experiments using multimodal stimuli has been to liken episodic memory to real-life experiences, the use of single image-sound pairing limits the ecological validity somewhat. The findings discussed above have been useful in providing an understanding of the circumstances surrounding better memory recollection for multimodal stimuli. However, it could be argued these paradigms are still far from resembling real-life events. A further limitation of past research has been the focus on using 'old/new' recognition and source memory tasks to study the effects of multisensory encoding on retrieval, with little focus on subjective aspects of memory retrieval for multisensory, versus unisensory events. Accuracy measures alone do not provide us with a holistic understanding of the relevance multisensory integration holds in relation to rich and vivid remembering. To better understand the involvement of multimodal contexts in rich and vivid remembering we must therefore assess not only the accuracy relating to unimodal Vs multimodal episodic events but also how multimodal information affects more subjective aspects of memory recollection, such as confidence and vividness.

Taking inspiration from the virtual reality (VR) literature, I was also interested in the concept of ‘sense of presence’ as a subjective measure during the encoding phase of tasks (Makowski et al., 2017). Sense of presence refers to the “subjective experience of being in one place or environment, even when one is physically situated in another” (p.225 in Witmer & Singer, 1998). This measure aims to assess the extent to which an individual has a feeling of ‘being there’, a concept that could be both informative when comparing across unimodal Vs multimodal modalities, as well as a quality check to ensure high levels of immersiveness during an experimental task. Various features can contribute to a heightened sense of presence, namely the field of view from which an individual experiences the virtual environment, as well as the presentation of coherent multisensory information (Coelho et al., 2006; Makowski et al., 2017; Smith, 2019). To date, few studies have investigated the relationship between presence and memory retrieval, with little consensus as to whether presence is positively correlated with or fails to enhance memory performance (Davis et al., 1999; Dinh et al., 1999; Lin et al., 2002). In a review, Smith (2019) argues that increased presence could lead to increased attention to the virtual environment, compared to the real-life physical environment. Through this logic, we would expect increased selective attention to the task to reduce external distractions, which in turn could result in a positive relationship between presence and memory performance. However, it has also been argued that qualities which make an environment more immersive (i.e., including ambient sounds) may lead to divided attention within the virtual environment, nullifying the effects seen from increased attention to the virtual environment compared to the real-life physical environment (Smith, 2019). In the present chapter, we decided to explore the effect of sense of presence for real world events on memory performance, using videos rather than a VR environment.

The purpose of this chapter is to evaluate a newly developed stimulus set designed to investigate memory retrieval of auditory and visual information presented in either a combined multisensory format or separately as individual modalities during the initial encoding process (e.g., audio-only or visual-only stimuli). This research aims to address the shortcomings discussed earlier by advancing current knowledge through the creation of a stimulus set with enhanced ecological validity, closely mirroring real-life scenarios compared to traditional experimental setups using paired images and sounds. The stimulus set comprises 10-second-long videos, each depicting everyday life events, such as non-competitive sporting activities and various scenic landscapes (e.g., cities and mountain vistas). This experimental setup allows us to assess both objective and subjective qualities of memory retrieval. Objective measures will consist in measuring the amount of details correctly remembered from the videos. To assess subjective aspects of episodic retrieval, in relation to multisensory settings, participants are presented with questions measuring confidence and vividness. Additionally, taking inspiration from the mentioned VR literature, participants will be asked to report their sense of presence when watching each video. To ensure the stimulus set is highly immersive, all videos were filmed from a first-person perspective and included rich and coherent multisensory information.

2.2 Experiment 1

The primary objective of this study was to pilot a newly created video stimulus set and assess the quality of this stimulus set. To achieve these goals, the study entailed quantifying the number of details freely recalled and recognised by participants, investigating potential floor and ceiling effects, and assess the overall immersiveness of the stimuli, measured with sense of presence ratings. We also wanted to select a subset of videos which would be used for Experiment 2 of this chapter, during which participants would be shown videos in either a unisensory (six audio-only, six visual-only) setting or multisensory one (six audio-visual videos). This selection is outlined in the results section of this experiment. Finally, for exploratory purposes we wanted to assess the relationship between different subjective measures used in the current study, such as comparing presence scores between familiar and non-familiar environments, the relationship between presence and vividness and assessing the relationship between subjective scores and retrieval performance. In line with the literature discussed in the introduction section, we also wanted to assess whether retrieval accuracy would be higher for visual details, compared to auditory ones when presented in a multisensory setting. For each video, an inventory of specific details, encompassing both auditory and visual elements, was compiled by the researcher. The auditory aspects spanned a range of 3 to 7 details per video, while visual details encompassed 12 to 20 per video.

2.2.1 Methodology

Design

This was an online within-subjects experiment conducted using Qualtrics (Qualtrics.com). All participants were asked to watch a series of videos, provide scores for sense of presence, familiarity, confidence and vividness and retrieve details for each video.

Participants

Participants were students from the University of East Anglia, recruited through the SONA system (un-paid credit system for their course). A total of 51 participants, 19 male, 32 female, between the ages of 18 and 29 completed the study (*M* = 22, *SD* = 3.172).

Stimuli

The stimulus set consisted of 21 videos (Field Videos Link), shot from a 1st person perspective, depicting everyday life events, from outdoor activities such as hiking to walking in a shopping centre and riding a go-kart on a track. Each video lasted 10 seconds and included both visual and auditory information. A list of details was created by the researcher to be later used as a checklist for a recognition memory task. Auditory details ranged from 3-7 per video and 12-20 for visual details.

Materials

An online questionnaire was created using Qualtrics (www.Qualtrics.com). Twenty-one videos (720p, duration of 10 seconds each) were presented. The questionnaire included questions regarding the vividness and sense of personal relation to the shown experience (Appendix A), as well as a list of visual and auditory information the participants may or may not have perceived while watching the video. The list included all potential details, as well as some semantically related but not present details, these made up 25% of the checklist and were proportional to the number of visual and auditory items present in the videos.

Procedure

Participants were asked to complete an encoding and retrieval phase for one video, before moving on to the next. The same exact procedure seen in Figure 2.1, was repeated for each video, with videos being presented in a randomized order. During the encoding phase, participants were asked to watch a video and state how present they felt while watching the video on a scale of 1-7 (1- ‘not at all present’ to 7- ‘felt like I was there’); whether they had previously experienced something similar or a similar environment in their own life (Yes, No, Maybe). Following the familiarity question, they were presented with the title again and asked to reflect on how vividly they were able to recall the stimulus (1-7 Likert scale; 1 - ‘Not at all vivid’; 4 -‘ Neutral’; 7 – ‘Extremely vivid’). This was followed by a free recall and recognition test. The free recall test required participants to type as much information about the video as they could remember. For the recognition test, participants were given a list of possible items present in the video, 25% of total items were semantically related lures (split to match the ratio of sensory modality of the video, i.e., two lures if the video had seven audio details, and five lures if the video had twenty visual details). Each item had to be dragged and dropped in one of the following boxes: ‘Old – High confidence’, ‘Old – Low confidence’, ‘New – High confidence’, ‘New – Low confidence’, ‘Neutral/unknown’. These questions and memory tests were repeated for all 21 videos (see Appendix A). The confidence data was not analysed in the present study. We calculated correct recognition performance by combining high and low confidence responses for hits, minus high and low confidence of false alarms. Each video had a restriction which meant it could only be seen once. There were no time restrictions to answer questions and the median duration of the whole task was 1 hour and 12 minutes. Participants were told they could take a break, if necessary, but only following the end of a block (video with questions and memory tests) and before the start of the next block. Participants were debriefed at the end of the study.

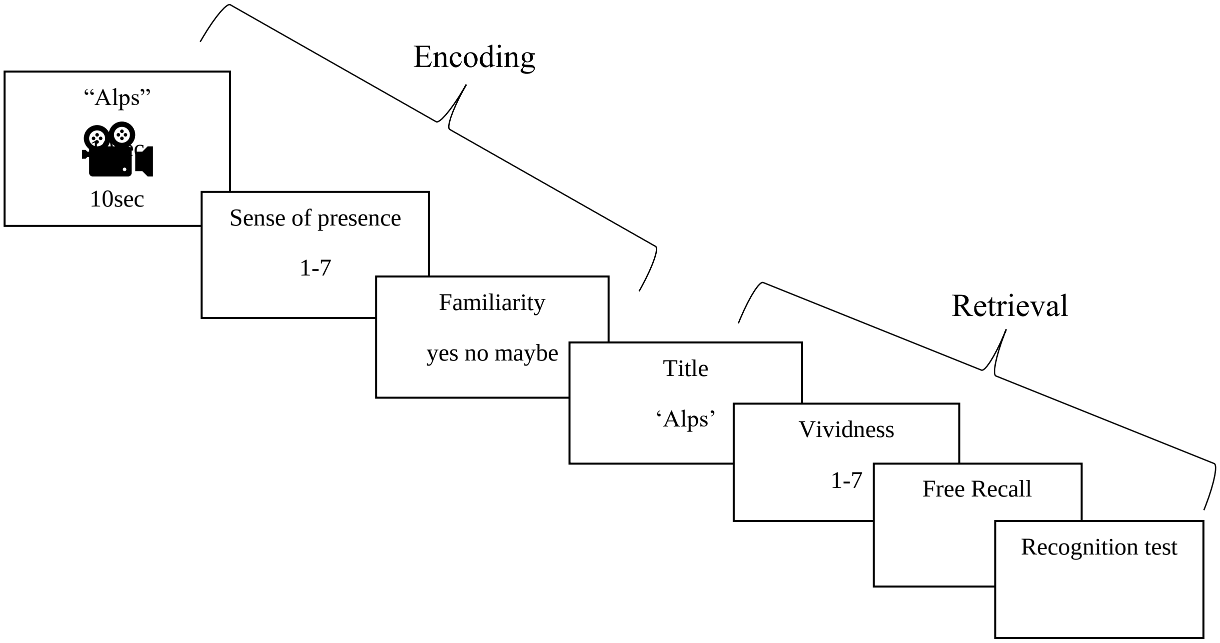

Figure 2.1. Experiment 1 procedure timeline. This is an example of one video trial, depicting encoding and retrieval phases.

Scoring

All written, free recall responses were scored. The scoring system for this study consisted in highlighting each accurately recalled visual and auditory detail (audio and visual details were scored separately). Details were accepted in the instances where spelling mistakes were present, and when synonyms were used. These were then tallied and divided by the number of total details that could be recalled. No scoring was conducted for additional descriptive information (i.e., the **car** (visual detail), was **blue** (descriptive, not counted). For details that could be interpreted as either visual or auditory (i.e.,' rain'), the researcher assessed the context of the memory and had to make a judgement call as to whether the item would be scored as 'visual' or 'auditory' or 'both'. For instance, if grouped with other auditory information, a detail would be scored as 'audio'. If paired with other visual descriptive information such as 'you could see **rain** drops on the pavement', it would be scored as visual.

For the recognition test, data was gathered for number of hits, correct rejections and false alarms (FA). Overall accuracy was measured by calculating Hits-FA. Hits were all correctly remembered details (audio and visual) for both high and low confidence, divided by the total details that could be recalled. FA were errors (new items recognised as old), divided by the total number of new items.

2.2.2 Results

All post-hoc tests were Bonferroni corrected. When sphericity was violated, Greenhouse-geisser values were reported.

Quality Checks

Floor and ceiling effects for memory retrieval performance. This study's purpose was primarily to establish the overall quality of the stimulus set. One main concern was the duration of each video (10sec) being too short and this resulting in the events being too easy to retrieve. It was therefore important to check floor and ceiling effects for memory retrieval performance. These were evaluated by calculating the percentage of performance in 20% increment brackets across participants, i.e. how many participants scored between 0-20% accuracy retrieval, 21-40%, 41-60%, 61-80% and 81-100%. Free recall accuracy scores (number of correct auditory and visual details divided by total details present in the video), were used to test for floor and ceiling effects; 88% of participants scored between 20-80% accuracy for the free recall test. 94% of participants scored between 20-80% accuracy for the recognition (Hits-FA) test, so there were no issues with any floor or ceiling in performance. This was also the case across all videos, with all scores averaging between 20-80% for the free recall condition and 86% of scores averaging between 20-80% accuracy for the recognition test.

With regards to overall immersiveness, presence scores were high overall, with the average across videos being 4.1 (SD = 0.41) out of a maximum presence score of 7. Videos with the highest and lowest presence scores were removed (two videos total were removed) for the selection of future studies to avoid potential confounds and to ensure presence was as consistent across all videos as possible (new *SD* = 0.29). Results from these two videos are included in the analyses of this experiment. These checks were conducted to ensure that any manipulations carried out to the stimulus set for future studies would not be confounded by the sense of presence associated with that video, as well as to ensure the overall ability for participants to feel ‘present’ or immersed in the experience of watching the video, adding to the key aspect of this project which was to create an ecologically valid video stimulus set.

Selection of Videos. Results from this study were used for the selection of videos for a future experiment that aimed to manipulate sensory modality at encoding and assess the effects of unisensory versus multisensory stimulus presentation on retrieval. The aim was to select six videos for each modality (audio, visual, audio-visual). The selected videos would then be edited and presented in either a unisensory or multisensory modality. The selection of videos was conducted by assessing the sensory dominance of each video. Sensory dominance was measured by the number of correctly freely recalled and recognised details for each sensory modality. More specifically, I compiled a list of videos where the number of auditory details correctly recalled (free recall and recognition) was higher than for other modalities, and the same again for visual details. Videos for which participants demonstrated similar accuracy for both sensory modalities (e.g., ‘Jump’ was 2nd in highest accuracy for auditory information and 3rd for visual) were selected for a ‘multisensory’ condition. These calculations were conducted in Excel (See Appendix B for formulas).

Cued Recognition	**Free Recall**
American Football	American Football
GoKarting	Rollercoaster
Volleyball	Alps
Carousel	Carousel
Surf	Jump
Mountainbike	Mountainbike

Table 2.1. Table listing the top six auditory stimuli with the highest cued recognition accuracy and highest number of freely recalled items.

Cued Recognition	**Free Recall**
Horse	Horse
Ice Hockey	Ice Hockey
Baseball	Volleyball
Skiing	Marathon
Car	Shopping Centre
Dog Grooming	Eggs

Table 2.2. Table listing the top six visual stimuli with the highest cued recognition accuracy and highest number of freely recalled items.

Cued Recognition	**Free Recall**
Jump	Car
City Walk	City Walk
Ducks	Ducks
Eggs	Baseball
Alps	GoKarting
Rollercoaster	Skiing

Table 2.3. Table listing the top six audio-visual stimuli with the highest cued recognition accuracy and highest number of freely recalled items.

As can be seen from Table 2.1, Table 2.2, and Table 2.3, there was some disparity across the top six audio, visual and audio-visual videos between the cued and free recall memory tests, demonstrating how memory retrieval is vastly affected by memory tests used. Lists from the two tests were combined to select a final list where videos were ranked highly and selectively for each modality across both memory test conditions. Again, where there was an equal standing of accuracy for both auditory and visual retrieval, these videos were selected for the multisensory condition. Overall, six videos were selected based on their higher memory performance for auditory details, compared to other modalities; six were selected based on their higher memory performance for visual details, and a final six videos that were successfully retrieved for both their auditory and visual information, equally, were selected for the multisensory condition. The final selection of videos can be seen below in Table 2.4.

Auditory	**Visual**	**Audio-Visual**
American Football	Horse	City Walk
Mountainbike	Ice Hockey	Ducks
Carousel	Shopping Centre	Car
Surf	Marathon	Baseball
Alps	Eggs	Gokarting
Volleyball	Dog Grooming	Skiing

Table 2.4. Table listing the final selection of videos for each sensory modality, following combination of free and recognition lists.

Subjective Ratings and Memory Retrieval

How video familiarity affects sense of presence. A One Way ANOVA was conducted with familiarity as a factor and presence as the dependent variable. Results demonstrated a main effect of familiarity F(1,19) = 182.116, $p < .001$, $\eta\rho^2 = 0.910$, where videos deemed familiar (*M* = 4.403, *SD* = .918) were more likely to receive a higher sense of presence scores than non-familiar ones (*M* = 3.178, *SD* = .762). As seen in Figure 2.2.

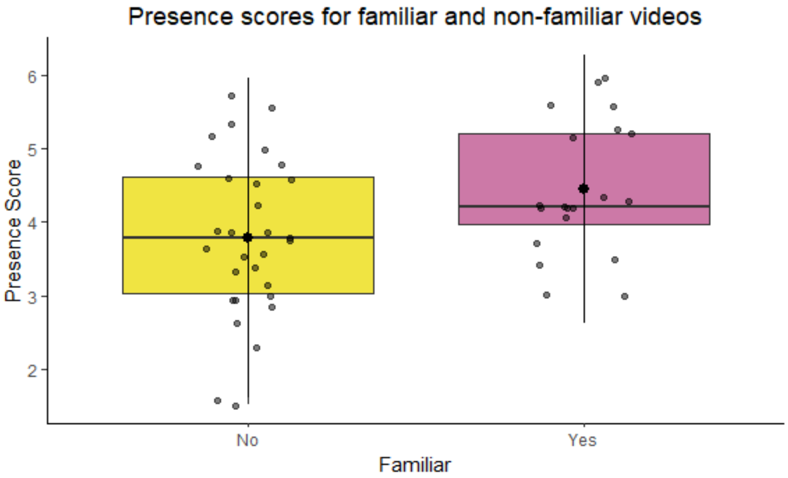

Figure 2.2. Bar graph illustrating differences of reported sense of presence between videos recognised as familiar and those recognised as non-familiar.

Investigating the relationship between sense of presence and vividness. A significant positive correlation was found rs(49) = .836, p < .001 between sense of presence and vividness. The higher the presence scores, the higher the vividness at recall (Figure 2.3).

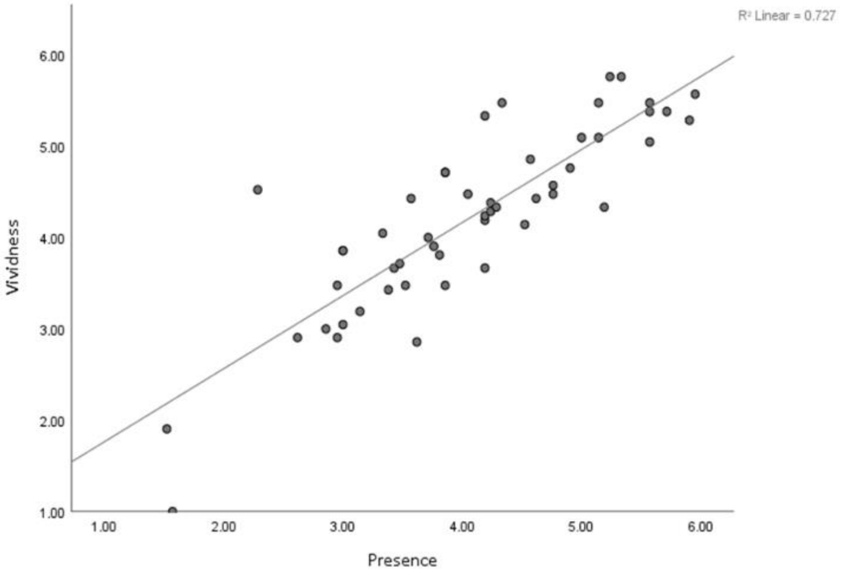

Figure 2.3. Scatterplot showing the relationship between reported vividness and sense of presence.

Two multiple linear regressions were also conducted to test if presence and vividness predicted retrieval performance, for both free recall and recognition accuracy. The overall regression was not statistically significant, $R^2 = .006$, F(2,48) = .154, *p* = .858, whereby presence and vividness were not significant predictors of recognition accuracy. Similar findings were found when analysing free recall accuracy, $R^2 = .01$, F(2,48) = .249, *p* = .781.

Retrieval Success

Assessing the differences in retrieval in relation to sensory dominance. Accuracy for visual and auditory details in the free recall test was analysed. A main effect of sensory modality was observed, F(1,50) = 106, p < .001, ηp^2 = .679, with higher recollection (details retrieved/total details) for visual (*M* = 49%, *SD* = .151) compared to auditory information (*M* = 29%, *SD* = .143). In contrast, no significant difference in recognition accuracy (Hits-FA) between auditory (*M* = 55%, *SD* = .182) and visual (*M* = 52%, *SD* = .138) details was found for the recognition test, F(1,50) = 2.63, p = .111, ηp^2 = .050 (Figure 2.4).

Figure 2.4. Violin plot demonstrating differences in free recall accuracy (Hits/total details) for auditory, compared to visual details.

2.2.3 Discussion

This experiment outlines the creation and first analysis of a new stimulus set, consisting of field (1st person perspective) videos for real world events. Twenty-one videos were collected and edited into 10-second-long clips, all depicting everyday-life events, rich in sensory details. Quality checks for retrieval accuracy, revealed no floor or ceiling effects, from which it was concluded that this would be a useful and appropriate stimulus set to use for future studies investigating memory for real-world events. The initial main concern that a 10sec long clip would be too easy to retrieve was discounted by these checks. By assessing 'sense of presence' scores across all videos, it was also discovered that all stimuli were regarded as being highly immersive, a useful feature for creating an ecologically valid stimulus set which can be used in future studies. Based on an assessment of sense of presence ratings, two stimuli were removed for potential use in future experiments, one obtaining the lowest and one the highest sense of presence ratings. By removing these two videos from the stimulus set for future studies, it was ensured that the 'presence' or immersiveness of the stimuli would be consistent throughout the database.

A second aim of this experiment was to select six videos for a future behavioural study, in which participants would encode videos with different sensory modalities (audio-only, visual-only, and audio-visual/multisensory). The selection of these videos was conducted by observing the sensory dominance of each stimulus, more specifically, for which videos did participants demonstrate better memory performance for auditory details and which were they better able at retrieving visual details. Comparisons were made separately for the free recall and recognition test. When there was overlap across modalities (i.e., high scores for visual and auditory details), videos were selected for the 'audio-visual'/multisensory group. The standing for each modality across free recall and recognition tests seemed to differ, with fewer differences in accuracy for auditory and visual details in the cued recognition test, compared to the free recall task. Studies have repeatedly shown that memory accuracy improves following cued memory tests (Eysenck & Keane, 2015). This could explain fewer distinctions of accuracy across modalities for cued recognition, compared to free recall. It could be argued that if accuracy is overall higher for the recognition test, it is less likely to identify striking differences in modality weighting across stimuli. Nonetheless, six videos were selected based on their sensory dominance across both retrieval tasks.

Exploratory analyses were also conducted as an initial investigation on the subjective measures used in the design, as well as differences in memory retrieval for auditory, compared to visual information. When assessing subjective measures, results showed higher ‘sense of presence’ scores for videos of environments deemed as familiar, compared to unfamiliar ones. This suggests participants feel more present or immersed when they can personally relate and are familiar with the environment of the stimulus, compared to when they are not. These findings are consistent with findings from the self-reference effect, whereby stimuli that are closely related to the self are more easily processed and receive more attention (Yaoi et al., 2015). Further analyses revealed a positive correlation between presence and vividness. Once again, this is consistent with evidence of more vivid recollection for self-relevant stimuli (Symons & Johnson, 1997; Yaoi et al., 2015), and with prior research also demonstrating a positive correlation between the vividness of visual images and the capacity to feel present within a virtual reality environment (Iachini et al., 2019). However, interestingly, presence and vividness scores were not significant predictors of accuracy, contradicting their link to fidelity of memory retrieval. This could be explained by the lack of low presence ratings across participants and stimuli. The overall high presence ratings across stimuli demonstrate how this stimulus set is realistic in nature and a valid measure of immersive, multisensory episodic memory. The above findings are promising for the use of this stimulus set in future studies.

The relationship between presence and familiarity, as well as presence and vividness, provides a useful base on which to investigate different components of rich and vivid remembering. One key limitation of the design that should be noted was that the retrieval phase was presented subsequently to the encoding phase for each video separately. No distraction tasks or breaks between the two task phases were included in the design. The main reason behind this decision was due to the large number of stimuli that would be presented to each participant in order to conduct the desired quality checks using a within-subjects design. The difficulty was deemed too high, had participants been asked to watch all 21 videos in succession during the encoding phase, and then be asked to retrieve all 21 in a separate retrieval phase, following a title cue. This limitation should be considered with care, particularly when interpreting results assessing subjective measures. For instance, with regard to a positive correlation between presence and vividness, one could argue the lack of a distraction task or break between subjective measures at encoding and retrieval might have led participants to interpret and respond to these two measures in similar ways. However, it should also be noted that despite the absence of breaks or distraction tasks, no ceiling effects were seen for any of the videos.

When assessing the types of details being retrieved, participants were significantly better at recalling visual details, compared to auditory details in the free recall test. These findings are consistent with the extensive literature demonstrating our preference and improved performance in retrieving visual details, compared to auditory information (Brady et al., 2008; Cohen et al., 2009; 2011; Colavita, 1974). The same results were not seen following the recognition test, with no differences seen in retrieval accuracy (Hits-FA) of visual, compared to auditory details. It could be argued that we demonstrate differences in verbal proficiency when describing visual, compared to auditory details, with more ease being shown for describing objects, compared to sounds. Research has shown how visual details are more commonly reported, compared to other sensory modalities (Rubin et al., 2003). This might result in differences seen in the retrieval of sensory details during a free recall test, but not necessarily for an old/new recognition test where details are presented to participants.

2.3 Experiment 2

From Experiment 1 we have established that individuals are better at recalling visual compared to auditory information during free recall tests. During Experiment 1, participants were shown videos in their multisensory nature, encoding both auditory and visual information simultaneously. Here I wanted to investigate what happens when we manipulate the information being encoded by presenting modalities in isolation (audio, visual and audio-visual). Experiment 2 assesses this question by investigating subjective measures such as familiarity, presence, confidence and vividness, as well as free recall accuracy for either audio-only, visual-only or audio-visual videos, shown at encoding. Based on prior research it was predicted that participants would demonstrate improved retrieval, higher confidence and vividness scores for multisensory videos, compared to unisensory ones, as well as improved retrieval for visual, compared to auditory videos. Furthermore, consistent with Gloede and Gregg's (2019) findings, it was predicted that participants would describe videos in greater detail, demonstrating greater fidelity for visual and audio-visual videos, compared to auditory ones.

The selection of videos for this study was conducted in Experiment 1. Two videos were removed based on their associated sense of presence scores, one with the highest average presence rating and one with the lowest. The remaining videos were subdivided based on their sensory dominance. In other words, videos with the highest accuracy for auditory details were selected for the audio-only condition, those with the highest accuracy for visual details were selected for the visuo-only condition and those where performance was equal between the two types of sensory details were selected for the multisensory condition.

This task was designed with the intent of conducting a TMS study. Participants would be shown 9 (3 audio, 3 visual, 3 audio-visual) of the 18 videos during week one, and the other 9 a week apart, counterbalancing vertex and AG stimulation. Due to COVID-19 restriction, this was adapted for an online study and the subset selection of videos were shown to separate subgroups of participants. Data for the analyses of this study was combined across the two subgroups.

2.3.1 Methodology

Design

An online, live experiment was conducted using Gorilla (www.Gorilla.sc) and Microsoft Teams. The task procedure and layout was identical for all participants, however, participants were randomly assigned to encode and recall 9 out of 18 videos. This permitted us to test a large sample of stimuli while ensuring that participants were not exposed to too many details.

Participants

Participants, 54 total, were either University of East Anglia students or participants recruited through the University's paid participant panel. Out of the 54 participants, 14 were Male, 40 Female, age ranging from 18-51 (M = 24.722, SD = 6.905).

Stimuli

The stimulus set consisted of 18 videos, each 10 seconds long, all selected based on results from experiment 1. Videos were also selected based on their sensory dominance (see election of videos section in Experiment 1). Out of the 18 videos, 6 were audio-only (sound played with a black screen), 6 were visual-only and 6 were audio-visual.

Materials

This study was conducted online, using Gorilla. Two separate Gorilla tasks were programmed. One encoding and one recall task. The recall phase of the experiment was conducted during a Teams call, with the researcher presenting the task from Gorilla by sharing their screen and while recording the free recall phase of the experiment.

Procedure

Participants were invited to a scheduled Teams call. They were sent a Gorilla link for the initial encoding task. Instructions were provided both verbally and in written form. The call was muted for the duration of the encoding and distraction task. During the encoding task, participants were shown a total of 9 videos. Each video was presented with an associated title. Following each video, participants were asked to state whether the video was familiar to them ("Have you ever experienced something similar in your personal life/Was it a familiar environment to you?" – Yes, No, Maybe) and rate how present they felt while watching the video (1 – "Felt completely remote" to 7 – "Felt like I was there"). Following the presentation of all 9 videos, participants partook in a short distraction task where they were asked to answer a series of simple math questions. They were then told they could have a 10-minute break before coming back for the second part of the experiment. During the second part, and recall phase of the study, participants were able to see the Gorilla task through the researcher's shared screen. The call was recorded following the participant's permission. Titles from each video shown at encoding were presented again in a random order. Following each title presentation, the participant was asked to recall the video, quietly, as was presented during the encoding phase and instructed they could close their eyes if they deemed it helpful. They were given 10 seconds (same duration as the video) to do this. This was timed with a blank screen. The purpose of this task was to get the participant to imagine the video from start to finish before starting the verbal recollection. They were then instructed verbally and in written form to start verbally and freely recollecting information pertaining to the video in question, with as many details as possible. They were also asked to specify whether stated details were auditory, visual or both. No specific prompts or cues were provided, only encouragement to recall as much information as possible. After each free recall, participants were asked to rate how confident they were of their response (1 – not at all confident; 2 – somewhat confident; 3 – very confident) and how vividly they were able to recall the video (1 – not at all vivid to 7 – extremely vivid). Once all 9 videos had been tested, participants were thanked and debriefed (Figure 2.5 and Appendix C).

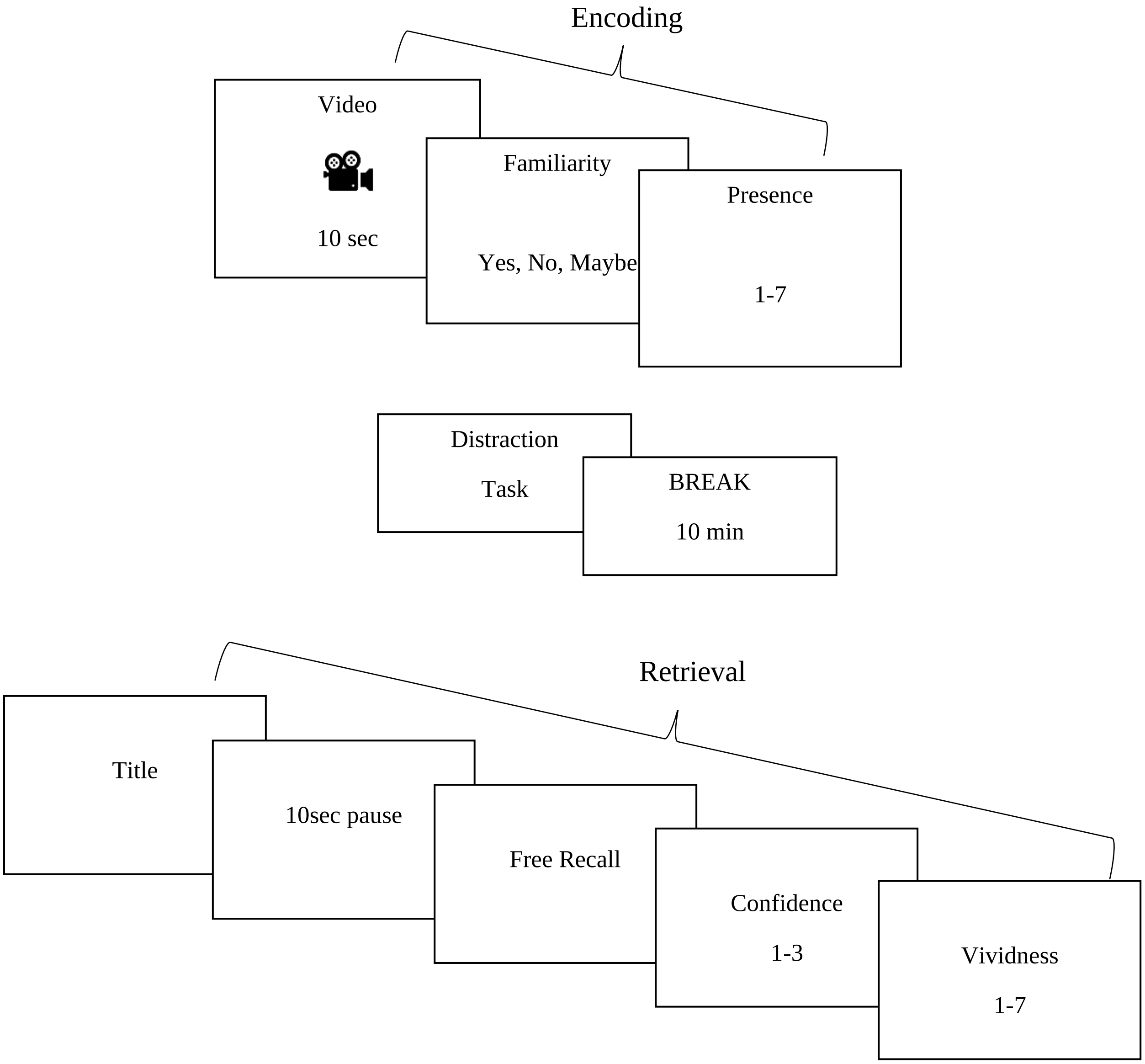

Figure 2.5. Timeline of procedure for Experiment 2. Both encoding and retrieval phases are depicted. In between phases, participants completed a distraction task and had a 10min break.

Scoring

All free recall protocols were transcribed and scored. Scoring was conducted for the following details (see Table 5 for a condensed outline):

Text segmentation and scoring labels:

1. Modality: Any information that suggests the participant correctly recalls the modality the video was presented in (i.e., 'this was just audio' or 'there was no sound for this one'). If the modality is not explicitly stated, the scorer should base their decision on the type of details recalled. For instance, if the title refers to an audio-visual video but the participant only recalls visual information, this should be scored as an incorrect modality. Labels for this segmentation are Corr_Mod or Inc_Mod).
2. Hits: Any correctly identified information, split by modality (either audio or visual). Labels for this segmentation are: Hit_V and Hit_A. Only key items should be scored with these labels, see richness section on how additional descriptive information was scored. Key items refer to main objects, actions, individuals and sounds. These were listed by the researcher for consultation.
3. Richness: These are additional descriptive details, whether auditory (Descr_A) or visual (Descr_V), i.e. "I didn't see what car brand it was uhmm but it looks quite tidyDescr_V and you know newDescr_V".
4. No memory: If no details are recalled by the participant, this is scored as 'No_Mem'. This includes videos for which the modality is recalled i.e., 'I can't remember anything for this one'.
5. Semantic associate: Any semantic details that either pertain to external details of the participant themselves (i.e. "I've never been good at recognizing cars.") or to the context

of the video (i.e. “the trolley sign was green, so probably an ‘Asda’ car park.”). The label for this segmentation is ‘Sem_Ass’.

6. Memory error/FA: Any details the participant incorrectly recalls about the event or new items.

Modality	**Hits**	**Richness**	**Additional**
Correct	Audio	Descriptive Audio	Semantic Associate
Incorrect	Visual	Descriptive Visual	No memory
			Memory Error (FA)

Table 2.5. Table outlining scoring themes and labels.

Below are a few example extracts of scored memories for videos (examples are in the following order; AV, A, V):

Video_Baseball

So baseball was from the point of view of.. I don’t know what they’re called, the people who squat down and catch behind the batterHit_V. And starts off with him getting into position. The audio is quite distortedDescr_A in that and seems, you could hear some talkingHit_A about but it’s quite, somewhat distorted, like the mic is blown. And hmm baller throwsHit_V which, a ball which the batsman missesHit_V I think and it’s caught by whoever sits there and crouchesDescr_V, from the *perspective we're on. Sunny day*Hit_V *and I think at one point you may glimpse, not sure if it's other players or just on the left hand side, either a crowd or players*Hit_V *watching from the sideline*Corr_Mod.

Video_Alps

*Uhmm this was a sound*Corr_Mod *only video and it sounded as if there were people like drinking and cheering on like the top so it kind of didn't really sound like, sounded like there was a large gathering of people*Hit_A*, you couldn't really hear anything snow related*Sem_Ass *and there were just a few cheers hmm cheers as in like noises and celebrations hmm and I think that's about it yeah.*

Video_Horse

*So I was on top of a horse*Hit_V*, the horse was like a cream*Hit_V *colour, I think. And it was in a woodland*Hit_V *area, forest. This was just visual*Corr_Mod *as well, there was no auditory. And then, we was going round this bend on this like muddy*Hit_V *path. And there was like a stream*Hit_V *next to us so there was like a fence*Hit_V*, a wooden fence and then we got round the corner there was a group of people*Hit_V*, I'd say 3 people maybe, like in front of us, like by a bridge that was going across the stream. I wasn't going fast on the horse at all*Descr_V*. That was about it for that one.*

2.3.2 Results

All post-hoc tests were Bonferroni corrected. When sphericity was violated, Greenhouse-geisser values were reported.

Subjective Ratings and Modality

Familiarity. A One x Three repeated measures ANOVA was conducted to investigate the impact of video modality (audio-only, visual-only, and audio-visual videos) on familiarity ratings. No main effect of modality was found, F(2,112) = .647, *p* = .525. This result was reassuring as any behavioural differences seen for other measures of retrieval were unlikely to be affected by the familiarity associated with a specific modality. As a result, ‘familiarity’ was not used as a control for future analyses comparing subjective ratings or free recall data across modalities.

Presence. A repeated measures ANOVA was conducted to investigate the impact of video modality on sense of presence. A main effect of modality was found F(2,112) = 31.2, p < .001, ηp2 = .357. Post-hoc, pairwise comparisons, using Bonferroni correction showed no significant difference between "Audio" (*M* = 3.62, *SD* = 1.26) and "Visual" (*M* = 3.65, *SD* = 1.26) t(56) = -.18, *p* = 1, but a significant difference between "Audio" and "Audio-Visual" (*M* = 4.94, *SD* = 1.11), t(56) = -6.46, *p* < .001, and a significant difference between "Visual" and "Audio-Visual" t(56) = -7.70, *p* < .001. "Audio-visual" stimuli were thus associated with higher sense of presence, compared to "Audio" and "Visual" only. These results demonstrate higher immersiveness for multisensory, compared to unisensory settings, with no difference seen between unisensory environments (Figure 2.6).

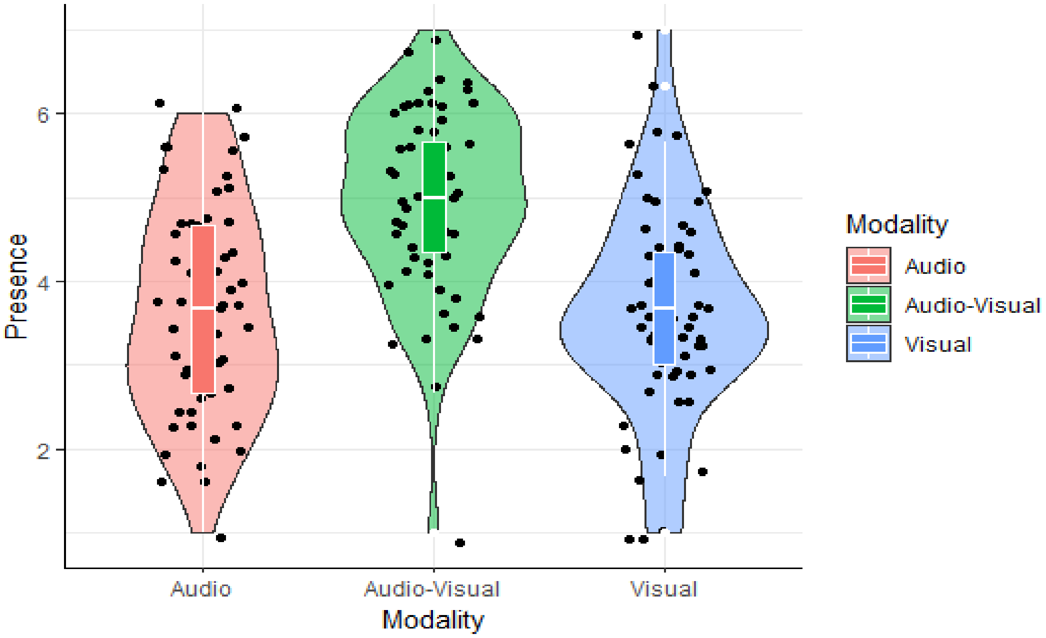

Figure 2.6. Violin plot illustrating differences of reported presence scores during the encoding phase, between audio, visual and audio-visual conditions. Presence scores were significantly higher in the multisensory condition (audio-visual), compared to the unisensory ones (audio, visual).

Confidence. A repeated measures ANOVA also revealed a significant difference in confidence scores between modalities F(2,112) = 6.33, p <.01, ηp2 = .102. Post hoc tests showed significantly higher confidence scores for "Visual" (*M* = 2.33, *SD* = .41), compared to "Audio" stimuli (*M* = 2.11, *SD* = .40), t(56) = -3.15, p < .01, and higher confidence scores for "Audio-Visual" (*M* = 2.31, *SD* = .38) videos, compared to "Audio" videos t(56) = -2.96, p = 0.012. No significant difference in confidence scores was found between "Visual" and "Audio-Visual" videos t(56) = .34, p = 1. Therefore confidence scores were higher for stimuli with visual information, irrespective of whether these were presented in a unisensory or multisensory context, compared to audio-only videos. Presenting videos with semantically congruent sounds did not seem to significantly affect confidence at retrieval for multisensory videos, compared to visual-only ones (Figure 2.7).

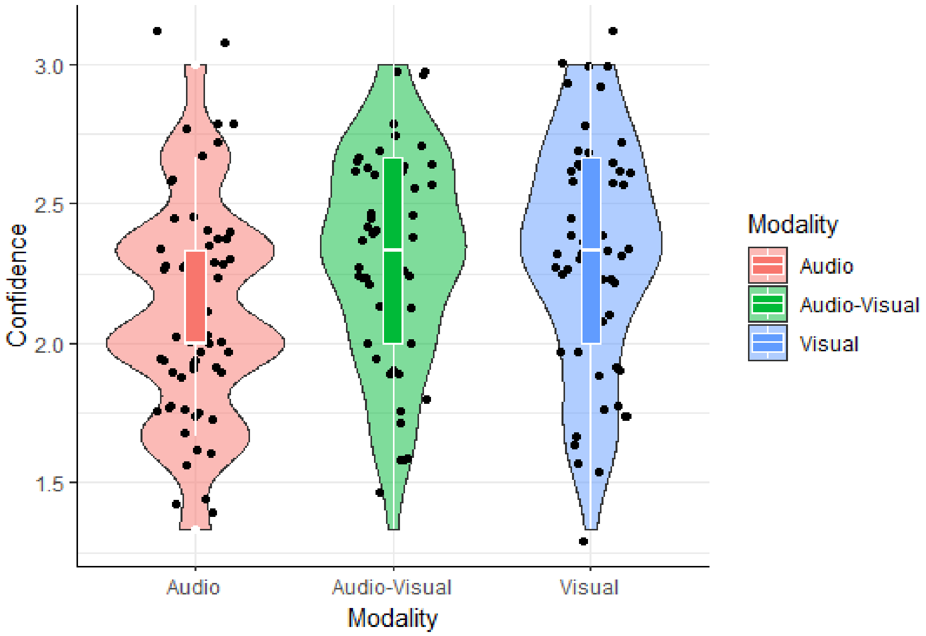

Figure 2.7. Violin plot illustrating differences in confidence scores at retrieval, between audio, visual and audio-visual conditions. Scores were significantly higher for visual and audio-visual videos, compared to audio ones.

Vividness. Finally, a repeated measures ANOVA was conducted to assess the impact of modality on vividness scores. A main effect of modality was found F(2,112) = 32.7, p < .001, ηp2 = .369. Post-hoc tests revealed a significant difference between "Audio" and "Visual" videos t(56) = -5.90, p < .001, with higher vividness scores reported for "Visual" (*M* = 4.83, *SD* = .86) compared to "Audio" videos (*M* = 3.85, *SD* = 1.11). Vividness scores were also significantly lower for "Audio", compared to "Audio-Visual" videos (*M* = 5.04, *SD* = .90), t(56) = -7.09, p < .001. No significant difference was found between "Visual" and "Audio-Visual" videos t(56) = -1.53, p = .394. Therefore vividness scores were significantly lower for "Audio" videos compared to "Visual" and "Audio-Visual". Similarly to differences seen between confidence scores, vividness scores were lower for audio stimuli. Presenting videos with semantically congruent sounds did not seem to yield higher vividness scores for multisensory videos, compared to visual-only ones (Figure 2.8).

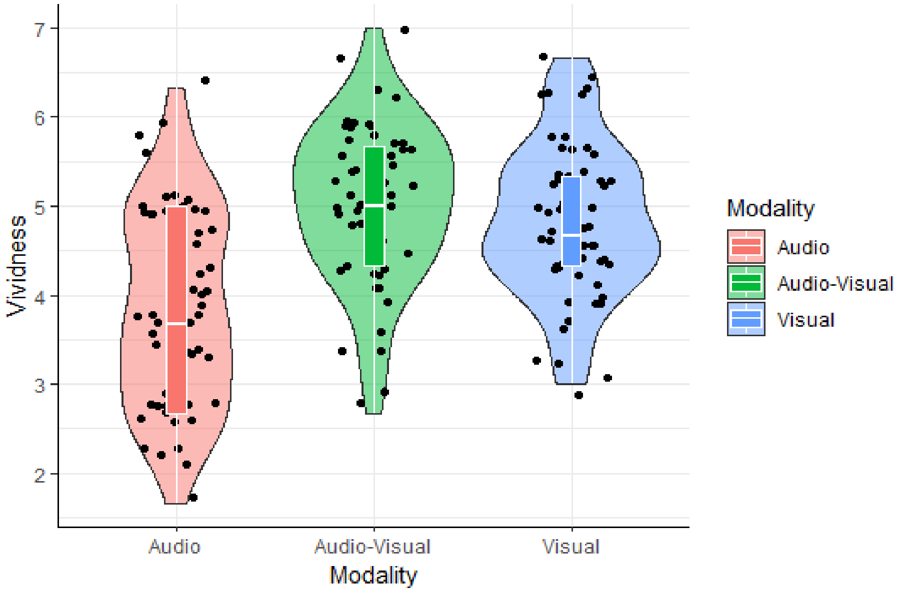

Figure 2.8. Violin plot illustrating differences in vividness scores at retrieval, between audio, visual and audio-visual conditions. Vividness scores were significantly higher when retrieving visual and audio-visual videos, compared to audio ones.

Free Recall

Accuracy. Accuracy scores were measured using the sum of scored 'hits', divided by the number of total details present in the video (see scoring procedure in methods section for additional information). A repeated measures ANOVA was conducted to assess differences in accuracy scores between modalities. A main effect of modality was found, F(2,112) = 15.5, p < .001, ηp2 = .216. Post-hoc tests showed higher accuracy scores for "Audio" (M = .45, SD = .14), compared to "Visual" videos (M = .34, SD = .11), t(56) = 5.07, p < .001, as well as between "Audio" and "Audio-Visual" videos (M = .39, SD = .11), t(56) = 3.26, p < .01. Inconsistent with our hypothesis, accuracy was thus highest for "Audio" videos. Significantly higher accuracy scores were also found for "Audio-Visual", compared to "Visual" videos, t(56) = -2.52, p = .04., demonstrating higher accuracy for the multisensory condition, but only compared to unisensory visual stimuli (Figure 2.9).

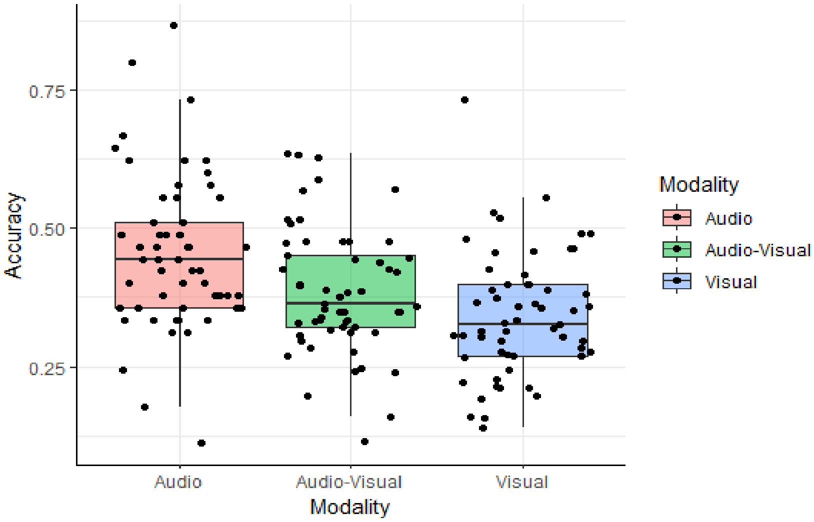

Figure 2.9. Box plot illustrating differences in accuracy scores (Hits/total details) between the three video modalities (audio, visual, audio-visual). Accuracy scores were highest for audio videos, and lowest for visual ones.

To investigate this effect further, a repeated measures ANOVA was conducted to assess the impact of modality on the total number of details that could be recalled by participants. A main effect of modality was found F(2,112) = 29036, *p* < .001, ηp2 = .998. Post-hoc tests revealed a significantly lower number of details for "Audio" videos (*M* = 4.17, *SD* = .168), compared to "Visual" (*M* = 14.5, *SD* = .840) and "Audio-Visual" (*M* = 19.7, *SD* = .672), t(56) = -116, *p* < .001, and t(56) = -232, *p* < . 001, respectively. There was also a significant difference between "Visual" and "Audio-Visual" videos, t(56) = -232, *p* < .001, with "Audio-Visual" videos having the highest number of details. Data was analysed across videos (rather than across participants) to further investigate the effect of total number of details on accuracy. There was a negative correlation between total number of details and accuracy, across video averages rs(16) = .-.459, *p* = .028, suggesting that the lower the number of total details, the higher the accuracy for such details (Figure 2.10).

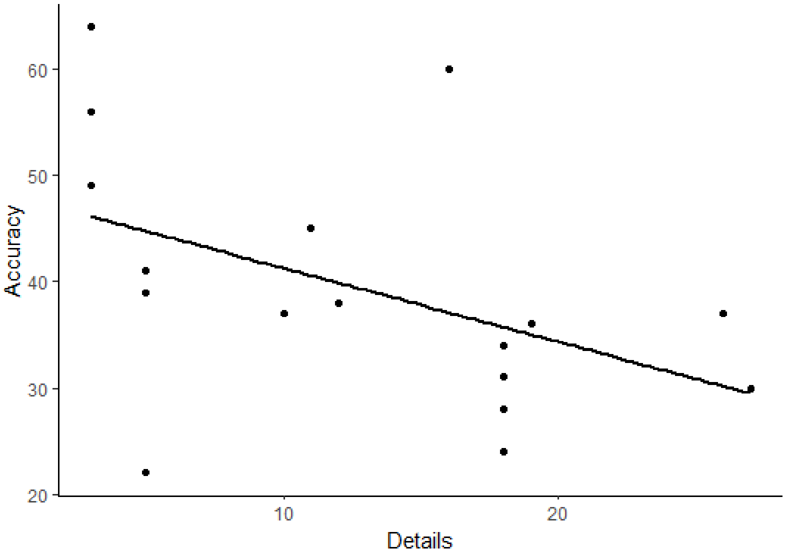

Figure 2.10. Scatterplot illustrating a negative correlation between total number of details between video modalities and overall memory accuracy (Hits/total details).

Accuracy for "Audio-Visual" videos. Accuracy differences were also assessed for details recalled for "Audio-Visual" videos, comparing free recall accuracy for visual and auditory details. A repeated measures ANOVA demonstrated significantly higher accuracy for visual (*M* = .37, *SD* = .11), compared to auditory (*M* = .23, *SD* = .15) details, F(1,56) = 38.4, *p* < .001, ηp2 = .407 (Figure 2.11).

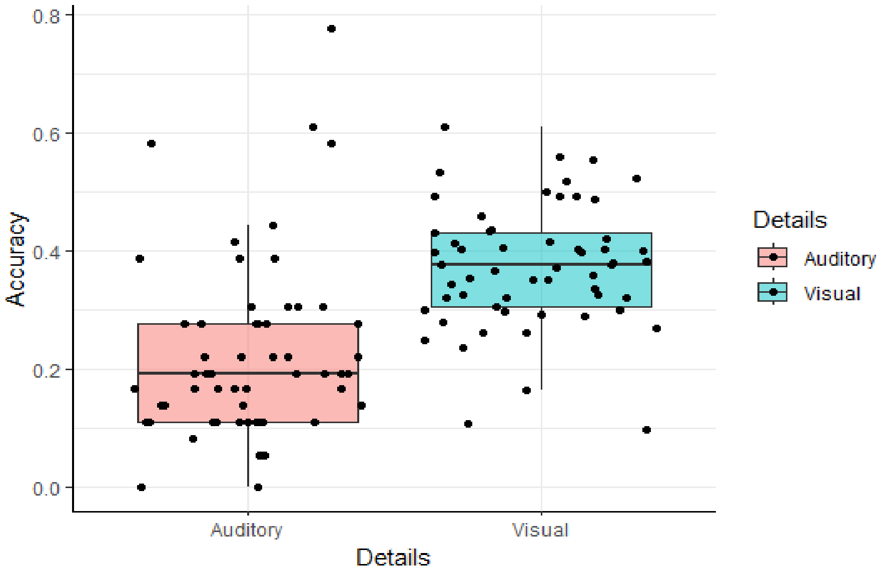

Figure 2.11. Box plot demonstrating better accuracy for visual details, compared to auditory details, when retrieving audio-visual stimuli.

Richness. The number of descriptive details freely recalled by participants was compared across modalities (please consult methods section for additional information on scoring for 'richness'). A repeated measures ANOVA was conducted to compare richness across the three sensory modalities. A significant main effect of modality was found, F(1.79,100.32) = 36.5, p < .001, ηp2 = .395. Post-hoc tests showed that participants freely recalled a greater number of descriptive details for "Visual" (*M* = 2.17, *SD* = 1.38) videos, compared to "Audio" (*M* = .77, *SD*

= .60), t(56) = -7.38, *p* < .001. Richness scores were also higher for "Visual", compared to "Audio-Visual" (*M* = 1.67, *SD* = 1.10), t(56) = 3.08, *p* = .01, and for Audio-Visual" compared to "Audio" videos, t(56) = -6.37, *p* <.001. Therefore, richness was highest for "Visual" and lowest for "Audio" videos, contradicting our predictions for highest richness for "Audio-Visual" videos (Figure 2.12).

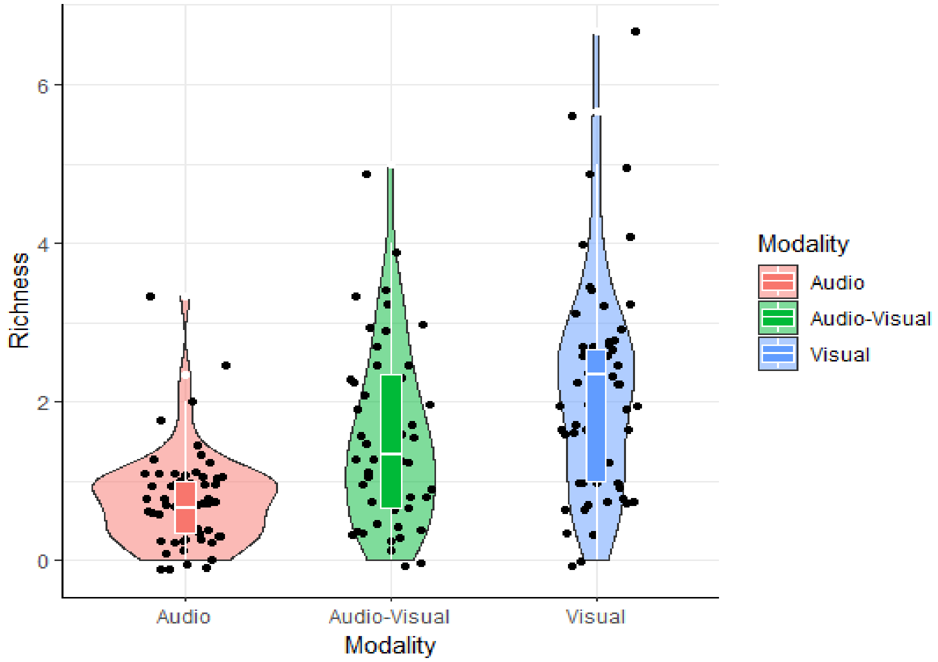

Figure 2.12. Violin plot illustrating highest richness scores for visual videos, and lowest for audio videos.

When comparing the type of descriptive details recalled for Audio-Visual (multisensory) videos, a One-Way repeated measures ANOVA revealed a significant difference between the number of descriptive visual details (*M* = 1.51, *SD* = 1.09), compared to auditory details (*M* = .16, *SD* = .21), F(1,56) = 83.9, *p* < .001, ηp2 = .600.

Memory Errors. A repeated measures ANOVA was conducted to assess differences in the number of memory errors across three modalities. There was a significant main effect of modality F(2,112) = 13.3, $p < .001$, ηp2 = .191. Post-hoc tests revealed highest number of errors for “Audio-Visual” videos (*M* = .51, *SD* = .45), compared to “Audio” (*M* = .16, *SD* = .30), t(56) = -4.91, $p < .001$ and “Visual” (*M* = .74, *SD* = .67), t(56) = -3.22, $p < .01$. No significant difference in number of memory errors was found between “Audio” and “Visual” videos t(56) = -1.91, *p* = .185.

Relationship Between Subjective Measures and Free Recall

A multiple linear regression was conducted to investigate the relationship between subjective measures as predictors: Familiarity, Presence, Confidence and Vividness, on overall retrieval accuracy. There was an overall significant model $R^2 = .20$, F(4,52) = 3.29, p = .018, with Familiarity being the only significant predictor of overall accuracy (β = .41, p = < .01).

2.3.3 Discussion

This experiment aimed to investigate behavioural differences at encoding and retrieval for videos of three different sensory modalities; audio, visual (unisensory conditions) and audio-visual (multisensory condition). When looking at differences for self-reported measures during the encoding phase, there was no significant difference in familiarity with the video content (evaluated by asking participants whether the video constituted a familiar environment to them) across the three modalities. This suggests that irrespective of the sensory modality each video was presented in, the content was just as easily discernible and recognisable. This was particularly relevant with regard to audio-only videos for which it could have been more challenging for participants to recognise sounds, without visual aids. Participants were also asked to report sense of presence ratings during the encoding phase. This measure aimed to assess the extent to which an individual has a feeling of ‘being there’. Analysis of these results revealed a higher sense of presence reported for multisensory (audio-visual) compared to unisensory (audio, visual) videos. This is consistent with literature suggesting that the presence of realistic multisensory inputs is an important aspect for the increase in sense of presence within virtual environments (Iachini et al., 2019; Makowski et al., 2017; Witmer & Singer, 1998).

During retrieval, participants were asked to report confidence and vividness scores. Confidence scores were significantly lower for ‘audio-only’ videos, compared to visual and audio-visual videos, with no difference between visual and audio-visual. Participants also reported higher vividness scores at recall for multisensory and visual-only stimuli, compared to audio-only stimuli. These findings demonstrate the impact of multisensory and visual information on the subjective ratings associated with rich re-experiencing of events, such as confidence and vividness.

Results analysed from the free recall protocols provide important information about the impact of multisensory, versus unisensory stimuli on recall accuracy (measured as hits/total details). When looking at retrieval accuracy, surprisingly and not in line with our predictions, participants demonstrated better performance for audio-only videos, compared to visual and multisensory ones. This contradicts prior findings demonstrating better performance for the retrieval of visual, compared to auditory information (Cohen et al., 2009; 2011) or findings demonstrating a visual dominance effect (Colavita, 1974), as well as improved retrieval and object recognition for multisensory, compared to unisensory stimuli (Bonnici et al., 2016; Lehmann & Murray, 2005; Murray et al., 2004; Schroeder & Marian, 2016; Thelen et al., 2014). However, an important variable to consider here is the large and significant difference in total number of details present between the sensory modalities, with audio-only videos containing significantly fewer total details, compared to visual and audio-visual stimuli. Though we are exposed to fewer sounds, compared to visual inputs in everyday life, for these not to be equally matched could skew results as seen in the current experiment. It could be argued that rather than a greater aptitude for retrieving auditory information, the current results may simply be due to differences in task difficulty, with participants demonstrating greater ease in accurately recalling few auditory details, when presented in isolation, compared to paying attention to and subsequently accurately retrieving a greater volume of visual details for the other modalities. Indeed, a negative correlation was observed between total number of details between video modalities and the overall memory accuracy.

When assessing post-hoc comparisons for the comparison of accuracy across sensory modalities, significantly better performance was seen for the multisensory, compared to the visual unisensory condition. These results support existing findings demonstrating better memory retrieval of multisensory, compared to unisensory stimuli (Bonnici et al., 2016; Lehmann & Murray, 2005; Murray et al., 2004; Schroeder & Marian, 2016; Thelen et al., 2014), while comparing videos with a less pronounced difference between total details presented, therefore diminishing possible confounding effects of task difficulty. However, it should still be noted that a significant difference was found between total details for audio-visual, compared to visual stimuli, with audio-visual videos containing a greater number of total details. This could somewhat weaken the argument of task difficulty proposed earlier in relation to better accuracy for audio-only videos as in these findings we still see better performance for the modality containing the greater number of total details presented in the video. Future studies should perhaps manipulate stimuli further to diminish the gap between total details presented in each modality to further investigate accuracy for sensory details presented in isolation, without the confound of task difficulty. Here, a complimentary analysis of sensory details recalled within the multi-sensory videos was conducted. Consistent with findings demonstrating our propensity to better recall visual, compared to auditory information (Brady et al., 2008; Cohen et al., 2009; 2011; Colavita, 1974), participants were significantly better at retrieving visual, compared to auditory information. This could be explained in terms of visual dominance effects and our extraordinary ability to retain large amounts of visual details.

These findings provide us with an understanding of retrieval performance when we encode sensory information separately, both providing an understanding of performance between auditory and visual modalities, as well as comparing retrieval performance for unisensory, versus multisensory stimuli. In addition, the current findings give some indication of the effects of task difficulty with this type of ecologically valid design that could form the basis for future research. However, from a qualitative perspective, participants often seemed to forget to mention or describe auditory details, even if closely related to a visual item they were describing, especially when retrieving multisensory stimuli, i.e., ‘there was a puddle’ but omitting the sound of rain. Only a couple of participants were an exception to this rule. When conversing with them following the debrief, it was discovered that they were either avid readers or writers and so possibly individuals had a more sophisticated descriptive vocabulary. Though some studies have controlled for vocabulary ability when conducting a free recall test (Moreland et al., 1997), these observations raise interesting questions and directions for future research. It could be extremely informative to consider individual differences between participants and verbal proficiency in describing auditory details, as well as implement new experimental designs which could limit the reliance on vocabulary, such as spot the difference tasks, scene drawing (Iriye & St. Jacques, 2021) and modified recognition tasks where participants are asked to correctly identify events they experienced compared to a similar environment filmed by someone else (Misra et al., 2018).

Closely relating to the ability to describe the videos during the free recall tasks, interviews were also scored for the richness of the memory. This was measured by counting the number of descriptive details (either visual or auditory) stated for each stimulus at retrieval. Results showed a higher number of descriptive visual details, compared to auditory ones. These findings could be explained by looking at Gloede & Gregg’s (2019) research, which argues that retrieval for auditory details is more ‘gist’ like in nature, compared to more detailed retrieval of visual input.

Finally, the relationship between subjective measures and retrieval accuracy was investigated. Results from a multiple linear regression only revealed the measure of familiarity as a predictor of retrieval accuracy. There was no direct link between sense of presence and memory success, adding to the existing, limited knowledge of this relationship (Smith, 2019). As argued by Smith (2019), one important aspect influencing sense of presence in virtual experimental environments is the lack of distractions present while the participant is performing a task. It should be noted that as this study was conducted online, during COVID-19, participants took part in the experiment at home, resulting in limited control for distractions and a lack of controlled experimental set-up when it came to their own home environment. A replication of this study in a laboratory set-up could assess these questions further, without the confounds of distractors and in particular assess the question of presence and its relationship to memory performance, while controlling for possible distractions during task procedure.

In conclusion, this is the first experiment that makes use of the newly created stimulus set, providing the basis and suggestions for future studies that can investigate these relationships further. This study provides a holistic understanding of retrieval differences, relating to the accuracy, richness and subjective measures when remembering real-world events presented in different, isolated sensory modalities, compared to multisensory environments. We see higher sense of presence scores being reported for multisensory conditions, compared to unisensory ones, demonstrating how participants feel more immersed in an environment if this is multisensory in nature. Interestingly, this multisensory effect was not seen for confidence and vividness ratings, with no difference seen between visual and audio-visual videos. However, confidence and vividness at retrieval were significantly lower for audio-only conditions. Surprisingly, presence, confidence and vividness measures were not significant predictors of memory performance. Also, in contradiction with our hypothesis, we found accuracy scores were highest for the audio-only condition. These results might be explained by the stark difference in the total number of details that could be retrieved for the audio-only videos compared to visuo-only and audio-visual, suggesting results may be representing task difficulty effects, rather than improved retrieval for auditory information.

2.4 Chapter Discussion

The focus of this chapter was to assess the effects of sensory representation and multisensory, versus unisensory encoding on retrieval of real-world events. Experiment 1 of this chapter outlined the creation of a new stimulus set and the selection of videos split between unisensory (audio, visual) and multisensory modalities (audio-visual) to be used in Experiment 2 and future studies. Experiment 2 investigated the retrieval differences when presenting participants with the new, edited stimulus set. Results assessed differences in retrieval accuracy and subjective measures when comparing unisensory to multisensory stimuli, as well as comparing between the three sensory modalities, and differences in retrieval accuracy for visual, compared to auditory items following the encoding of multisensory stimuli.

Results from Experiment 1 revealed no floor or ceiling effects for retrieval accuracy and provided information for which a selection of videos was conducted, to be later used for Experiment 2. This selection consisted in establishing which videos were more dominant in one of three sensory categories (audio, visual, audio-visual). Videos were selected based on the number of correctly recognised or freely recalled details for each sensory modality. For instance, which videos were better recalled for their auditory information, compared to visual. Videos where accuracy was evenly distributed for remembered visual and auditory details were selected for the multisensory (audio-visual) condition.

This experiment provided some initial findings for the retrieval of multisensory information of real-world events. Namely, participants demonstrated better retrieval accuracy for visual details, compared to auditory details in the free recall test, but no difference was seen for results from the recognition test. These findings were supported in Experiment 2, where participants only took part in a free recall test, during which retrieval of visual details was better, compared to auditory details, when recalling multisensory stimuli. However, as discussed previously, the differences seen during free recall, but not recognition tests would add to the suggestion that perhaps we as individuals have greater difficulty in describing auditory items, compared to visual ones. In the discussion for Experiment 2, I proposed new methodological approaches to investigate the effect of vocabulary ability on retrieval accuracy for free recall tests, in particular when comparing our ability to describe visual, compared to auditory information.

Finally, findings from this chapter provided interesting insights into the relationship between sensory modalities and subjective measures of retrieval. With the exception of the measure of familiarity in Experiment 2, subjective measures did not seem to predict retrieval accuracy. Experiment 1 shed light on the relationship between familiarity and presence, as well as vividness and presence. Videos were given a higher sense of presence rating if familiar to the participant, compared to unfamiliar environments. A positive correlation was also found between presence and vividness; however, this was not replicated in Experiment 2. As there was no distraction task or measured break between questions for Experiment 1, this inconsistency in results may be due to presence and vividness measuring similar interpretations of the question. When looking at videos, split between sensory modalities in Experiment 2, participants reported higher sense of presence ratings for multisensory, compared to unisensory stimuli, and higher confidence and vividness scores for visual and audio-visual videos, compared to audio-only videos.

In conclusion, the experiments discussed in this chapter provide a greater understanding of our retrieval of multisensory information, as well as behavioural differences in retrieval when encoding events from different sensory modalities. Future studies will be able to make use of the newly created stimulus set to investigate memory for real world events further, using videos that are highly immersive and representative of everyday life environments. The next chapter will assess subjective and objective aspects of retrieval, following the manipulation of visual perspective (field versus observer), using the same videos as in this chapter, and a new subset of observer videos for real-world events.

Chapter 3 Visual Perspective Manipulation at Study and Memory Retrieval

3.1 Introduction

Visual imagery is integral for the subjective re-experiencing of episodic events and a sense of reliving (Rubin et al., 2003). Each experience must hold a viewpoint both at encoding and retrieval in one's mind eye (St Jacques, 2022), namely, a field perspective (perspective from one's own eyes), or observer perspective (as would be viewed from the perspective of an observer; Nigro & Neisser, 1983). Adopting either perspective at retrieval seems to be associated with a series of determinants. Distinctions have been made for the type of information being retrieved, such as the description of feeling states for field, compared to concrete details for observer perspectives. Older memories are more likely retrieved from an observer perspective, suggesting a temporal component and determinant as well (Nigro & Neisser, 1983; McIsaac & Eich, 2004; Rice, 2010).

Perspective differences have also been associated with phenomenological differences in memory retrieval. Studies assessing the effects of perspective shifting (from field to observer) at retrieval have found a reduction in vividness ratings (Butler et al., 2016; Verghaegen et al., 2018), as well as a reduction in episodic details being retrieved and a decrease in accuracy for shifted, compared to non-shifted conditions (Akhtar et al., 2017; Marcotti & St Jacques, 2018). These phenomenological differences have been explained as a possible reduction of visual information for episodic events, resulting from the shift to an observer perspective and difficulty in adopting a novel field of view. Some argue this could be due to observer memories typically being more remote memories, compared to field ones, therefore more likely to have a reduced amount of information, compared to more recent memories being retrieved from a field perspective (Verhaeghen et al., 2018). However, this does not explain findings where a reduction in vividness and fidelity of memories is seen when shifting to an observer perspective shortly after the encoding of new, experimentally encoded memories (Butler et al., 2016; Marcotti & St Jacques, 2018). The selectivity of these changes, only seen for shifts from a field to observer perspective in memory retrieval may be due to a permanent reduction of visual information of the event (Butler et al., 2016), irrespective of the temporal timeline relating to that memory.

There seems to be some consensus about the effects and characteristic differences of memories retrieved from a field or observer perspective. Less is known of the differences in memory retrieval when visual perspective is manipulated at encoding. Few studies have been conducted where participants are asked to encode from either a field or observer perspective (Bergouignan et al., 2014; Iriye & St Jacques, 2021; Leynes et al., 2017). Within this small pool of studies, there does not seem to be a clear consensus regarding the effects of perspective manipulation at encoding on subsequent retrieval. For instance, Leynes et al., (2017) and Bergouignan et al., (2014) found that events encoded from an observer (or out of body perspective, see Bergouignan et al., 2014 and literature review chapter for more information), were associated with decreased source memory accuracy for word lists (Leynes et al., 2017), and retrieval of significantly fewer episodic details for events (Bergouignan et al., 2014), as compared to encoding from a field perspective. However, Iriye and St Jacques (2021) found no difference for cued-recall accuracy or reported vividness of memories encoded from either a field or observer perspective. It is difficult, from the existing literature, to ascertain whether effects seen at retrieval are simply a result of task difficulty in shifting from a field to observer perspective and a loss of visual information, or whether differences also exist in the amount of information being encoded when presented with one perspective rather than another. The studies conducted and discussed in this chapter will further investigate the effects of perspective manipulation at encoding on subsequent retrieval.

Thus far, studies have used VR environments to investigate this area of research on perspective and memory (Bergouignan et al., 2014; Iriye & St Jacques, 2021). There has been a recent move to use more ecologically valid assessments in the field of memory, such as VR (Serino & Repetto, 2018). VR environments allow researchers to create simulations of real-life scenarios, while maintaining experimental control (Smith, 2019). However, a pitfall of using computer-generated environments is the diminished perceptual realism presented to participants during these tasks, compared to recordings of real-life situations which are a closer representation of the real world (Serino & Repetto, 2018). Naturalistic video stimuli have increasingly been used to investigate cognitive and neural processes of perception and subsequent memory (Bird et al., 2015; Buchsbaum et al., 2012; Samide et al., 2020). The aim of this chapter was to explore differences in memory retrieval for videos of real-life events, filmed from either a Field or Observer perspective. A new stimulus set was created, selecting 10-second-long clips of a series of videos collated from www.YouTube.com. Specifically, I tested whether memory performance would differ between events encoded from a field or observer perspective and predicted higher vividness scores for field videos, compared to observer videos.

Taking inspiration from the VR literature, I included the measure of ‘sense of presence’ (Dinh et al., 1999; Witmer & Singer, 1998). This terminology focuses on the ability to create immersive environments and measure the extent to which an individual has a feeling of ‘being there’ (Makowski et al., 2017). Research adopting virtual environments to study memory has found that a field perspective is associated with a higher sense of presence, compared to an observer perspective (Denisova & Cairns, 2015; Iriye & St Jacques, 2021; Kallinen et al., 2007). Makowski et al., (2017) also found that participants’ factual memory (measured by asking questions relating to movies the participant had seen) was positively correlated with their sense of presence, suggesting that the subjective measure of presence may be a predictor of retrieval accuracy. Here, I predicted that videos encoded from a field perspective would yield a higher sense of presence, compared to observer videos, and that in turn, this would predict higher accuracy scores for field videos.

3.2 Experiment 3

Following on from Chapter 2, a new subset of stimuli needed to be constructed to compare retrieval of field perspective videos (used in Chapter 2 experiments) and a new set of observer videos. One key difficulty in creating this distinction is ensuring participants are able to discern and perceive videos filmed from a field or observer viewpoint, as such. As none of the videos depict events experienced first-hand by the participants it could be argued that, conceptually, all videos represent an observer perspective, making this distinction more difficult to measure. As such, the subset created in this experiment included two types of observer videos, filmed either with a static or moving camera shot. This first pilot aimed to assess the quality of this new subset and whether lack of movement (static videos) would increase the likelihood of participants perceiving videos as being filmed from an observer perspective, rather than field, making the distinction of observer vs field perspectives in future studies more obvious. Similarly to the quality checks conducted in Experiment 1, Chapter 2, the number of details recognised by participants was measured to identify any floor or ceiling effects. Specific to this pilot, it was also important to assess participants' accuracy in identifying the correct perspective the video was presented in. These assessments provided the basis for the selection of videos to be used in future studies for which perspective (Field vs. observer) would be manipulated at encoding.

As all videos depicted similar everyday life environments, we used the subjective measure of familiarity as a control to test whether behavioural differences during memory retrieval were a result of personal, past experiences with the environments being shown. As personal experience with the environment being shown was unlikely to differ between video types, we predicted no differences in familiarity scores between video types (moving Vs static). We predicted an increased sense of presence for moving videos, compared to static ones due to the heightened immersiveness of this style of filming, and based on overall high presence scores seen for videos assessed in Experiment 1, Chapter 2. Thus, we also predicted higher vividness scores being reported for moving videos, compared to static ones, based on results seen from Experiment 1 showing a strong positive correlation between presence and vividness.

Little emphasis was placed on accuracy measures for this study as all videos were filmed from an observer perspective (not filmed by the main actor performing an action and removed from the main scene being shown), with no direct comparison to field videos. Exploratory analyses were conducted to gain an initial understanding of differences in memory performance between dynamic versus static videos. A list of details for each video was created by the researcher (including auditory and visual information). Auditory details ranged from 3-7 per video and 12-20 for visual details.

3.2.1 Methodology

Design

This was a within-subjects design. All participants were asked to watch the videos and answer questions regarding perspective and memory recollection. Independent Variable = video type (2 levels: static versus moving), DV = perspective judgement accuracy, subjective measures scores and retrieval performance.

Participants

Participants were University of East Anglia students, recruited through the SONA system. Data was collected from 52 participants. Two participants were removed for the analyses, due to not having completed all questions for the task. Ages ranged from 18 to 52 (M = 21.79, SD = 5.43), of whom 17 were males and 35 were females.

Materials

Fourteen videos (720p, duration of 10 seconds each, Observer Videos Link) depicting a range of everyday life activities and landscapes were presented. These were all filmed from an observer perspective, either from a static angle (placed on a firm surface) or using a moving camera shot (from the point of view of an observer following the main actor performing an action). An online questionnaire was created using Qualtrics (www.qualtrics.com). The questionnaire included questions regarding perspective of the video, vividness, familiarity and sense of presence. A list of audio-visual details the participant may or may not have seen in the video was also created as part of a cued recognition test. The list included all details present in the video, as well as some semantically related but not presented details. These lures made up 25% of overall details, with the audio-visual ratio being the same as that for ‘true’ items.

Procedure

Participants were asked to watch 14 videos and answer a series of questions following each video. Participants were given a visual representation (cartoon image, Figure 3.1. Cartoon image of observer and field perspectives as presented to participants during the task.) of a ‘field’ and ‘observer’ view and asked to select which perspective more closely resembled the perspective of the seen video.

Figure 3.1. Cartoon image of observer and field perspectives as presented to participants during the task.

They were asked to rate how present they felt while watching it (1 – not at all, completely remote to 7 – ‘felt like I was there’) and whether the video represented a familiar environment/if they had experienced something similar (1 = Not familiar, 2 = Maybe familiar, 3 = Very familiar), followed by reporting how vividly they could think about the video in that instance (1 – not at all to 7 – extremely vividly). Following these questions, two memory recollection tests were conducted. Firstly, participants undertook a free memory recall test, whereby they were invited to write all the details they could recall. It was specified to include visual, auditory and any feelings they might have had while watching it. This test was followed by a cued memory recognition task. A list of possible details (auditory and visual) was presented. Participants were required to 'drag and drop' items from the list in one of five boxes: "High Confidence Old"; "High Confidence New"; "Low Confidence Old"; "Low Confidence New"; "Other/Unknown". Recognition accuracy was calculated by combining high and low 'old' confidence, minus high and low confidence false alarms (Hits-FA). Confidence judgements were not analysed separately. Qualtrics had been set up so that all items must be allocated to one of the above options before being able to move on. Overall testing duration varied between 45 minutes and 1:30hr. However, this was mostly dependent on the pace of typing as well as the amount of details/phrasing used during the free recall phase (see Figure 3.2 for the procedure outline and Appendix A for screenshots of the task).

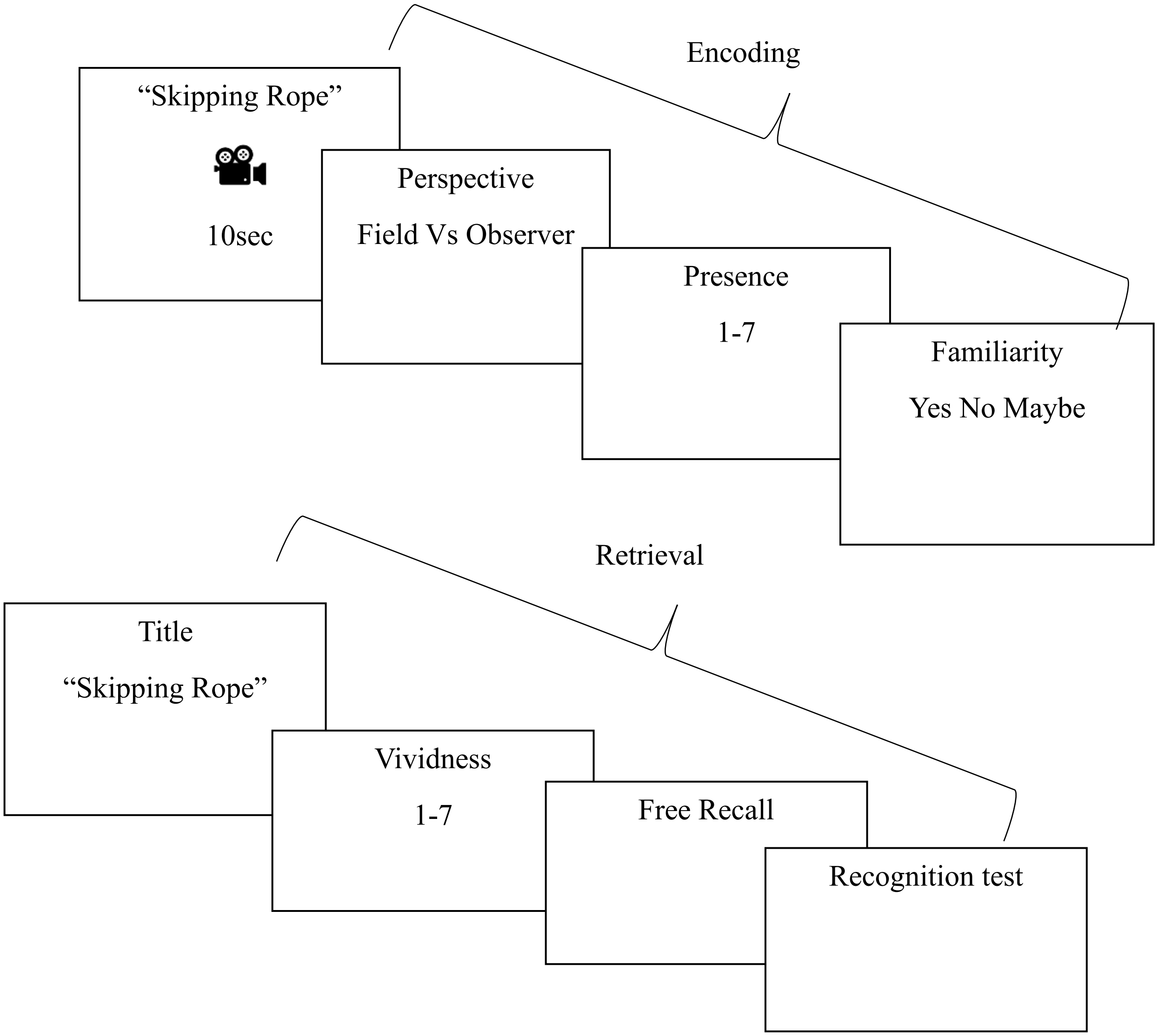

Figure 3.2. Experiment 3 procedure timeline. This is an example of one video trial, depicting encoding and retrieval phases.

3.2.2 Results

Validation of Stimulus Set

Quality Checks. Floor and ceiling effects in memory performance were assessed by observing accuracy scores for the recognition test. Participants' mean hit rate score was 51% for static videos and 58% for moving videos. The lowest accuracy scores were 17% and 6%; and the highest accuracy scores were 71% and 73% for static and moving videos, respectively. Median scores were 54% and 61% for static and moving videos, with the mode being 60% for both video types. Finally, 98% of participants scored between 20-80%, with only one participant for either type of video scoring lower than 20% for recognition accuracy. From these assessments, it was established that there were no concerns for floor and ceiling effects in relation to the recognition test.

Static and Moving Perspective Recognition. A One-Way repeated measures ANOVA (video type x perspective judgement) was conducted to compare number of times videos were incorrectly identified as ‘Field’ between moving and static videos. A significant difference was found, with moving (*M* = 2.50, *SD* = 1.93) videos being associated with a higher number of incorrect perspective judgements F(1,49) = 11.5, *p* = .001, ηp2 = .19, compared to static videos (*M* = 1.56, *SD* = 1.85). Mean values represent average number of times each participant incorrectly provided a ‘Field’ perspective judgement.

Subjective Measures of Memory Retrieval

Familiarity. A One-Way repeated measures ANOVA assessing differences in familiarity scores between static and moving videos was conducted. This analysis was conducted as a control for future analyses to mitigate the potential effect of familiarity with the environment shown on other aspects of retrieval, in particular accuracy. A significant difference was found, with participants reporting higher scores of familiarity for moving videos, ($M = 2.16$, $SD = 0.38$), compared to static ones ($M = 1.64$, $SD = 0.39$), $F(1,49) = 84.1$, $p < .001$, $\eta p2 = .63$. As a result of these findings, the below analysis assessing differences in accuracy between video types incorporated familiarity as a covariate.

Presence. A One-Way repeated measures ANOVA was conducted to assess differences in presence scores between static and moving videos. A significant difference was found, with presence scores being higher for moving videos ($M = 4.23$, $SD = 1.10$), compared to static ones ($M = 3.79$, $SD = 1.14$), $F(1,49) = 20.2$, $p < .001$, $\eta p2 = .29$, consistent with our predictions that participants would feel more immersed when watching a dynamic video, compared to a static one.

Vividness. A One-Way repeated measures ANOVA comparing vividness scores between moving videos ($M = 4.60$, $SD = 0.91$), and static ones ($M = 4.43$, $SD = 0.89$), only approached significance $F(1,49) = 3.43$, $p = .07$. A Pearson correlation was also run to assess the relationship between presence and vividness scores. A significant positive correlation was found, $r(48) = .73$, $p < .001$, consistent with findings from Experiment 1, Chapter 2 (Figure 3.3).

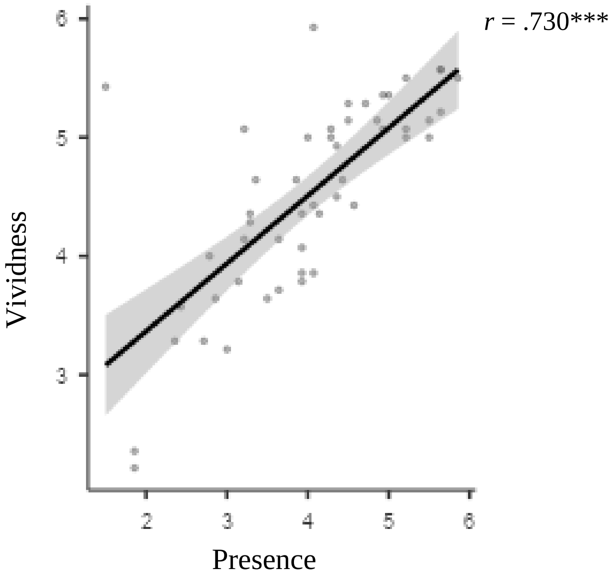

Figure 3.3. Scatterplot showing the relationship between reported vividness and sense of presence.

Recognition Accuracy

Accuracy. A One-Way ANCOVA was conducted to assess differences in accuracy scores (hits-FA, reported as percentage in decimal form) between static and moving videos, with familiarity as a covariate. A marginally significant difference was found F(1,49) = 4.158, *p* = .04, ηp2 = .04. Accuracy scores were higher for moving videos (*M* = 0.58, *SD* = 0.13), compared to static ones (*M* = 0.51, *SD* = 0.11). The covariate of 'Familiarity' was not statistically significant, F(1,49) = .41, *p* = .52.

3.2.3 Discussion

The main aim of this study was to validate a new stimulus set and establish whether it would be suitable for future studies assessing the effect of visual perspective on memory retrieval. Floor and ceiling effects were assessed, demonstrating that 98% of participants scored between 20-80% accuracy in the recognition task, suggesting there are no concerns for floor and ceiling effects with this stimulus set. It was also necessary to assess perspective judgement accuracy. Though all videos shown were from an observer perspective, it was possible to assess whether moving videos were more likely incorrectly recognised as ‘field’ compared to static ones. This was in fact the case, suggesting that to achieve a starker difference between perspectives when presenting observer videos in conjunction with field ones, static videos would be more successfully differentiated and correctly recognised as being filmed from an observer perspective, than moving ones. As mentioned previously, one difficulty in using videos for the manipulation of perspective at encoding is that participants do not have first-hand experience with the environment/scene presented to them, making all videos somewhat observer in nature. It could be argued that using static videos for future studies would increase the likelihood of the video being perceived as ‘observer’, rather than field, thereby increasing the ability to measure retrieval differences between perspectives.

However, this would also result in significant stylistic differences between field and observer videos, with field (as used for Chapter 2) depicting events filmed with a GoPro camera (placed on the forehead of the main actor), with lots of movement, and static videos filmed by placing a camera on a still surface and including no camera movement. As seen from previous research (Iriye & St Jacques, 2021), the angles and format of a virtual environment can substantially affect memory retrieval, irrespective of the perspective being shown. Participants in this study demonstrated better retrieval accuracy for the observer VR condition due to a wider camera lens being used. These effects were not observed when this factor was controlled. Similarly, with this new video stimulus set, differences in filming styles may lead to undesirable effects on memory retrieval, not representative of perspective manipulation at encoding. Following these deliberations, a further study was designed to assess perspective judgements when comparing moving observer, static observer, and field videos presented in the same experiment. This would allow the comparison of perspective judgement accuracy between all the videos selected thus far, and most importantly comparing perspective judgements for moving field and observer videos.

For exploratory purposes, data from the study were analysed to ascertain an initial understanding in differences in subjective measures of memory retrieval and recognition accuracy, between the two video types (moving Vs static). Participants were significantly more likely to identify a moving video as being shot from a field perspective. Thus, some of these findings could be linked to existing research on memory and perspective (Akhtar et al., 2017; Bergouignan et al., 2014; Butler et al., 2016; Leynes et al., 2017; Verhaegen et al., 2018). However, this should be done with caution, as participants were asked to state whether each video was filmed from a field or observer perspective while only being shown observer videos. It could be argued that this experimental procedure would have encouraged many to wrongfully select some of the videos as being field.

Subjective ratings for encoding and retrieval tasks revealed a higher sense of presence scores for moving videos, compared to static ones, but only a trend for a similar difference in vividness scores between the two types of videos. As our visual world is intrinsically dynamic (Gibson, 1979) it is easily comprehensible that a more dynamic stimulus would result in higher sense of presence than a static one. Consistent with findings from Experiment 1, Chapter 2, a significant positive correlation was found between presence and vividness. This is consistent with findings from the VR literature showing that the higher the vividness of reported mental imagery, the stronger the reported sense of presence people experience in the VR environment (Iachini et al., 2019).

Surprisingly, familiarity scores differed between the two types of videos. This measure was intended as a control to mitigate the potential effect of familiarity on retrieval accuracy but was not found to be a significant covariate when added to the ANOVA model. A marginally significant difference in accuracy scores between videos was found, with higher accuracy for moving, compared to static videos. This could be linked to perceived perspective differences and would be in line with some prior findings suggesting impoverished memory retrieval when encoding stimuli from an observer perspective (Bergouignan et al., 2014). However, it could also be a result of a ‘*dynamic superiority effect’* (Goldstein et al., 1982). Research has shown how recognition accuracy is better for moving/dynamic stimuli, compared to static ones (Matthews et al., 2007, 2010). Though this has mainly been found by comparing static images to moving videos, these findings seem to be present even when comparing moving to ‘multistatic’ conditions (Buratto et al., 2009). An argument to not use static videos for future studies comparing perspective at encoding would be to control for this potential movement effect and compare field Vs observer stimuli where both modalities include moving camera shots. This will be covered in Experiments 4 and 5 of this chapter.

3.3 Experiment 4

Following Experiment 3, a pilot study was conducted to finalise the selection of videos for future analysis in which perspective will be manipulated at encoding. Results from Experiment 3 showed participants were significantly more likely to wrongfully recognise moving videos as being filmed from a field perspective, compared to static ones. These differences were also associated with memory performance changes at retrieval for both subjective measures and retrieval accuracy. However, due to the drastic difference in filming style between static observer videos and field videos selected in Chapter 2 (all filmed using a GoPro and depicting movement), it was deemed necessary to conduct a pilot study to ask participants to state the perspective of videos shown when all three modalities were presented (observer – static, moving, and field). Results from this pilot would determine which videos will be selected for a future experiment manipulating perspective at encoding. The selection was conducted by matching the accuracy ratio (correct: incorrect) in identifying the perspective of each video between field and observer stimuli.

3.3.1 Methodology

Design

This was a within-subjects design. All participants watched static and moving ‘shot’ observer videos and field perspective videos. IV = video perspective, DV = perspective judgement accuracy.

Participants

Participants were 19 staff and students from the University of East Anglia, data was collected through opportunity sampling and no payment or reward was offered for participating. Ages ranged from 23 to 50 (*M* = 28.5, *SD* = 6.96), of which, 12 females and 7 males.

Stimuli

A series of 10-second long videos were split into three modalities: Field, Observer Static, and Observer moving. Eighteen field videos were taken from Experiments 1 and 2 of Chapter 2. Observer videos were taken from Experiment 3 and were 14 in total, 7 static and 7 using a moving filming shot.

Materials

Thirty-five videos, 18 field and 14 observer, (720p, duration of 10 seconds each) depicting a range of everyday life activities/landscapes were presented. An online questionnaire was created using Qualtrics. The questionnaire included questions regarding the perspective of the video (Field vs. observer).

Procedure

Each participant was shown a series of 10-second long videos; 18 ‘Field’ and 14 ‘Observer’ (7 moving Vs 7 static – see experiment 3 for clarification). Following each video presentation, they were provided with a cartoon image, the same as what was shown in Experiment 3, (see Figure 3.1) of either perspective and were asked to tick which perspective more closely represented the video just shown. Once all videos had been presented and perspective answers provided for each one, participants were debriefed (see Figure 3.4).

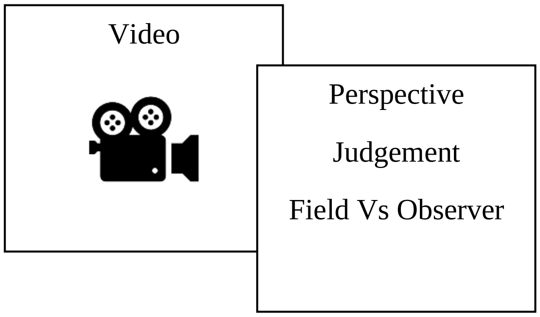

Figure 3.4. Experiment 4 procedure outline. Participants watched a video and were asked to report from which perspective the video was filmed.

3.3.2 Results

Perspective Recognition

Average accuracy scores in correctly stating a video was filmed from either a ‘Field’ or ‘Observer’ perspective were measured. A repeated measures ANOVA was conducted with video type (field, observer moving, observer static) as a factor and accuracy scores of correctly identified videos as the dependent variable. A significant main effect of video type was found, F(1.40, 25.13) = 4.35, *p* = .02, ηp2 = 0.20. Post hoc, Bonferroni corrected tests revealed a significant difference in correctly identifying the video’s perspective between Field and Observer Static videos, t(18) = -4.00, *p* < .01, with higher accuracy seen for observer static videos (*M* = .99, *SD* = .03), compared to field videos (*M* = .89, *SD* = 0.11). Difference between observer static and moving (*M* = .90, *SD* = 0.16) videos t(18) = -2.48, *p* = .07, just missed significance, and no significant difference was seen between field and moving observer videos, t(18) = -0.12, *p* = 1 (see Figure 3.5).

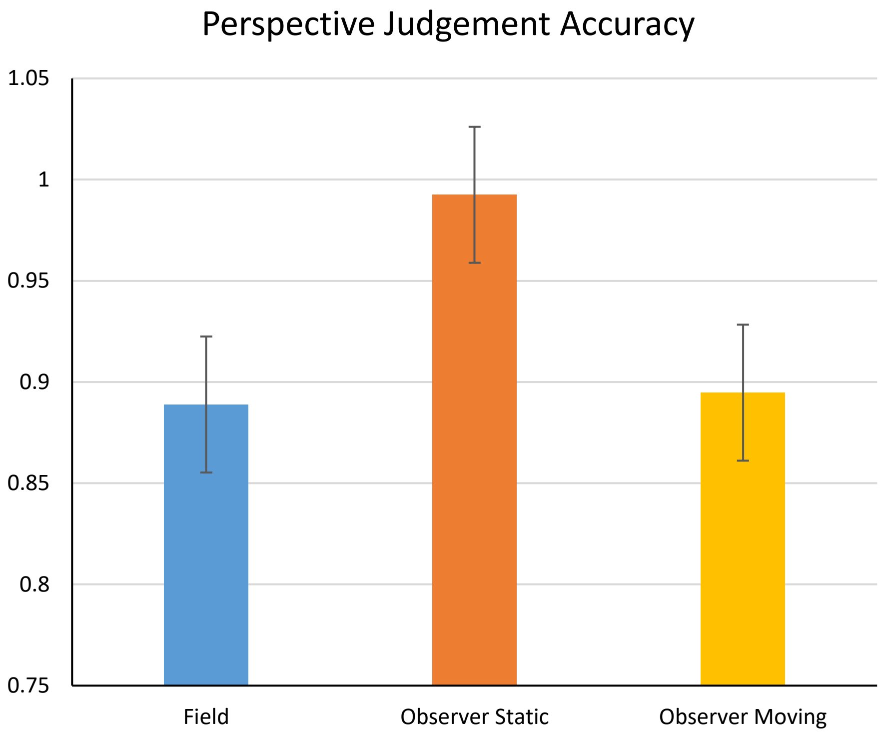

Figure 3.5. Graph showing accuracy for perspective judgements of videos. Highest accuracy seen for 'observer static' videos, no difference seen between 'observer moving' and 'field' videos.

Selection of Videos

As a result, it was established that a smaller, equally matched sample from each of these two stimulus sets would be selected for future studies: 6 Observer moving, 6 Field videos (Table 3.1). This selection was conducted by matching perspective accuracy ratios for both condition correct: incorrect (i.e., Observer statements for observer videos: field statements for observer videos) perspective judgements.

Observer	**Field**
Cyclist	Baseball
Haircut	Car
PitStop	City Walk
Tractor	GoKarting
Skipping Rope	Horse
Swimming	Mountainbike
92% accuracy in recognising perspective	**94% accuracy in recognising perspective**

Table 3.1. Final selection of videos for field and observer perspectives based on perspective judgement accuracy ratios.

3.4 Experiment 5

Experiments 3 and 4 were necessary for assessing the quality of the stimulus set, as well as selecting videos that would be presented to participants in this study (see results from Experiment 4). The aim of this study was to assess the impact of perspective manipulation at encoding on retrieval performance. This experimental design resembled very closely that of Experiment 2 (Chapter 2), with the exception of asking participants at the end of the task to provide a perspective judgment. This was used as a quality check to assess accuracy in correctly identifying the perspective each video was filmed from.

Subjective measures were analysed, namely familiarity, presence, vividness, and confidence. Familiarity was used as a control measure to ensure behavioural differences between video modalities would not be due to previous experience with the environment shown. Due to the videos depicting similar, everyday life events, it was predicted that there would be no differences in familiarity scores between field and observer videos. In line with existing research, it was also predicted that participants would report higher sense of presence for field videos, compared to observer perspective ones (Iriye & St Jacques, 2021), as well as higher vividness scores at retrieval for field videos, based on findings suggesting a loss of visual information when retrieving from an Observer perspective (Butler et al., 2016; Verhaegen et al., 2018).

Less consensus exists regarding the effect of perspective, manipulated during study, on retrieval accuracy (Bergouignan et al., 2014; Iriye & St Jacques, 2021; Leynes et al., 2017). Arguably, if vividness and sense of presence have been associated with the fidelity and amount of information being retrieved, a reduction of these measures for observer videos would suggest we should also see impoverished retrieval accuracy for these videos, compared to field ones. Finally, in line with the above stated findings, it was predicted that observer videos would be associated with less descriptive detail at retrieval, thereby resulting in less ‘rich’ retrieval of events, compared to field videos.

3.4.1 Methodology

Design

An online experiment was conducted using Gorilla (www.Gorilla.sc) and Microsoft Teams. This was a within-subjects design, where participants were shown and asked to recall videos filmed from either a ‘Field’ or ‘Observer’ perspective.

Participants

Participants were recruited through the University of East Anglia SONA system and paid participants panel. Participants through the SONA system were undergraduate students who received credits for their course following participation. Each paid participant panel individual was awarded £12 for participating. These participants were either members of the public or other UEA students/staff. Three participants had to be removed either as a result of completing the study in an inappropriate setting or due to internet connection issues which created interruptions at the recall phase of the experiment. Results from sixty participants, ages ranged between 18-53 (M = 23.3, SD = 7.48) of which 18 male and 2 non-binary, were analysed.

Stimuli

Stimuli were split between videos filmed from a Field perspective (6 videos) and Observer (moving) perspective (6 videos). These were selected based on results from Experiment 4. All videos were 10sec long and depicted neutral everyday life events and were presented in a randomized order at encoding.

Materials

This study was conducted online, using Gorilla. Two separate Gorilla tasks were programmed. One encoding and one recall task. The recall phase of the experiment was conducted during a Teams call, with the researcher presenting the task from Gorilla by sharing their screen while participants verbally recalled details from the videos.

Procedure

Participants were invited to a scheduled Teams call. They were sent a Gorilla link for the initial encoding task. Instructions were provided both verbally and in written form. The call was muted for the duration of the encoding and distraction task. During the encoding task, participants were shown a total of 12 videos. Each video was presented with an associated title. Following each video, participants were asked to state whether the video was familiar to them ("Have you ever experienced something similar in your personal life/Was it a familiar environment to you?" 1-7 Likert scale) and rate how present they felt while watching the video (1 - "Felt completely remote" to 7 - "Felt like I was there"). Following the presentation of all 12 videos, participants partook in a short distraction task where they were asked to answer a series of simple math questions. They were then told they could have a 10-minute break before coming back for the second part of the experiment. During the second part, and recall phase of the study, participants were able to see the Gorilla task through the researcher's shared screen. The call was recorded following the participant's permission. Titles from each video shown at encoding were presented in a random order. Following each title presentation, the participant was asked to recall the video, quietly, as was presented during the encoding phase. They were given 10 seconds (same duration as the video) to do this. The purpose of this task was to get the participant to imagine the video from start to finish before starting the verbal recollection. They were then asked to freely recall in as much detail as possible what they could remember from the video. No specific prompts or cues were provided, only encouragement to recall as much information as possible. After each free recollection, participants were asked to rate how confident they were of their response (1 – not at all confident; 2 – somewhat confident; 3 – very confident) and how vividly they were able to recall the video (1 – not at all vivid to 7 – extremely vivid). Finally, a final questionnaire was administered during which participants were asked to watch each video again and state whether they thought each video was filmed from a 'Field' or 'Observer' perspective. This questionnaire was adapted from experiment 4, for each perspective question participants were shown a cartoon image example of what would be classified as 'Field' and 'Observer'. After completion of this questionnaire, participants were debriefed (see Figure 3.6 and Appendix C).

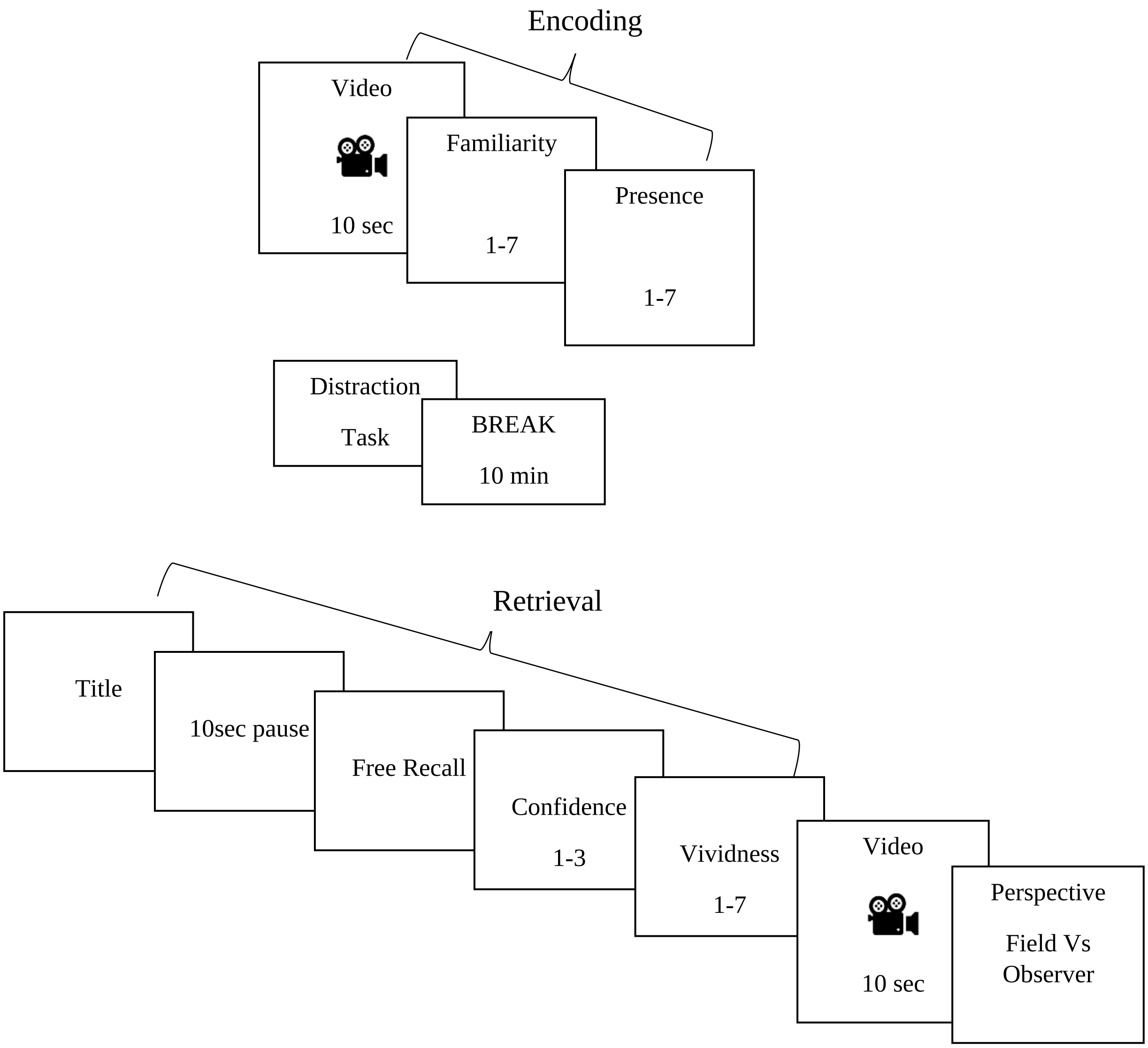

Figure 3.6. Experiment 5 procedure outline. Participants watched 12 videos (6 observer, 6 field) during the encoding phase and asked to report familiarity and presence scores. They then completed a distraction task and had a 10min break before starting the retrieval phase. This last task included a free recall interview, confidence, and vividness questions, as well as a question regarding the perspective from which the video was filmed.

Scoring

The same scoring system used for Experiment 2, Chapter 2, was utilised for this study. Once transcriptions of free recall interviews were made, responses were scored for number of details correctly identified, and these were measured separately for visual and auditory details, richness (measured through identification of additional descriptive details), as well as memory errors (items not present in the original video but recalled by the participant).

3.4.2 Results

Study Phase

Familiarity. A repeated measures ANOVA was conducted to compare participants' familiarity scores between "Field" and "Observer" perspective videos. No significant difference in familiarity scores was found, F(1,59) = 6.15e-4, *p* = .98. As a result, familiarity was not used as a covariate for future analyses.

Sense of Presence. Examining differences in presence scores, a repeated measures ANOVA with factors of perspective ("Field", "Observer") showed a significant difference in presence scores, with Field videos (*M* = 4.75, *SD* = 1.04) having higher presence scores, compared to Observer videos (*M* = 3.48, *SD* = .94), F(1,59) = 109, p < .001, ηp2 = .648 (see Figure 3.7).

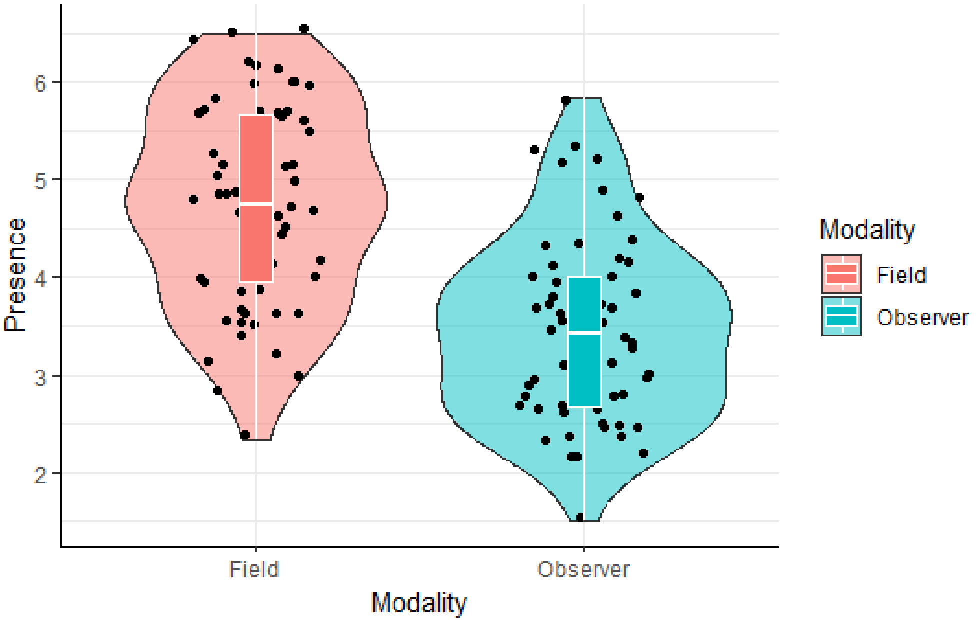

Figure 3.7. Violin plot showing differences in presence scores between video modalities. Higher sense of presence scores were attributed to field, compared to observer videos.

Test Phase

Confidence. A repeated measures ANOVA examining differences in confidence scores between modalities showed no significant difference between “Field” and “Observer” videos, F(1,59) = 1.74, *p* = .192.

Vividness. A repeated measures ANOVA examining differences in vividness scores between perspectives also showed no significant main effect F(1,59) = .75, *p* = .389.

Free Recall

Word Count. A repeated measures ANOVA was run to examine whether there were differences in word count for retrieval of “Field” compared to “Observer” videos. This was done in order to rule out any possible effect the number of words retrieved would have on retrieval accuracy and richness. No significant difference was found between modalities (F(1,59) = .138, *p* = .712). As a result, word count was not used as a control for future analyses.

Accuracy. A repeated measures ANOVA showed no effect of perspective (“Field” Vs “Observer”) on free recall accuracy, F(1,59) = .382, *p* = .539.

Number of Sensory Details Recalled. A Two x Two repeated measures ANOVA was performed to analyse the effect of perspective (Field Vs Observer) and type of details retrieved (visual Vs auditory) on retrieval accuracy. A significant interaction between perspective and type of details was found F(1,58) = 20.39, *p* < .001, ηp2 = 0.260 (See Figure 3.8). Simple main effects analysis showed that perspective did have a significant effect on retrieval accuracy F(1,58) = 7.27, *p* = .009, ηp2 = 0.111. A simple main effect of type of detail was also found F(1,58) = 168.85, *p* < .001, ηp2 = 0.260.

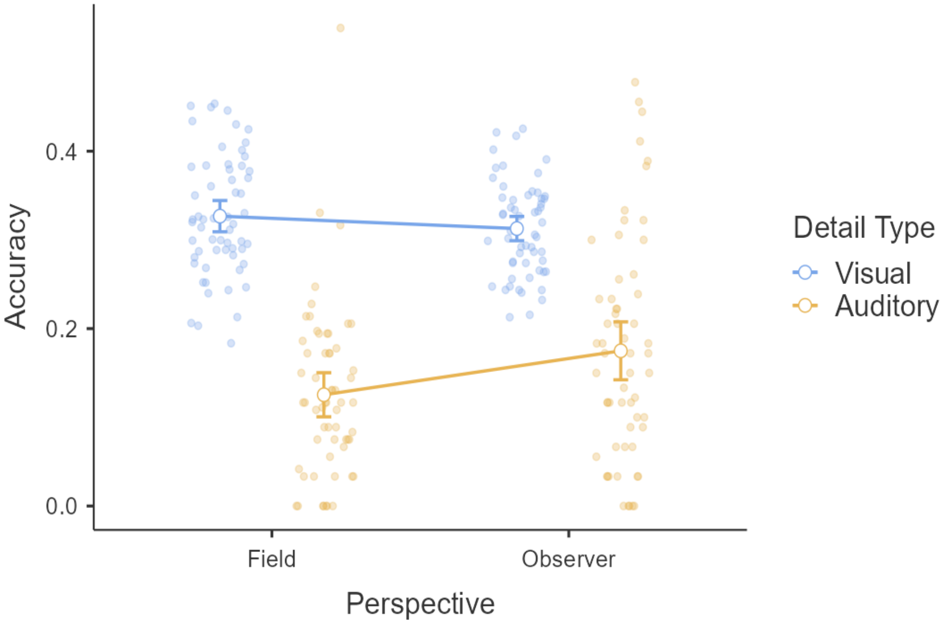

Figure 3.8. Figure showing interaction between perspective (field vs observer) and detail type (visual vs auditory).

Post-hoc, Bonferroni corrected tests showed a significant difference between accuracy scores for auditory details, compared to visual details for “Field” videos (t(59) = -15.84, *p* <.001), with higher percentage accuracy scores (reported as decimals) demonstrated for recall of visual

(*M* = .33, *SD* = .07) details, compared to auditory (*M* = .13, *SD* = .09). The same was found for retrieval accuracy of visual (*M* = .31, *SD* = .05) and auditory (*M* = .17, *SD* = .13) details of “Observer” videos (t(59) = -8.55. *p* < .001). Participants showed better accuracy for auditory details when retrieving details of an “Observer” video, compared to a “Field” video (t(59) = -3.97, *p* < .01). No such significant difference was found when comparing accuracy for visual detail between modalities (t(59) = 2.26, *p* = .167). See Figure 3.9.

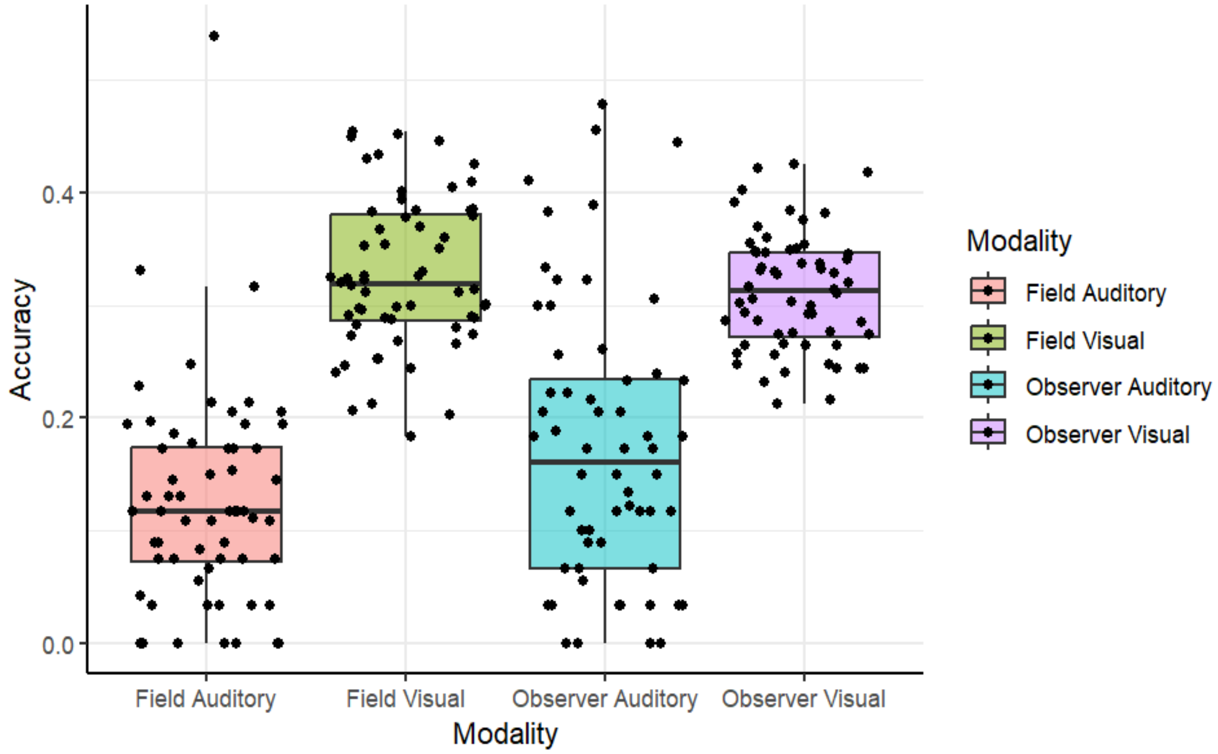

Figure 3.9. Box plot showing post-hoc comparisons for accuracy scores of visual, compared to auditory detail, across field and observer videos.

Richness. A repeated measures ANOVA was conducted to compare the number of additional descriptive details freely recalled by participants across modalities ("Field" Vs "Observer"). A significant main effect was found (F(1,59) = 27.5, *p* < .001, ηp2 = .318), with a significantly higher number of descriptive details retrieved for "Observer" videos (*M* = 2.74, *SD* = 1.08), compared to "Field" (*M* = 2.18, *SD* = 1.08). See Figure 3.10.

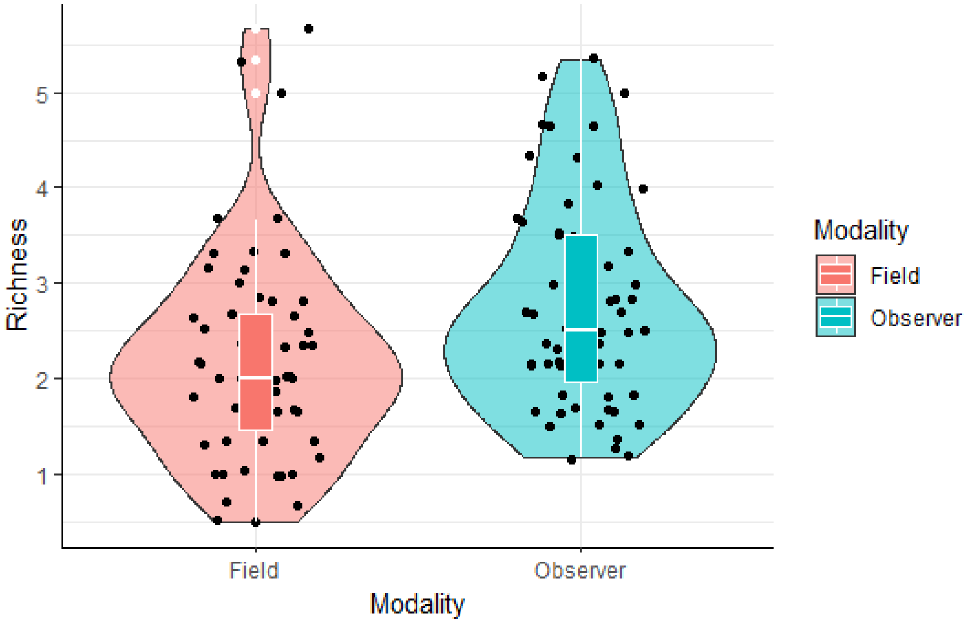

Figure 3.10. Violin plot showing differences for average number of descriptive details retrieved for each event, between video modalities. Richness of retrieved content was higher for observer videos, compared to field ones.

Memory Errors. A repeated measures ANOVA was run to compare the number of memory errors recalled between modalities (“Field” Vs “Observer”). A significant difference was found, F(1,59) = 5.47, *p* = .023, ηp2 = .085, with participants making a higher number of errors when retrieving details for “Observer” videos (*M* = .41, *SD* = .33), compared to “Field” (*M* = .28, *SD* = .30).

Relationship Between Subjective Measures and Free Recall

Similarly, to Chapter 2, a multiple linear regression was run to investigate the relationship between subjective measures during encoding, as predictors: Familiarity and presence on overall retrieval accuracy. The overall model was not statistically significant $R^2 = .001$, F(2,57) = .041, *p* = .960. The same was conducted by assessing the relationship between subjective measures at retrieval (confidence and vividness) and memory accuracy. The overall model was again not statistically significant $R^2 = .034$, F(2,57) = .996, *p* = .376, with neither confidence nor vividness scores being significant predictors of memory accuracy. These results demonstrate no significant relationship between subjective measures and memory performance.

Perspective Judgements post-task

Following the retrieval phase, participants were asked to watch each video again and state whether they thought each video was filmed from a ‘Field’ or ‘Observer’ perspective. This was conducted as a quality check to ascertain participants’ accuracy in correctly recognising each video’s perspective. Accuracy scores for perspective judgements were analysed, revealing no significant difference between “Field” (*M* = .91, *SD* = .03) and “Observer” (*M* = .92, *SD* = .04) videos, F(1,5) = 2.36, *p* = .19. Both video modalities were, on average, correctly recognised over 90% of instances.

3.4.3 Discussion

The main purpose of this study was to assess differences in memory retrieval for real world events, when encoded from either a field or observer perspective. Subjective measures for encoding and memory retrieval were first assessed. The control measure of familiarity showed no significant differences between video modalities, suggesting that differences seen for the phenomenology of memory retrieval would not be a result of prior experience with the event being shown. In line with our predictions, a significant difference was found for presence scores between field and observer videos. These findings support existing research suggesting that field VR environments are associated with a higher sense of presence, compared to observer perspective environments (Iriye & St Jacques, 2021). These findings would suggest sense of presence ratings can be used as a measure for dynamic stimuli, such as videos, and not solely for VR experimental designs, and that perspective does seem to be associated with presence scores.

Contrary to our predictions, no significant differences were found for subjective ratings at retrieval. Participants demonstrated no differences in reported vividness and confidence between field and observer videos. These results differ from studies assessing the effects of perspective shifting during retrieval where a reduction in vividness, as well as retrieval performance, have been shown (Butler et al., 2016; Verhaegen et al., 2018). Arguably, a reduction in reported vividness when shifting to an observer perspective could result from a loss of visual information and increased task difficulty in shifting away from the original field perspective (Butler et al., 2016). When shifting is not imposed at retrieval, such as is the case in the present study, these effects are not seen. This interpretation is further supported when looking at retrieval accuracy. Contrary to prior findings demonstrating a reduction in the number of details and accuracy when shifting to an observer perspective (Marcotti & St Jacques, 2018), the current findings revealed no differences in accuracy between field and observer videos. However, when looking at the type of memory being retrieved, participants were significantly better at freely recalling auditory details for observer videos, compared to field videos. Interestingly, previous research has argued that a stronger sense of presence during encoding may increase retrieval accuracy (Krokos et al., 2019; Makowski et al., 2017). This is not supported by the current study whereby differences in presence scores, with higher presence ratings for field, compared to observer videos were not reflected in differences for free recall accuracy between modalities. Results analysed from the free recall phase also shed light on the impact of perspective on recall accuracy and richness of memories (measured through the use of additional descriptive information). Inconsistently to what was originally predicted, more descriptive details were retrieved for observer videos, compared to field. Our initial predictions were to see higher presence scores, accuracy and by default higher number of descriptive details for field, compared to observer videos. Interestingly, presence was not a predictor of accuracy or richness, contradicting our hypothesis of the relationship between these two measures.

One possible explanation for the findings relating to greater richness for observer, compared to field videos can be ascertained by consulting early and seminal work in the field of perspective and memory. If we consider Nigro and Neissser's (1983) original conceptions of perspective and memory, supported by McIssac and Eich's study (2004, for a review of both, see Rice, 2010), a field perspective was consistently related to higher emotional valence, and greater description of feeling states, whereas Observer view memories were associated with more description of concrete details (i.e., appearance and actions). This view could help explain the current results, suggesting that though accuracy did not differ between conditions, the type of additional descriptive details participants retrieved for either perspective varied. Due to the nature of the current stimulus set and criteria used to calculate richness, it could be argued that the measure would favour the retrieval of more concrete details, rather than emotional, psychological ones. To clarify, as participants did not experience the events first-hand, it could be argued the emotional, physical and psychological valence related to such events is limited. In addition, richness was scored by counting the number of additional, visually descriptive details of items already scored as ‘hits’, such as colours of objects, additional actions of actors and so forth. Arguably, the type of details being scored for the measure of richness resemble much more closely the type of ‘concrete details’ observed by Nigro and Neisser (1983) and McIsaac and Eich (2004) during observer recall, than those associated with a field perspective. Future studies should incorporate measures of emotional intensity to investigate this dichotomy further.

Though observer memories were associated with more descriptive and rich retrieval of events, they also yielded a greater number of errors. These errors included additional descriptive details, not associated with the event or items that were not present in the videos. Differences in word count between modalities did not significantly differ between field or observer videos, suggesting the combination of greater richness, as well as memory errors for observer, compared to field videos cannot simply be due to a higher overall number of descriptive information and verbal word count. Heaps and Nash (2001) found that false childhood memories were more likely to be recalled from an observer perspective. It has been suggested that as false memories rely more heavily on semantic knowledge, plausible to the context being retrieved, individuals would be more likely to construct observer perspective false memories (Rice, 2010). Similarly, memory errors seen in the free recall of this task were generally semantically related to the environment shown in the video, such as incorrect description of items, objects or actions that would be plausible to the video context (i.e., recalling cars parked in what was actually an empty car park, or yellow taxi in a NY scene). Linking findings from richness and memory errors measures, the reliance on more concrete details for observer retrieval, compared to field, could result not only in an increase of descriptive details but semantically related memory errors to such details as well. In other words, the propensity individuals demonstrate in retrieving details relating to the appearance and actions of events for observer memories could arguably also increase the likelihood of retrieving semantically related but incorrect details of the same type.

Finally, the perspective judgement task, (post retrieval phase), shows high accuracy in correctly recognising the video's intended perspective. This not only adds to the validation of this new stimulus set but also adds credibility to current findings, suggesting that differences in memory encoding and retrieval are in fact a result of perspective manipulation, clearly recognised by participants.

3.5 Chapter Discussion

This chapter aimed to collate and create a new stimulus set that could be used for the investigation of perspective manipulation at encoding and its effects on subsequent retrieval. As discussed previously, to our knowledge, this manipulation has only been investigated in three studies, two of which used VR environments (Bergouignan et al., 2014; Iriye & St Jacques, 2021; Leynes et al., 2017). The first two studies discussed in this chapter covered quality checks conducted, as well as the process used for the selection of videos for future analysis. These revealed no floor and ceiling effects for recognition accuracy of items retrieved from the videos and indicated the importance of controlling for dynamic movement of stimuli, in line with findings relating to the "dynamic superiority effect" (Goldstein et al., 1982). Results did demonstrate a preference and higher accuracy for observer moving, compared to static videos. As a result, stimuli for the third and final experiment of the chapter were selected based on similar perspective judgement accuracy, while ensuring all videos were similar in dynamic style (moving observer and moving field videos).

Experiment 5 demonstrated no significant difference in familiarity judgements between the two modalities (Field vs. observer), and a significant difference in presence scores, in line with existing predictions. However, no significant difference was found between modalities for confidence and vividness judgements. Accuracy scores did not differ between video types, but observer videos did seem to yield more accurate recollection of auditory details, compared to field videos. Finally, a significant difference was found for richness scores, demonstrating a higher number of additional descriptive details being reported for observer, compared to field videos.

This area of research is still relatively unexplored, with existing research providing contradictory results (Bergouignan et al., 2014; Iriye & St Jacques, 2021). The current results would support Iriye and St Jacques' (2021) findings, demonstrating a higher sense of presence and immersiveness in VR environments for field, compared to observer settings, but no differences in accuracy scores between the two modalities. The current results would suggest that higher vividness and accuracy scores for field, compared to observer perspectives seen when shifting perspective at retrieval (Ahktar et al., 2017; Butler et al., 2016; Marcotti & St Jacques, 2018), are not supported by a manipulation of perspective at encoding. This could be explained due to the task difficulty of shifting perspective and subsequent permanent loss of visual information, as suggested previously (Butler et al., 2016). Finally, as suggested in the discussion for Experiment 5, higher richness scores for observer, compared to field videos, may be a result of the type of information that pertains more closely to each perspective, namely more concrete details for observer retrieval and greater retrieval of feeling states and emotions for field memories (Nigro & Neisser, 1983). Future studies should consider these differences when formulating experimental designs to ensure participants are also asked to report details relating to emotional states to assess these differences further. A further, interesting future direction would be to investigate differences in types of sensory information being recalled. The current results provide new evidence suggesting that recollection of auditory details is better for observer, compared to field videos. One possible avenue that could relate to these findings is the differentiation between retrieval for central and peripheral details (Talarico et al., 2009). Perhaps future studies should further assess the retrieval accuracy of peripheral details using this new stimulus set and its relation to the type of sensory information being retrieved.

In conclusion, the experiments discussed in this chapter provide a greater understanding of the effects of perspective manipulation at encoding on subjective and objective aspects of memory retrieval. Most of the existing literature has focused on the effects of shifting perspective at retrieval, with few studies assessing the effects of perspective manipulation at encoding. Results discussed in this chapter add to this limited existing knowledge, showing how the effects commonly associated with a shift to an observer perspective are not observed when a memory is encoded from an observer perspective. Results showed higher presence scores for field videos, but no differences in confidence, vividness and accuracy scores between the two perspectives. Interestingly, the number of correct auditory details retrieved and total perceptual descriptive details reported were higher for observer, compared to field stimuli. So far, the studies outlined in this thesis have assessed behavioural components for the retrieval of rich and vivid real-world events. In the next chapter, we move on to discuss the neural correlates associated with the retrieval of rich and detailed memories.

Chapter 4 Angular Gyrus Function in Episodic Memory Retrieval: An Integrative Account

4.1 Anatomy of the Angular Gyrus

The angular gyrus is part of the ventral lateral parietal cortex. The ventral parietal cortex comprises at least 7 regions, based on distinct cytoarchitectonic characteristics and inter-regional connectivity: five in the rostral part, on the supramarginal gyrus (covering the region of Brodmann area 40), and two in the caudal part on the angular gyrus (covering the region of Brodmann area 39; Caspers et al., 2006; see also Caspers et al., 2013; Nelson et al., 2010; Wang et al., 2017). Within the angular gyrus are two cytoarchitectonic distinct regions, one rostral (PGa) and one caudal (PGp; Uddin et al., 2010; Jung et al., 2017). Area PGa and PGp border with the intraparietal sulcus (IPS) dorsally and with the occipital lobe, ventrally. Similar to other multimodal association regions, the AG is lightly myelinated, compared to primary sensory regions (Glasser & Essen, 2011). It is believed that lightly myelinated regions have greater synaptic plasticity, compared to heavily myelinated areas (Glasser et al., 2014). The latter seems to be more suited for speed of sensory and motor processing, with lightly myelinated circuits serving more complex and higher-order cognitive functions (Kwon et al., 2020). Positioned at the junction between the occipital and temporal lobes (Seghier, 2013), AG has little or no input from primary sensory regions but is connected to other association regions. The connectivity of the AG thus makes it an ideal candidate for the integration of multimodal information (Simons et al., 2022), suggesting it may act as a convergence zone (Hagmann et al., 2008; Tomasi & Volkow, 2011; Seghier, 2013). Diffusion tensor imaging studies have demonstrated a rich anatomical connectivity pattern linking the AG with lateral temporo-frontal subsystems and medial regions (hippocampus, caudate and precuneus; Makris et al., 2007; Seghier, 2013; Uddin et al., 2010). The connectivity between the AG and sensory association areas has been used to explain the possible involvement of the AG in multimodal feature integration (Bonnici et al., 2016), while connectivity with precuneus is consistent with a contribution of AG to recalling events within an egocentric/first-person perspective framework during subjective remembering (Bonnici et al., 2018). Other studies have found greater involvement of the AG when adopting a novel observer perspective (Faul et al., 2020; Iriye & St Jacques, 2020; St Jacques et al., 2017), suggesting a role in reconstructing memories from a novel viewpoint, rather than solely being involved in egocentric/first-person perspective retrieval.

4.2 Episodic Memory

In the last twenty years, a consensus has developed that the lateral parietal cortex has a role in episodic memory (Rugg & Henson, 2002; Wagner et al., 2015). Episodic memory refers to the ability to recollect personally experienced events situated within a unique spatial and temporal context (e.g., I remember sitting in my office last autumn, staring at the screen, trying to start writing this chapter; Tulving, 2002). Recollection can support both recall and recognition memory. Successful recognition of a stimulus event, however, can also be supported by an assessment of its familiarity (Yonelinas, 2002), in the absence of memory for the circumstance in which the event was initially experienced. Debate exists on whether recollection is best modelled as a threshold (with contextual information being either retrieved or not) or as a continuous signal (Micke et al., 2009; Parks & Yonelinas, 2009; Norman, 2010; Yonelinas, 1994), while familiarity is widely assumed to be a continuous process (familiarity is "experienced in degrees"; Mickes et al., 2009). As discussed in Chapter 1, episodic memory is measured with both objective and subjective measures, such as using source memory retrieval judgements, R/K procedures and using subjective measures, such as vividness and confidence ratings. Evidence suggests subjective and objective measures are often correlated, such as high vividness ratings during study predicting subsequent recall (D'Angiulli et al., 2013; Alghamdi & Rugg, 2020), and successful source retrieval, being associated with high confidence judgments (Yonelinas, 1994, 2001).

4.3 Episodic Memory and The Parietal Cortex

Early findings on the possible involvement of the parietal cortex in recollection came from event-related potential (ERP) studies (for reviews, see Rugg and Curran, 2007; Wilding & Ranganath, 2012). Notably, an ERP component with a maximum amplitude over the left parietal scalp has consistently been associated with recollection processes. Its amplitude was shown to vary with the amount of information recollected (Horne et al., 2020; Vilberg et al., 2006; Wilding, 2000), the success of source monitoring judgments (Senkfor & Van Petten, 1998; Wilding & Rugg, 1996) and the subjective experience associated with retrieval (larger amplitudes for "Remember" than for "Know" judgements; Curran, 2004; Duzel et al., 1997; Smith, 1993). Analogous results were reported in fMRI studies, with greater BOLD response of the posterior parietal cortex (PPC), including the AG, for hits (accurate endorsement of old items as previously studied) relative to correct rejections (accurate rejection of new items as not previously studied; Konishi et al., 2000; Wagner et al., 2015). In addition to 'old/new effects', studies have also explored PPC BOLD responses in relation to recollection versus familiarity, as operationalized through the R/K procedure. Using this experimental procedure greater AG activity was found for 'remember' compared to 'know' responses (Eldridge et al., 2000; Kim, 2010). Similarly, greater AG activity was observed for accurate than inaccurate source memory judgements (Thakral et al., 2022). The above-mentioned retrieval activity led to the postulation of the PPC, and more specifically the AG, being strongly linked to recollection.

Patients with parietal lobe lesions have demonstrated intact ‘objective’ memory judgments in tasks such as cued recall, source memory and associative memory (Berryhill et al., 2009; Davidson et al., 2008; Simons et al., 2010). Rather, impairments were restricted to seemingly ‘subjective’ aspects of recollection, such as reduced confidence and vividness, both observed in patients with parietal lobe lesions (Ciaramelli et al., 2017; Hower et al., 2014; Simons et al., 2010). Patients were also reported to produce a reduced number of details compared to controls during free recall of autobiographical memories (Berryhill et al., 2007; Berryhill, 2012). As we discuss in more detail below (see *Subjective Experience of remembering account*), it is important to note that almost all lesion studies have looked at unilateral lesions, which might account for their relatively mild effects. It is also unclear whether some of these effects of chronic lesions also reflect encoding deficits and how much results are influenced by post-lesion recovery and reorganization. Finally, it is important to question and unpick the extent to which the nature of the task allows us to effectively measure ‘objective’ memory impairment. It could be questioned whether cued recall tests or source memory judgements are sufficiently challenging and/or sophisticated to give us an understanding about the level of ‘objective’ memory impairment in patient populations.

As a result of these findings, several theories have been proposed to explain the AG’s involvement in episodic memory. As subdivided by Davis et al., (2018), theories discussing the role of the AG in declarative memory can be split into two groups, ‘attentional/experiential’ and ‘representational’ hypotheses. Attentional or experiential theories suggest the AG indirectly interacts with memory, for instance through the involvement of attentional processes or subjective aspects of memory recollection (i.e., confidence and vividness). The attention to memory model

(AtoM) argues that the AG is responsible for bottom-up attentional processing, which captures contextual or internal retrieval cues during memory recollection (Cabeza, 2008). The subjective experience of remembering account (Simons et al., 2010; 2022) argues that the AG contributes to 'subjective' aspects of memory recollection, such as confidence and vividness judgements

'Representational' theories focus on the direct holding, integrating or accessing of mnemonic representations (Davis et al., 2018). These include the episodic buffer hypothesis, proposing a temporary storage for multimodal details (Vilberg & Rugg, 2008; Vilberg & Rugg, 2012) and the cortical binding of relational activity theory (CoBRA) in which the AG acts as a convergence zone, binding together information represented in distributed cortical regions (Shimamura, 2011). It is acknowledged that the AG has been associated with a multitude of cognitive functions and may even be considered a domain-general region (Humphreys et al., 2021). However, for the purpose of this review, the focus is on its involvement in episodic memory retrieval.

4.4 Attentional and Experiential Hypotheses

As mentioned above, attentional or experiential theories propose the AG indirectly interacts with memory. Whether by reflecting metacognitive processes associated with memory retrieval, such as subjective experience, typically measured through recollection confidence and vividness processing; or by re-directing attention towards internal memories, as discussed in the AtoM model.

Subjective Experience of Remembering Account. A key theoretical account proposed to explain the role of the AG in recollection is the subjective experience of remembering account (Yazar et al., 2012). Subjective aspects of episodic recollection studied in relation to the AG have included vividness (Tibon et al., 2019), confidence, and 'remember' responses elicited with the R/K procedure (Berryhill et al., 2009; Simons et al., 2010 & Ciaramelli et al., 2017; Davidson et al., 2008). As mentioned above, lesion studies have reported intact source memory and cued memory recognition but lower reported confidence scores in patients (Berryhill et al., 2009; Simons et al., 2010). Patients also provided fewer 'remember' responses compared to controls, suggesting that parietal damage is associated with reduced subjective remembering (Ciaramelli et al., 2017; Davidson et al., 2008).

Given these findings, one would predict the AG's role lies in the remembering of more subjective aspects of recollection, such as those also associated with successful retrieval, i.e., vividness and confidence. However, there seems to be some inconsistency on this point. Ben-Zvi et al., (2015) investigated the effects of bilateral VPC lesion effects on cued memory recall for three different experiments assessing memory for word pairs, picture-sound pairs and picture pairs. Patients' memory recognition was impaired in all three experiments, compared to the controls. One key difference between Ben-Zvi et al., (2015) and other mentioned lesion studies is the time window of the conducted study from onset, with the longest window being 16 weeks post-stroke in the Ben-Zvi sample, as opposed to years after the time of brain damage in the other studies. This is an important facet to keep in mind since impairments could be ameliorated following compensatory plasticity (Haramati et al., 2008; Schoo et al., 2011). Nonetheless, the extensive area of damage often found in patients partaking in these lesion studies (in some cases extending to the occipital lobe, ventrolateral prefrontal cortex; Ciaramelli et al., 2017) makes it difficult to determine specific parietal areas responsible for the reported observed impairments (Rugg & King, 2018). It is also challenging to establish whether memory impairments should indeed be attributed to difficulties during retrieval or whether they might in fact be related to impairments during encoding (Rugg & King, 2018).

As briefly introduced earlier in this review, we also need to consider whether we are using the best measures to identify ‘objective’ memory impairments following parietal lesions. Studies have started to investigate the role of the AG in precision memory tasks. Korkki et al., (2022) investigated age-related precision and retrieval success deficits. The precision task consisted of recreating either the location or colour of studied objects using a 360^o response dial. Age-related reduction in AG activity was found for memory precision but not successful retrieval (hit rate). A significant association was also found between AG grey matter volume and memory precision but not between AG grey matter volume and probability of retrieval success. Taking inspiration from these methodological approaches and findings, it would be recommended to use precision tasks to measure ‘objective’ memory impairments following parietal lesions. These could help establish the involvement of the AG for subjective compared to objective memory recall and help answer the question of whether any distinction between these measures is a result of different cognitive processes or whether it is dependent on the difficulty of the task.

To overcome some of these limitations, studies have assessed memory recollection following transcranial magnetic stimulation (TMS). Complementing results from lesion studies, Bonnici et al., (2018) assessed autobiographical and word-pair cued memory retrieval following stimulation to the AG. As per standard protocol, the vertex was stimulated as the control region, with one week between two stimulations. While cued memory remained intact, free recall of autobiographical memories contained significantly fewer details following AG stimulation, compared to the vertex. Specifically, participants reported fewer internal (specific details about the event in question) compared to external details (such as semantic details about the event being remembered) and were significantly less likely to experience the event from a first-person perspective. The ability to retrieve context features of scenes in a source memory task has also been shown to be impaired following AG stimulation, compared to vertex (Yazar et al., 2017). Participants were shown a scene with an object (for which location was manipulated – left right, top under another object) and the name of the object was presented auditorily (English accent or Scottish accent). Source memory conditions were split into three modalities: single source (object to left or right of screen?), within-modal source (left/right/top/under), and a cross-modal judgement (English/Scotting/Top/Under). Impairment was seen only for cross-modal items, with no difference being observed for items of the same sensory modality (Yazar et al., 2017). Also consistent with lesion study results and supporting the AG involvement in subjective aspects of memory recall, Yazar et al., (2014) found intact source memory recollection but reduced confidence ratings following AG stimulation. However, with a growing body of literature highlighting the limitations of TMS experiments, these should also be considered carefully (Thapa et al., 2021; Ozdemir et al., 2021). Some of the key criticisms and concerns have included intra and inter-variability across participants and poor reproducibility across sessions (Ozdemir et al., 2021).

Some neuroimaging studies also lend support to the idea that the activity of the AG is sensitive to subjective experience. For instance, Tibon et al. (2019) and Kuhl & Chun (2014) observed that activity in the AG was proportional to reported vividness elicited during recall. Several studies also reported greater activity in AG for high than low confidence source judgements (Yu et al., 2012; Leiker & Johnson, 2015; Thakral et al., 2015). In an experiment combining a source and a R/K judgement, Thakral et al., (2022) reported that test items associated with R judgements elicited greater activity than those associated with K responses, regardless of the accuracy of the source memory judgement. However, other studies using MVPA reported that retrieved content in the AG could be decoded as well based on R versus K responses (Thakral et al., 2017), based on high versus low vividness ratings (Kuhl & Chun, 2014). Therefore, not in concordance with univariate findings, multi-voxel pattern analysis (MVPA) classifiers have not been able to decode between recollection and familiarity in the AG, contradicting a distinction between 'objective' and 'subjective' recollection in the AG. MVPA findings are thus more consistent with the view that recollection is a continuum, rather than a threshold. With this view, some form of recollection is still taking place during K and familiarity judgements, but the continuous memory strength contains increasing amounts of source information as memory strength increases, which would be greater for a R rather than K judgement (Wixted & Mickes, 2010). This would not be possible if no recollection was taking place. Therefore, if we are looking at recollection as a continuum, we are not asking whether or not content is recalled but rather, how much content are we recalling in order to reach a subjective notion of 'recollection' (Mickes et al., 2009; Yu et al., 2012). Perhaps, once again, existing paradigms lack sensitivity in making such distinctions.

Attention to memory model. According to the Attention to Memory (AtoM) model (Cabeza, 2008), the dorsal parietal cortex (DPC, including the intraparietal sulcus, superior parietal lobule and precuneus) is thought to be associated with top-down attention, while the VPC (including the supramarginal gyrus and AG) would be involved with bottom-up attention. Contrastingly to other theories of bottom-up attention, where attention is directed to low-level, external stimuli, Cabeza (2008) extends this definition to also encompass internal stimuli, in this case, memories and memory cues (Cabeza, 2008; Cabeza et al., 2008; Ciaramelli et al., 2008). The VPC is thought to detect these stimuli temporarily and not hold or accumulate the information. To investigate this theory, Cabeza et al., (2011) conducted an event-related fMRI study using memory and perception tasks, where participants were asked to search their memory for a string of words previously studied when shown the first word of the chain and press a key when they detected the last word of the chain, measuring top-down and bottom-up attention, respectively. Findings demonstrated detection-related activity in the VPC but more specifically, detection-related activity for the memory task was found in the AG, providing support for their hypothesis, and suggesting a clearer, more specific role of the AG within the AtoM model.

This theory has been used to help explain differences in activation between the VPC and DPC during high vs low confidence recognition and recollection vs familiarity, respectively (Kim & Cabeza, 2007; Wheeler & Buckner, 2004). High confidence has been linked with bottom-up attentional process as it is assumed to occur when lots of information is being retrieved, specific to a memory. Low confidence would occur during poorer retrieval of information and would in theory require a more effortful, goal directed memory search, therefore more likely to involve top-down attentional processes, activating the DPC. The same understanding can be associated with recollection vs familiarity paradigms, with greater activation in the VPC demonstrated during recollection and greater DPC activation for familiarity.

However, this theory has not gone unchallenged. As mentioned above, the AtoM model argues against the role of the VPC in holding and maintaining memory cues. If relevant to the role of the AG, we would expect not to find sustained activity for the duration of the retrieved content, which would instead support a more representational role for the AG. Vilberg and Rugg (2012,

2014) conducted an experiment using word-picture pairs, in which studied or unstudied words/pictures were presented and followed by a delay period during which the paired word/picture had to be held in the participants' minds before answering to a response cue. Interestingly, activity in the AG tracked this delay period, suggesting a more representational role of the AG, rather than a re-directing of attention to memory cues (Rugg & King, 2018).

4.5 Representational accounts

A parallel set of hypotheses explain the role of the AG, and more broadly the VPC as representational in nature. These include the proposition that the VPC would act as an ‘episodic buffer’, integrating information from multi-dimensional codes and bridging episodic memory and executive systems (Baddeley, 2000; Vilberg & Rugg, 2008); that the AG would act as an online dynamic buffer, integrating multisensory and spatiotemporal information of events (Humphreys et al., 2021); or as argued by the ‘cortical binding of relational activation (CoBRA), that it would act as a convergence zone, integrating sensory information distributed within the perceptual cortex (Shimamura, 2011). According to Damasio (1989), convergence zones are a way to bind cortically disparate features to help provide a more holistic representation of the world. Binder and Desai (2011) expanded on this theory suggesting that the AG is one such convergence zone, storing and representing event concepts (e.g., birthday party). Given the anatomical findings discussed earlier in this paper, the connectivity and location of the AG make it an ideal candidate for a cross-modal integrative hub, acting as an interface between perception and recognition and converging multisensory information (Seghier, 2013).

Buffer hypotheses. First introduced by Baddeley (2000), the episodic buffer is a temporary storage system, limited in capacity, that acts as an interface between episodic memory and executive functions. Due to the complexity and importance of this system, it is not believed to have a single anatomical location (Baddeley, 2000). Vilberg and Rugg (2008) pointed to the inferior parietal cortex as one such region. It was suggested that this acts as an online temporary storage, connecting with nearby cortices to collate episodic, multimodal features (Baddeley, 2000; Vilberg & Rugg, 2008). This theory helps explain fMRI and ERP findings linking the AG with recollective, rather than familiarity processes (Vilberg & Rugg, 2008). Recollection processes would arguably entail greater retrieval of qualitative content, compared to familiarity processes (Cabeza et al., 2008). Therefore, greater recollection-related rather than familiarity related activation would make the AG an apt candidate for an episodic buffer, integrating and representing multi-modal online information. Findings from neuroimaging studies reporting that the AG is sensitive to the amount of recollected information (Villberg & Rugg, 2007; 2009ab; Hutchinson et al., 2014; see also Rissman et al., 2016; Richter et al., 2016) and to the accuracy of source judgements (Yu et al., 20212; Leiker & Johnson, 2015; Thakral et al., 2015) are compatible with this perspective. Similarly, studies using MVPA of fMRI data also consistently reported that remembered content (e.g., associate judgements: to which item was a stimulus paired with, Kuhl et al., 2013; Kuhl & Chun, 2014) could be successfully decoded from the AG.

As we discussed, recollection-related activity in the AG has also been found to be maintained across a delay period, providing support to the notion that the AG could act as an episodic buffer, providing an online representation of recollected information (Vilberg & Rugg, 2012; 2014). However, the consistent involvement of the AG in semantic cognition (Binder et al., 2009; Binder & Desai, 2011; Fernandino et al., 2016; 2022; Kuhne et al., 2022) has led to the alternate proposal that recollection effects in the core recollection network may reflect reinstatement of conceptual processing (Renoult et al., 2019; Rugg & King, 2018; Rugg, 2022).

More recently, variations of the buffer hypothesis have been proposed in the literature, such as the contextual integration hypotheses (Ramanan et al., 2018) according to which multi-modal representations would be maintained and integrated in the AG, or the dynamic buffer hypothesis according to which the AG would enable a temporary (online) multimodal buffering of internal and external information, sensitive to the spatiotemporal structure of an event (Humphreys et al., 2021; Humphreys & Tibon, 2023). The latter hypothesis was developed as an attempt to help explain the involvement of the AG in a wide array of cognitive functions, and in particular as an effort to combine research from both a semantic and episodic memory perspective.

The AG as a multi-modal convergence zone. An early example of a model proposing an integrative and multimodal role of AG was CoBRA. According to the CoBRA model, medial temporal lobe (MTL) regions form associations at encoding, but through consolidation the vPPC, specifically AG, would allow reactivating, or “re-collecting,” the ensemble of relevant episodic details (Shimamura, 2011). Shimamura (2011) argues that though this theory proposes a similar role for the vPPC to that attributed to the MTL, the vPPC plays a more critical role in the retrieval of more remote memories, by establishing links within the neocortex. The AG is seen as a convergence zone which binds episodic details distributed within the perceptual neocortex. This process occurs following encoding and develops with the passing of time (Shimamura, 2011). As discussed earlier, the anatomical location of the AG and its connection to neocortical regions (Seghier, 2013) makes it an ideal candidate for the binding of multimodal episodic features. A key aspect of the CoBRA account is the importance of the parietal cortex in the retrieval of multimodal features. CoBRA predicts that there should be greater vPPC activity when memories contain greater multi-modal details because their retrieval requires more cross-cortical links of feature information. This is supported by evidence showing impairment in cross-modal pairing tasks following AnG damage (Tibon & Levy, 2014), greater AG activity for multimodal memory recollection compared to unimodal items (Bonnici et al., 2016) and significant reduction in source accuracy for multimodal stimuli following AG TMS stimulation, compared to vertex stimulation (Yazar et al., 2017). Also consistent with the sensitivity of the AG to the number of multi-sensory features, an fMRI study investigating the neural correlates of semantic richness reported that both familiar and newly learned words with many semantic features (rich meaning) evoked increased activity in the left angular gyrus than words associated with less semantic features (Ferreira et al., 2015). Other studies have reported increased AG activity for concrete/high imageability as compared to abstract/low imageability words (Graves et al., 2010; Binder et al., 2005; Sabsevitz et al., 2005).

4.6 Discussion

In summary, although conceptually distinct, these attentional/relational and representational theories are not easily dissociable. For instance, the integrating (multi-modal convergence hypotheses) or maintaining (buffer hypotheses) of multimodal features would theoretically enable the rich and vivid re-experiencing of events reported in studies addressing the subjectivity account. Both sides of the debate can be explained by associating the AG's involvement in episodic memory with retrieval success. It could be argued that the more multimodal, complex and rich a memory is, the more highly it will rate on scales of vividness and confidence, and the more likely it will result in remember responses.

It is important to note that objective and subjective measures of recollection are highly correlated (Alghamdi & Rugg, 2020). Moreover, the precision of stimulus representation content, such as sensory representations in the visual cortex, has been linked to subjective judgements, like confidence (i.e., when sensory evidence was more precise, participants were more confident in their responses; Geurts et al., 2022). It has also been shown that high confidence in a response often indicates high accuracy (Roediger & Tekin, 2020). Findings from the role of the AG in episodic memory retrieval have suggested that AG activity does not relate only to subjective recollection but mirrors the quality and richness of the retrieved event and its contextual details (Rugg & King, 2018; Yu et al., 2012). However, we believe that memory accuracy (or retrieval success) does not provide a holistic picture of this region's role in episodic memory recollection, as shown by evidence demonstrating a lack of AG activation despite normal recollection performance (Hou et al., 2022)

We propose that the role of the AG is closely related to the richness of the recollected memory. Here, richness refers to the amount of detail and the corresponding subjective experience of vividness. After reviewing the above discussed evidence and theories, we argue that the initial involvement of the AG would be dependent on reaching a level of awareness, synonymous with the allocation of attention to that memory (in line with the AtoM model, Cabeza, 2008). However, awareness alone would not be sufficient to explain the activation of the AG, with evidence demonstrating its sensitivity to the content being retrieved. The level of activation that follows would be dependent on the amount of content, or richness being retrieved. This proposal would encompass findings of increased activation for ‘remember’ responses, but also findings from MVPA that memory content can be decoded from the AG (and elsewhere) as accurately for K as for R trials, despite differences in mean BOLD signal between R and K. It could also help explain findings demonstrating AG activity associated with rich semantic retrieval, as involvement of the AG should reflect memory richness and content, irrespective of the type of memory information being retrieved (episodic Vs semantic). The association between AG and subjective measures of retrieval could be representing the association between subjective and objective measures of memory, with higher vividness and confidence scores often being correlated with better retrieval. Increased activation for multisensory, compared to unisensory retrieval, could be a by-product of the overall increase in information being recalled, once again supporting the belief that the AG specialises in the richness of a recollected memory. We would argue that the richer a memory, the greater the amount of information being combined and recollected, and the higher the subsequent confidence and vividness reported.

Future studies could help clarify whether AG involvement in retrieval is selective to subjective aspects of recollection, or whether these effects are a by-product of the relationship between richness/memory content. As discussed above, there seems to be a close link between subjective and objective measures. One suggestion for future research on the functional role of the angular gyrus would be to increase sensitivity of objective memory tasks (i.e., by using precision tasks). As discussed in the main text of this review, TMS and lesion studies have shown impaired subjective but not objective retrieval (Berryhill et al., 2009; Ciaramelli et al., 2017; Davidson et al., 2008; Hower et al., 2014; Simons et al., 2010). It could be argued that subjective recollection would require higher and more complex cognitive processing and greater amount of information being recalled, making subjective measures more challenging and sophisticated than perhaps a source memory or cued recall test. This potential disparity in task difficulty leads us to question to what extent the nature of the task allows us to effectively measure ‘objective’ memory impairment.

Following ideas from the dynamic buffer hypothesis (Humphreys et al., 2021; Humphreys & Tibon, 2023), there is also scope to further investigate differences and/or similarities in AG activity between episodic and semantic memory. Finally, little research has investigated disparities in the role of AG subregions Pga and Pgp on memory retrieval. Often discussed under the umbrella of the parietal cortex, few studies have gone even further in trying to dissociate and investigate the role of AG subregions (PGa and PGp) individually.

Chapter 5 - The role of the Angular Gyrus in the Elaboration of Specific and Categoric Memories

5.1 Introduction

Autobiographical memory (AM) allows us to remember past events from our lives and encompasses a wide array of processes, such as retrieval of episodic and semantic information, self-reflection, emotion, visual imagery and executive processes (Svoboda et al., 2006; Cabeza & St Jacques 2007; St Jacques, 2012). Our AMs can be distinguished between memories of specific events, such as the first time I climbed a route outdoors, and categoric (or repeated) events, such as going hiking in the Alps every summer as a child. The neuroimaging literature on retrieval of specific (episodic) AM memories has generally reported a very similar network of brain regions as that activated in laboratory studies of episodic memory (Rugg & Villberg, 2013) and to the default mode network (Addis, 2018; Irish & Vatansever, 2020), namely the medial prefrontal cortex, medial temporal lobes (including hippocampus and parahippocampal gyrus), posterior cingulate/retrosplenial cortex, precuneus, and ventral parietal cortex (including the angular gyrus, AG; Cabeza & St Jacques, 2007; Moscovitch et al., 2016; Svoboda et al., 2006; St Jacques, 2012).

A few neuroimaging studies have compared retrieval of specific and categoric events, operationalized as memories of unique versus repeated events, and have reported that memories of specific events were associated with greater activity in the medial prefrontal cortex, parahippocampal gyrus, posterior cingulate and precuneus (Ford et al., 2011; Holland et al., 2011; Levine et al., 2004). Addis et al., (2004) observed that specific AMs were associated with greater activation of the right and left precuneus and posterior cingulate region, while activity for categoric AMs was more highly associated with left parahippocampal and fusiform gyri. In contrast, they found no differences in activation between specific and categoric AMs in the hippocampus. However, when assessing recollective qualities of memories, the amount of detail reported by participants positively correlated with activity in the left hippocampus for specific memories and with activity in the right hippocampus for general AMs (Addis et al, 2004).

Other brain regions of the core recollection network (or AM retrieval network as described in Cabeza & St Jacques, 2007), namely the precuneus and AG, have been related to the phenomenological experience reported by participants during recall. The amount of reinstatement (strength of correlation between encoding and retrieval) in the posterior cingulate cortex (including the precuneus) was correlated with the number of details of the videos that participants could remember one week later (Bird et al., 2015). Functional neuroimaging data have shown an association between activity in the precuneus and vividness of visual imagery during memory retrieval (Fuentemilla et al., 2014; Gilboa et al., 2004; Richter et al., 2016). Lesion studies have also linked damage to the precuneus with impaired retrieval of perceptual details and visual imagery deficits (Ahmed et al., 2018; Gardini et al., 2011). As discussed in Chapter Four, studies of patients with parietal lobe lesions have reported that these patients tended to retrieve a reduced number of AM memory details, compared to controls (Berryhill et al., 2007; Berryhill, 2012). Consistent with these findings, administering TMS stimulation to the AG has been shown to reduce the number of AM details being retrieved (Bonnici et al., 2018).

Neuroimaging studies have linked the AG with the quality and richness of memories and their contextual details (Rugg & King, 2018; Yu et al., 2012). The association between the richness of AMs and the AG does not seem to be limited solely to episodic memory, with findings demonstrating increased activity in the left AG for words with high semantic richness, compared to those with poorer/less semantic features (Ferreira et al., 2015). The involvement of the AG in the retrieval of semantic memory (Binder et al., 2009; Binder & Desai, 2011; Fernandino et al., 2016; 2022; Kuhnke et al., 2023) can be related to the proposal that recollection effects in the core recollection network may reflect reinstatement of conceptual processing, or may be related to the amount of information being retrieved during both semantic and episodic tasks (Renoult et al., 2019; Rugg & King, 2018; Rugg, 2022). In an attempt to reconcile the functional role of the AG in semantic and episodic retrieval, the ‘dynamic buffer hypothesis’ (Humphreys et al., 2021) proposes that the AG would enable a temporary (online) multimodal buffering of internal and external information. This hypothesis considers the AG as a domain-general region, supporting its involvement in a wide array of cognitive functions. However, the role of the AG in semantic and episodic memory is based largely on indirect comparisons.

A further relatively underexplored issue is whether AG subregions have different roles in memory retrieval. As discussed in Chapter 4, the AG is subdivided into two cytoarchitectonic subregions, PGa and PGp (Caspers et al., 2006). Differences in structural and functional connectivity have been reported for these two regions. Uddin et al., (2010) showed greater connectivity of PGa with caudate, bilateral frontal poles, anterior/posterior cingulate gyrus, and of PGp with regions encompassing the default mode network (i.e., hippocampus, parahippocampal gyrus, precuneus, medial prefrontal cortex) and thus with regions of the core recollection network. These results were reflected in structural connectivity findings, demonstrating a greater density of fibres connecting PGp with the hippocampus and parahippocampal regions (Uddin et al., 2010). We would expect separate cytoarchitectonic structures to reflect functional differences (Fedorenko & Kanwisher, 2009; Kuhnke et al., 2023), and Uddin et al.,’s (2010) findings only add to this view. Nonetheless, few studies have assessed memory processes associated with PGa and PGp separately.

In a recent study, Bellana et al (2023) investigated the recollection of famous versus non-famous faces, using a remember/know (R/K) paradigm. Using a region of interest (ROI) based approach, seven subregions of the inferior parietal lobe, including PGa and PGp, were selected (Bellana et al., 2023). Retrieval-related activity in the left AG, specifically PGp, was sensitive to both successful recollection (correct old > new recollection, correct old/new recollection > non-recollected faces) and access to prior knowledge (famous > non-famous faces), providing support for a role of AG in both episodic and semantic retrieval. These findings, as well as the observation of greater activity for the retrieval of faces that were presented for longer during study, are compatible with accounts of the functional role of the AG as related to recollection success and recollection strength (Rugg & King, 2018). However, it should be noted that analyses for this study were mostly restricted to area PGp, therefore providing little insight into the role of PGa, as well as potential functional differences of these two subregions during memory retrieval.

In the domain of semantic memory, a recent study (Kuhnke et al., 2023), combined fMRI data from five studies on semantic processing and analysed the response profiles from PGa and PGp. They reported consistent modulation of AG by semantic processing, both for PGa and PGp (with possibly a greater role of left PGa to access fine-grained semantic information in some of the studies) and proposed that the AG would act as a "multimodal convergence zone" that would bind semantic features associated with the same concept. One issue with this study is the somewhat confusing distinction of PGa and PGp, here separated as ventral and dorsal areas of the AG and compared to Seghier (2013) who subdivided left AG into ventral (greater overlap with PGp) and dorsal (greater overlap with PGa) subregions based on data from four neuroimaging studies. The interchangeable naming of ventral and PGp or dorsal and PGa regions is also seen in other studies, where the distinction expands to ventral and dorsal areas of the parietal cortex (Humphreys et al., 2021). Further research is needed to expand our knowledge of the role of PGa and PGp, using more well established and easier to interpret cytoarchitectonic subdivisions (Caspers et al., 2006) of these areas, as seen in the Bellana et al., (2023) study. Here, PGa and PGp areas were selected using the Juelich Histological Atlas, as part of FSL.

To clarify the role of the AG in episodic and semantic retrieval, and its sensitivity to the richness of information being retrieved, in the present study we compared the retrieval of specific versus categoric AMs in a cue word paradigm similar to the Autobiographical Memory Test (AMT; Williams & Broadbent, 2000). Participants first received a probe indicating whether they would have to think about a specific or categoric memory in the next trial. They were then asked to press a key when they had a memory in mind and to then elaborate ("Continue thinking about the details of the memory") on the event. The key press allowed us to separate memory search and elaboration phases for each trial. A control task was used to compare with the memory conditions, requiring attention to external rather than internal processes, where participants had to observe a series of letters and press a button when a letter change was detected. To test the hypothesis that the AG is sensitive to the richness of the content that is being retrieved, we asked our participants to rate the amount of details that they retrieved in each trial. The self-reported measure of details was used as a parametric regressor to investigate BOLD activity during the elaboration phase. Taking inspiration from Bellana et al., (2023), the Juelich Histological Atlas (in the tool FSLeyes) was used to select PGa and PGp regions separately.

To investigate the sensitivity of the AG to the richness of retrieved content, we focused these analyses on the elaboration phase. Studies have shown that effects associated with vividness occur during the elaboration phase, rather than the search (or construction) phase (Daselaar et al., 2008; St. Jacques et al., 2011; 2012), hence our focus on the elaboration phase in this study. We also wanted to assess AG activity for specific and categoric memories, adding to the limited research assessing episodic and semantic memory retrieval within the same study paradigm, as well as assessing potential differences between PGa and PGp regions. Based on recent evidence and theoretical proposals, we predicted that AG activity would be higher for both types of memory as compared to the control task, and we expected a positive relationship between activity in the left AG (specifically PGp) and number of details retrieved. Finally, for completeness and in line with the extensive evidence reviewed above demonstrating key involvement of both the hippocampus and precuneus in the retrieval of AMs, we also included these two brain areas within our mask-based approach.

5.2 Methods

This project was funded by grant MR/S011463/1 from the Medical Research Council (MRC): "The neural correlates of personal semantic memory across the life course. Data was collected by the 'Memory and Ageing' lab at the University of East Anglia.

Participants

Forty-two healthy, right-handed young adults with no prior history of neurological or psychiatric impairment, participated in this study. Five participants' data was removed from the analysis. Two of these five were removed due to excessive movement during scanning (MCFLIRT mean displacement was greater than 3mm). Three participants were removed due to not having completed the task per instructions. More specifically, participants failed to press a key, indicating the retrieval of a memory and the start of the elaboration phase (for both categoric and specific memories). Of the remaining thirty-seven participants, 25 were females, and their mean age = 23.62 (ranging from 18 to 34).

Stimuli

Cue words were 20 nouns selected from the Clark and Paivio (2004) extended norms. All were high in Thorndike Lorge (Thorndike & Lorge, 1994) frequency (*M* = 1.55, *SD* = .42), imageability (*M* = 5.77, *SD* = .40) and concreteness (*M* = 6.86, *SD* = .29) to increase the likelihood that an event could be generated. Fifteen words were selected for the specific memory trials, fifteen for categoric and fifteen letter change trials for the control task.

Procedure

An ABCABC (or BCABCA and CABCAB) block design was used. Each block included five trials, where A refers to specific (or episodic) trials, B to categoric and C to control. Two different versions of the task were used, this was so all cue words were seen as both specific and categoric, but each participant would have seen each word only once. Immediately prior to scanning, participants were asked to take part in a practice task (computer task using PsychoPy 2022.2.4). This was conducted in a separate room from the scanner. The practice run included one trial of each category (specific, categoric memory and control task), using different words as those used for the main task, but could be repeated should the participant need to do so.

For the memory trials, participants received the following instructions at the start of both the practice and scanner task: "*You see a word in the middle of the screen and your task is to remember a past event related to this specific word. Once you have a memory in mind, you will need to press a button and keep thinking about the memory for the rest of the trial".* Instructions also stated there would be two different memory trials: specific and categoric. Specific trials referred to memories *"of a specific event from your past"*, while categoric memories were events *"that occurred several times in your past".* Examples of specific and categoric events were also provided ("*for a specific memory related to the word "sea" I could think about last summer when I was swimming in the ocean in Portugal; for a categoric memory related to the word "holiday" I could think about my holidays when I was younger when I was going to the mountains with my grandparents every year").*

The control task was a letter change detection task. Participants were shown a series of letters and had to press a button when a letter change was detected. The following instructions were provided: *"In addition to the memory trials, you will also see Letters trials. In the Letters* *trials, you will be asked to pay attention to the string of letters you see on the screen. When the letters change, you will be asked to press a button on the response box and to continue paying attention to the new string of letters for the rest of the trial. Don't press the button until the letters change.* Examples were also provided for the control task (*as an example, I could be paying attention to the string "hhhhhhh" that after a while changes into "ppppp". I should press a button after this change occurs").*

During scanning participants were presented with fifteen specific, categoric and control trials each, across the whole experiment. Stimuli were presented via back projection onto a screen that subjects could view via a 45-degree mirror placed above their eyes. Subjects responded using MRI-compatible button boxes (2 button boxes with 2 buttons each, curved line, fORP, SKU: N1346) placed in their left (buttons "1" and "2") and right ("3" and "4") hands and were given practice inside the MRI scanner prior to data acquisition.

For the memory trials, participants first saw a fixation cross for 4 seconds, followed by a word statement specifying whether the trial was 'specific' or 'categoric'. These instructions (word and trial type) remained on the screen for 20 seconds, irrespective of when the participants pressed a button to signify they had thought of a memory associated with the word shown. The button press meant the retrieval task could be split between a memory search phase (or construction phase as discussed in Addis et al., 2007), and an elaboration phase. The button press was associated with a change in the background colour of the text box containing the cue, indicating that subjects should elaborate on their chosen memory for the remainder of the trial. Following the elaboration phase, participants were shown a fixation cross for five seconds before being asked to report how detailed their memory was. To answer this question, participants were instructed to press one of the four buttons, corresponding to a 1 - 4 Likert scale (1 – No details, 2 – Few details, 3 – Many details, 4 – Highly detailed), going from left to right on the remotes (Figure 5.1). After choosing the rating, the selected number was highlighted. The control task used the same timing parameters, with an initial fixation cross presented for 4 seconds, and a 20-second block for the letter change detection phase. Participants had to press any key, using the button boxes provided, when they detected a change in the string of letters presented (See Figure 5.1). Similar to the word cues, following a detected letter change, the text box background changed colour.

Following scanning, participants took part in a post-scan task (programmed with Gorilla) where they were presented with the same cue words seen during scanning and were asked to retrieve the previously recalled memory by providing a verbal account and were then asked to answer questions regarding each memory. For example, participants were asked to report the time in which the event took place (‘Within last year’, ‘Less than 5 years’, ‘Between 5 and 10’, ‘More than 10’, ‘Across my life’), emotional intensity (1 – Not emotional at all to 5 – Intense emotional experience) and perspective (1 – Own eyes to 5 – Observer) of that memory. Due to technical difficulties, thirteen participants did not perform a complete version of this post-scan task. As a result, emotional valence, memory remoteness and perspective were not analysed in the current chapter.

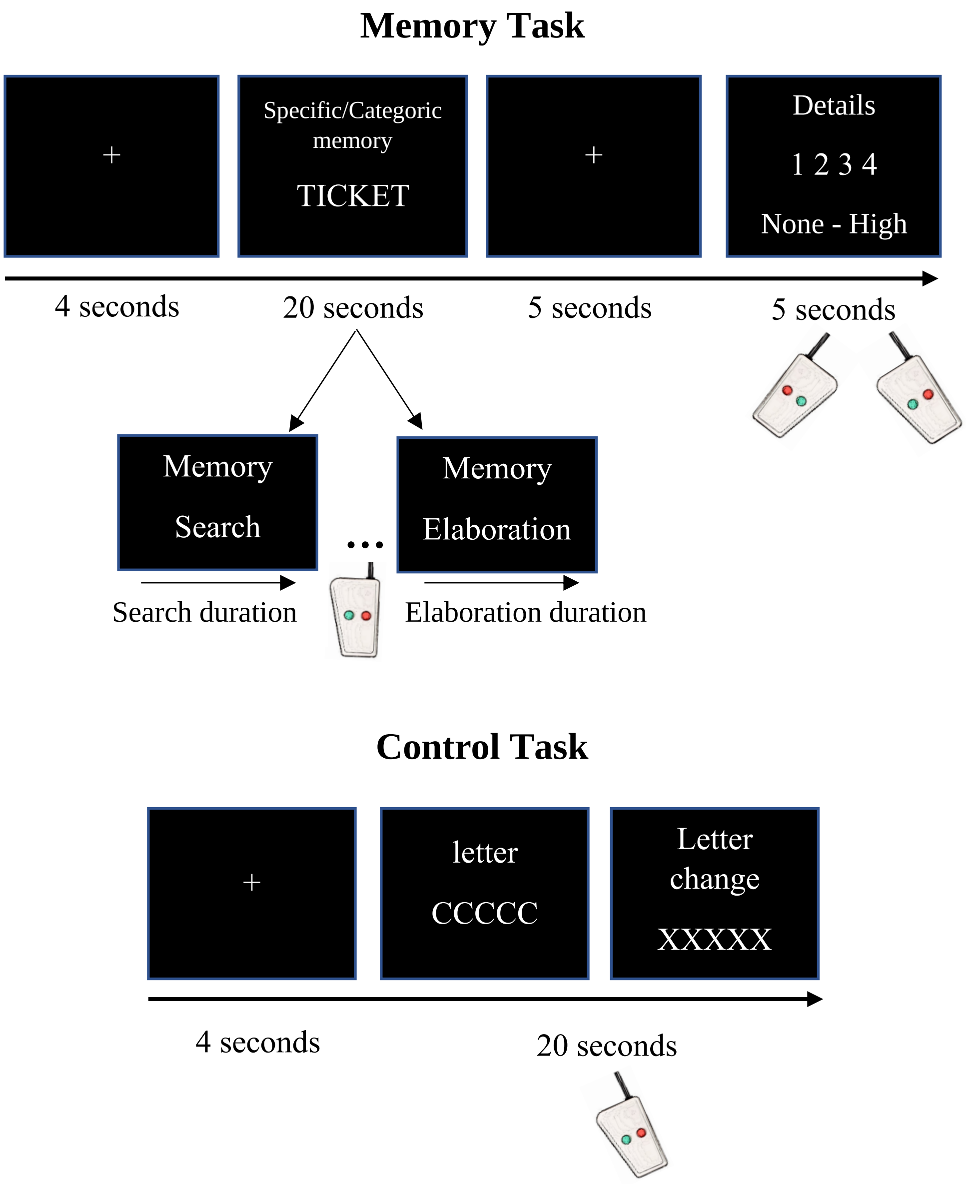

Figure 5.1. Procedure of scanning task. Participants were presented with a word and instructed to think of either a specific or categoric memory (search phase). Once they had a memory in mind, they pressed a button, marking the onset of the elaboration phase. Participants were then asked to report how detailed the memory was on a scale of 1-4 (by pressing one of four buttons). The control task consisted of a letter change detection task, where participants pressed a button once they saw a change in the strings of letters being presented.

Data Acquisition

Imaging data was acquired using a 3-tesla MR scanner (3T Siemens Prisma) and receive-only 32 channel head coil. Participants were instructed to remain as still as possible during scanning and memory foam padding was placed beside their head to minimise head motion. Following the acquisition of a localiser image, a three-dimensional structural scan was acquired with the following parameters, sagittal T1-weighted MPRAGE pulse sequence, TE/TI/TR = 2.17/900/2200ms, flip angle = 9°, GRAPPA acceleration factor = 2, voxel size = 1.0 x 1.0 x 1.0mm, and bandwidth = 210Hz/Px. Subsequently, functional data were acquired in a transversal orientation, with an echo-planar imaging (EPI) sequence: TR/TE = 2000/30ms, flip angle 76°, multi-band acceleration factor = 3, resolution 3 x 3 x 3mm, bandwidth = 2604 Hz/Px, echo spacing of 0.49ms and with interleaved multi-sliced mode, with 51 slices. The memory task had a duration of 708 measurements (i.e., 23m36s). At the end, a field mapping sequence was acquired in a transversal orientation, with the following sequence parameters TE1/TE2/TR = 4.92/7.38/520ms, flip angle 60°, resolution 3 x 3 x 3mm, bandwidth = 596 Hz/Px and with interleaved multi-slice mode, with 49 slices.

fMRI Analysis

Functional images were pre-processed using FEAT (FMRI Expert Analysis Tool) version 6.00, part of FSL (FMRIB's Software Library, www.fmrib.ox.ac.uk/fsl). The following pre-processing steps were applied; motion correction using MCFLIRT (Jenkinson et al., 2002); non-brain removal using BET (Smith, 2002); spatial smoothing using a Gaussian kernel of FWHM 5mm; grand-mean intensity normalisation of the entire 4D dataset by a single multiplicative factor;

highpass temporal filtering (Gaussian-weighted least-squares straight line fitting, with sigma=45.0s). Motion correction and fieldmap unwarping were performed in a single step to minimise the amount of smoothing arising from multiple interpolation steps. Registration of motion-corrected, unwarped, functional imaging data to a standard was performed using Boundary Based Registration (BBR, Greve & Fischl, 2009) and 6 degrees of freedom (dof) linear registration to each subject's own skull stripped T1-weighted structural, followed by 12 dof affine registration using FLIRT (Jenkinson et al., 2002) and non-linear registration to the MNI152 T1-weighted 2mm resolution template brain (Andersson et al., 2007a; 2007b).

First-level analyses were conducted for each participant's data in acquired space (i.e., not normalized to MNI) using FEAT in FSL. Time-series statistical analysis was carried out using FILM with local autocorrelation correction (Woolrich et al., 2001). Simple main effects were estimated by creating difference contrast images between conditions at the first level. Three separate models were run. Firstly a 'whole-trial' model assessed contrasts between the following conditions: categoric, specific (episodic) retrieval, and control; contrasts between memory conditions and the control task (categoric > control, specific > control); as well as between memory conditions (categoric > specific and specific > categoric) for search and elaboration phases combined, in other words, the 20sec retrieval task was considered as a whole-trial. A second model 'elaboration' looked to refine the analysis, by using the timing of the button press to split the block into search and elaboration phases separately and applied the same contrasts. For this 'elaboration' model, the same contrasts between specific and categoric memory retrieval were run only for the elaboration phase (i.e., specific elaboration > categoric elaboration; categoric elaboration > specific elaboration). Finally, a parametric regression model named 'details' was conducted, which included participants' responses to the details question as separate weights applied to each of the trials. This analysis focused on data from the elaboration phase only and included both a regressor with a weighting of 1 (as used in the other models) and the separate parametric regressor (details). This model aimed to help discriminate regions that are active during elaboration, but where activity differs (Buchel et al., 1998) to the standard model using a weighting of 1. The greater specificity of this model can help assess whether activity follows the amount of detail retrieved, telling us something more specific about the memory process and its relation to richness. All three models ('whole-trial', 'elaboration' and 'details') included regressors to account for neural activity associated with keypresses occurring during the task, including during the control condition and responses to questions. For all regressors, a temporal derivative was included to help account for slight differences in the timing of BOLD responses, when sampling across the brain volume with a 2-second TR.

Higher-level group analyses were then conducted, using the same models and contrasts to assess these effects at the group level. To achieve this, the contrast of parameter estimates (COPE, sometimes called "beta") images were transformed to standard space for group analysis using the warp fields determined during first level analysis. Whole-brain group differences were assessed with a one-sample t-test in FEAT, using a mixed-effects model (FLAME 1+2). Finally, in line with main hypotheses of this chapter, a set of anatomical masks were selected. Mask-based analyses were conducted in FEAT, as well as non-parametric group analysis with permutation testing performed using RANDOMISE (in FSL). Group level inference was performed using cluster-based thresholding, based on Gaussian Random Field theory (Worsley, 2001), and followed best practice in the field (Eklund et al., 2016). A cluster forming threshold of $Z>3.1$ was used, and a family-wise error correction for cluster extent controlled for false positives at (corrected) $P<0.05$. Where non-parametric permutation testing was used, thresholding was based on threshold free cluster enhancement (TFCE) with cluster corrected $P<0.05$ (Smith & Nichols, 2009).

The results of these analyses are presented in table and figure format. Tables were created with Autoaq (part of FSL). For the whole brain analyses, atlas labels for the represented clusters are included. The percentages stated in these labels represent the degree of overlap with probabilistic atlases. Depending on the size of a cluster, this could belong to more than one anatomical region, so it is important to note that percentage values do not report the size of the mentioned region being active, but rather, report the overlap between the cluster and the region listed in the probabilistic atlases. The atlases used to create the tables included the “Harvard Oxford Cortical Structural Atlas”, “Harvard Oxford Subcortical Structural Atlas”, “Cerebellar Atlas in MNI152 space after normalization with FNIRT” and “Juelich Histological Atlas”. Only those structures to which the cluster had a 5% chance of belonging to, are presented. The reported coordinates are in MNI space (in mm) and represent the location of the voxel of highest Z-score in each cluster. Finally, figures were created using snapshot images from FSLeyes. Slices were selected by inputting peak MNI coordinates. For mask analyses figures, masks were overlapped with functional images to provide the outline of the mask used for the analysis.

Mask selection

Brain regions were selected as masks to restrict the analysed brain regions for group level parametric and non-parametric (with permutation testing) analyses. The left and right AG were subdivided into PGa and PGp, using the Juelich Histological Atlas, consistent with Bellana et al., (2023). These two masks were merged to provide separate left and right AG masks. The precuneus was selected using the Harvard-Oxford Cortical Structural Atlas, and finally left and right hippocampus masks were selected using the Harvard-Oxford Subcortical Structural Atlas. These selected masks are shown in Figure 5.2 below. All regions were thresholded at 40% (as per Bellana et al., 2023).

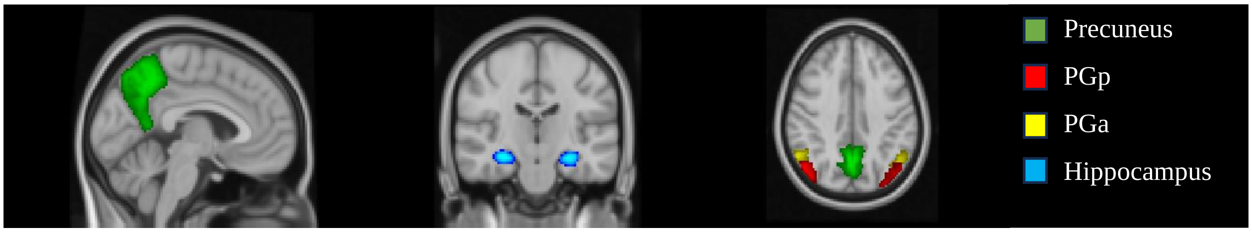

Figure 5.2. Image depicting masks selected from Julich and Harvard-Oxford Cortical and Subcortical atlases on FSL. Masks include the precuneus, left and right PGp and PGa, and Hippocampus. Image shows regions thresholded at 40%. PGa and PGp masks were merged using FSL to create a left and right AG masks.

5.3 Results

5.3.1 Behavioural Results

Firstly, the average number of responses to word cues in the memory task was calculated for each condition separately. Trials were retained only if participants pressed a button when they thought of a memory (either specific or categoric), as they were instructed to not press a button if they could not think of a memory. For specific memories, the number of trials ranged from 7 to 15 (the maximum possible), with an average of 14.3 (SD = 1.4) across participants. For categoric memories, the number of trials ranged from 9 to 15, with an average of 14.4 (SD = 1.3).

The duration of the search phase was compared between specific and categoric trials. For the search phase, a paired t-test revealed no significant difference between categoric ($M = 4.63$ seconds, $SD = 1.99$) and specific memories ($M = 5.00$, $SD = 1.92$), t(36) = -1.72, $p = 0.09$, CI = -0.80, 0.067. For the elaboration phase, a paired t-test similarly revealed no significant difference between the categoric ($M = 15.37$, $SD = 1.99$), and specific ($M = 15.00$, $SD = 1.92$) elaboration duration, t(36) = 1.72, $p = 0.09$, CI = -0.067, 0.80. Finally, a paired t-test was conducted to assess the difference of duration between the search and elaboration phase of the retrieval task, across all specific and categoric trials. A significant difference was seen, with search time being significantly shorter ($M = 4.82$, $SD = 1.95$) than elaboration time ($M = 15.18$, $SD = 1.95$), t(73) = 22.90, $p < .001$, CI = 9.46, 11.27. Due to the significant difference between the duration of search and elaboration phases, it was not deemed appropriate to contrast these different components of the experiment in the subsequent fMRI analysis.

Finally, self-reported detail scores were compared between memory conditions (categoric Vs specific, using a 1 to 4 rating scale, see methods). A One-Way repeated measures ANOVA showed there was no significant difference in detail ratings between categoric (*M* = 2.78, *SD* = 0.29), and specific (*M* = 2.87, *SD* = 0.36) memories, F(1,36) = 2.73, *p* = 0.11.

5.3.2 Whole Brain Analyses

Following transformation, contrasts determined at the first level were averaged for the group to provide statistical maps summarising contrasts in each model of interest i.e., for 'whole-trial', 'elaboration' and 'details'. Of the remaining thirty-seven participants absolute and relative mean displacement following MCFLIRT motion correction was an average of 0.40mm and 0.08mm, respectively (range for absolute = 0.05 – 1.48, range for relative = 0.03 – 0.23).

Memory Effect: Memory Vs Control

To identify brain regions involved in the retrieval of categoric and specific autobiographical memories, we conducted a whole-brain analysis, using a mixed-effects model, comparing BOLD signal associated with categoric and specific memories to the control task, separately. As seen in Figure 5.3, Figure 5.4, and Table 5.1, contrasts from the 'whole-trial' (search + elaboration) demonstrate activity in regions associated with the core memory retrieval network (Cabeza & St Jacques, 2007; Maguire & Mummery, 1999; Maguire et al., 2000; 2001; Moscovitch et al., 2016; Svoboda et al., 2006; Vilberg & Rugg 2013), namely, the left medial prefrontal cortex, angular gyrus, and parahippocampal gyrus; posterior cingulate/retrosplenial cortex, lateral temporal cortex; bilateral precuneus and hippocampus. In addition, greater activity for the memory tasks, compared to control, was seen for subregions of left Broca's areas, cerebellum, and bilateral subregions of the visual cortex, for both the categoric and specific contrasts. For a list of abbreviations and corresponding brain regions, please consult Table 5.8 in the Supplementary Material.

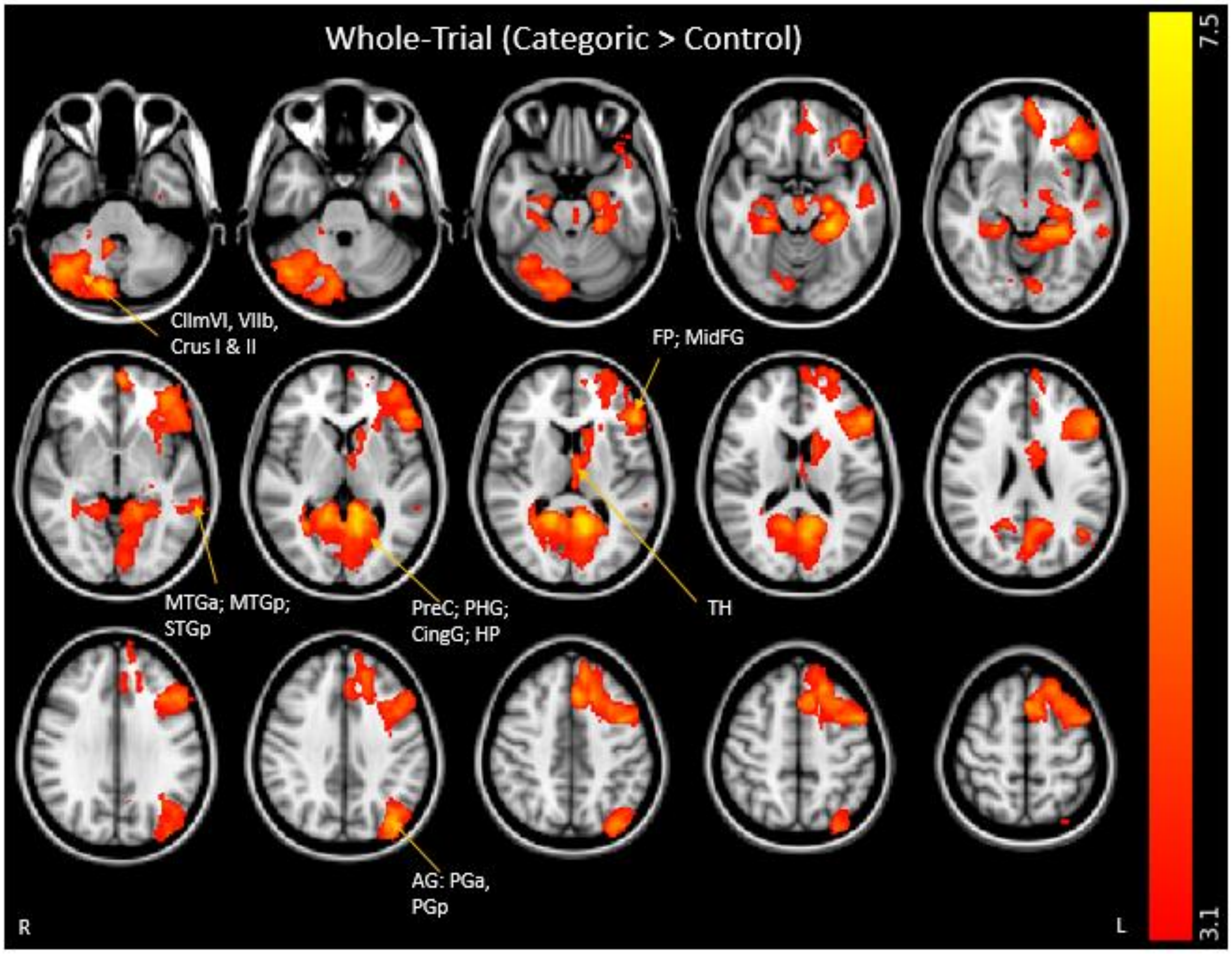

Figure 5.3. BOLD activity when contrasting AM categoric retrieval (search + elaboration) with control task. Indicated are regions in the cerebellum (Cllm): VI, VIIb, Crus I and II; Frontal Pole (FP), Middle Frontal Gyrus (MidFG); Thalamus (TH); Middle Temporal Gyrus (MTG); Superior Temporal Gyrus (STG); Precuneous (PreC); Parahippocampal Gyrus (PHG); Cingulate Gyrus (CingG); Hippocampus (HP); Angular Gyrus (AG).

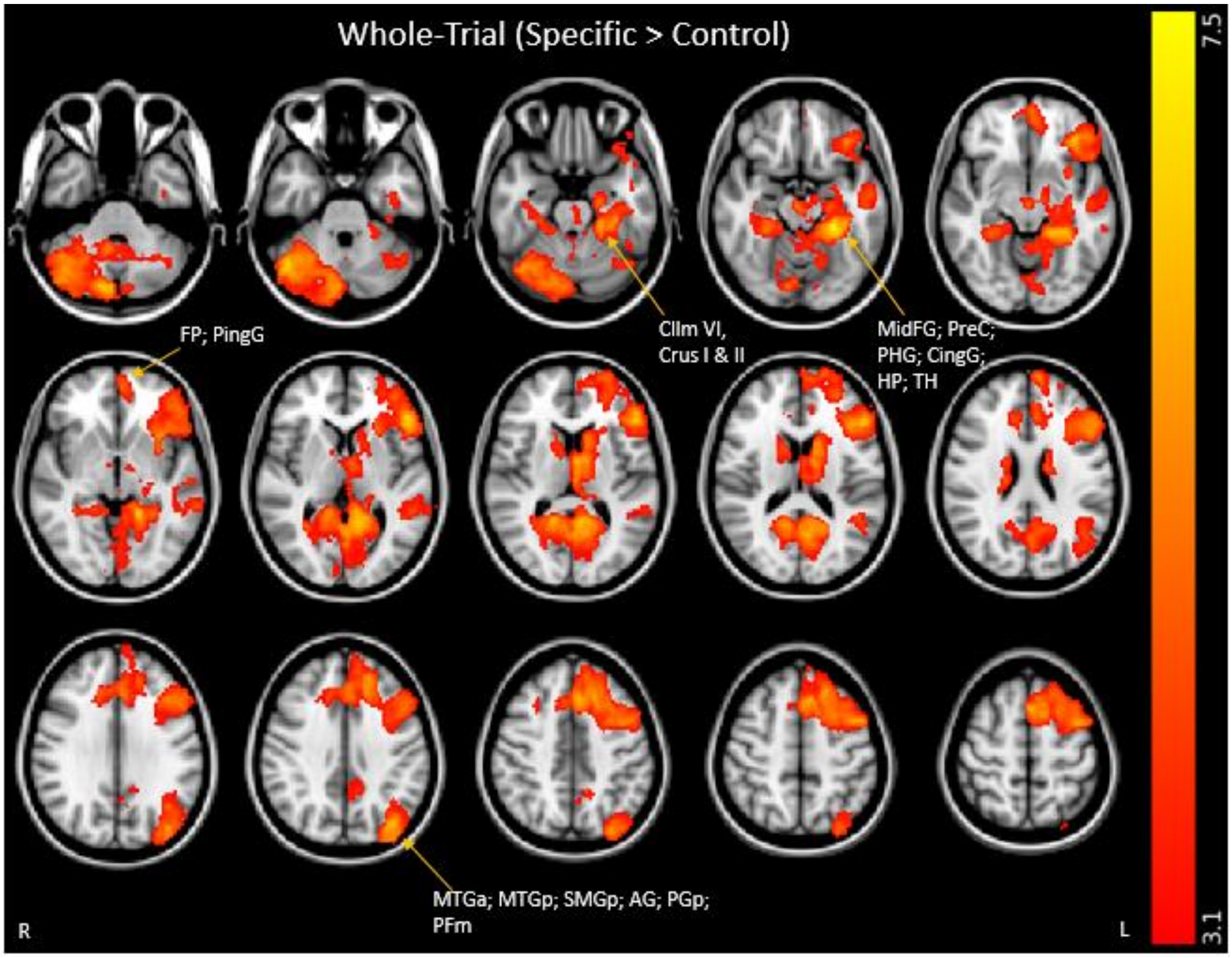

Figure 5.4. BOLD activity when contrasting AM specific retrieval (search + elaboration) with control task. Indicated are regions in the cerebellum: VI, Crus I and II; Frontal Pole, Middle Frontal Gyrus (MFG); Thalamus (TH); Middle Temporal Gyrus (MTG); Precuneous (PreC); Parahippocampal Gyrus (PHG); Cingulate and Paracingulate Gyrus (CingG, PingG); Supramarginal Gyrus (SMG); Hippocampus (HP); Angular Gyrus (AG); Inferior Parietal Lobule PFm.

Brain regions activated during AM Categoric memory retrieval, compared to the control task (letter change task)

Cluster Index	Voxels	Z score	MNI X (mm)	MNI Y (mm)	MNI Z (mm)	Atlas label(s)
8	11672	6.86	-52	34	8	Frontal Pole (12.4%); Left Cerebral White Matter (30.2%); Left Cerebral Cortex (53.8%)
7	10433	7.48	-10	-60	8	Lingual Gyrus (11.5%); Left Cerebral White Matter (16.1%); Left Cerebral Cortex (28.6%); Right Cerebral White Matter (11.1%); Right Cerebral Cortex (18.7%)
6	4314	6.43	44	-70	-40	Right Crus I (32.5%); Right Crus II (27.5%)
5	1633	6.33	-38	-76	36	Lateral Occipital Cortex, superior division (47.6%); Left Cerebral White Matter (19.5%); Left Cerebral Cortex (54.6%); GM Inferior parietal lobule Pga L (14.5%); GM Inferior parietal lobule PGp L (30.4%)
4	950	5.06	-4	-14	12	Left Cerebral White Matter (32.7%); Left Lateral Ventricle (15.0%); Left Thalamus (22.4%); Left Caudate (25.8%); WM Callosal body (12.4%)
3	559	6.07	-4	60	-4	Frontal Pole (33.3%); Frontal Medial Cortex (24.8%); Left Cerebral White Matter (23.2%); Left Cerebral Cortex (61.3%)
2	273	4.18	-62	-44	-4	Middle Temporal Gyrus, posterior division (30.1%); Middle Temporal Gyrus, temporooccipital part (13.8%); Left Cerebral White Matter (37.6%); Left Cerebral Cortex (59.1%)
1	247	4.18	-54	-6	-16	Superior Temporal Gyrus, posterior division (10.5%); Middle Temporal Gyrus, anterior division (15.0%); Middle Temporal Gyrus, posterior division (18.7%); Left Cerebral White Matter (40.3%); Left Cerebral Cortex (59.0%)

Brain regions activated during AM Specific memory retrieval, compared to the control task (letter change task)

3	34088	7.53	-24	-34	-18	Left Cerebral White Matter (18.9%); Left Cerebral Cortex (31.8%)
2	3350	6.52	-32	-80	40	Lateral Occipital Cortex, superior division (27.4%); Left Cerebral White Matter (29.8%); Left Cerebral Cortex (58.2%); GM Inferior parietal lobule PGp L (17.0%)
1	419	5.25	-4	56	-6	Frontal Pole (30.1%); Frontal Medial Cortex (26.6%); Paracingulate Gyrus (15.9%); Left Cerebral White Matter (17.7%); Left Cerebral Cortex (65.5%); Right Cerebral Cortex (10.3%)

Table 5.1. Clusters with peak co-ordinates of regions activated during memory task, compared to control. Cluster forming threshold Z>3.1 and (corrected) P < .05. Only structures to which the cluster had a >5% chance of belonging to are represented in this table. Also of note is activity in the hippocampus for which overlap was <5%. Cluster 7 for categoric contrast demonstrated activity overlapping with left and right hippocampus (4.3% and 2%, respectively). Cluster 2 for specific contrast demonstrated activity overlapping with left hippocampus (1.2%). For a more extensive table with no % threshold see Table 5.9 in supplementary materials.

Differences Between Memory Types: Specific Vs Categoric

Whole-Trial Model. Contrasts from the 'whole-trial' model assessed the main effect of memory condition and demonstrated higher activation during specific, compared to categoric retrieval (Figure 5.5 and Table 5.2) in the right paracingulate and cingulate gyri, middle temporal gyrus, supramarginal gyrus, and precuneus, the inferior parietal lobe (namely right PGa, left PF, and bilateral PFm), left cerebellum, and bilateral frontal regions, such as right Broca's area, inferior frontal gyrus (IFGT), frontal orbital cortex (OFC) and left frontal operculum cortex (FO), middle frontal gyrus and insular cortex (INS). No clusters met thresholding parameters of $Z>3.1$ and corrected significance level of $p< .05$ for the reverse contrast (categoric > specific).

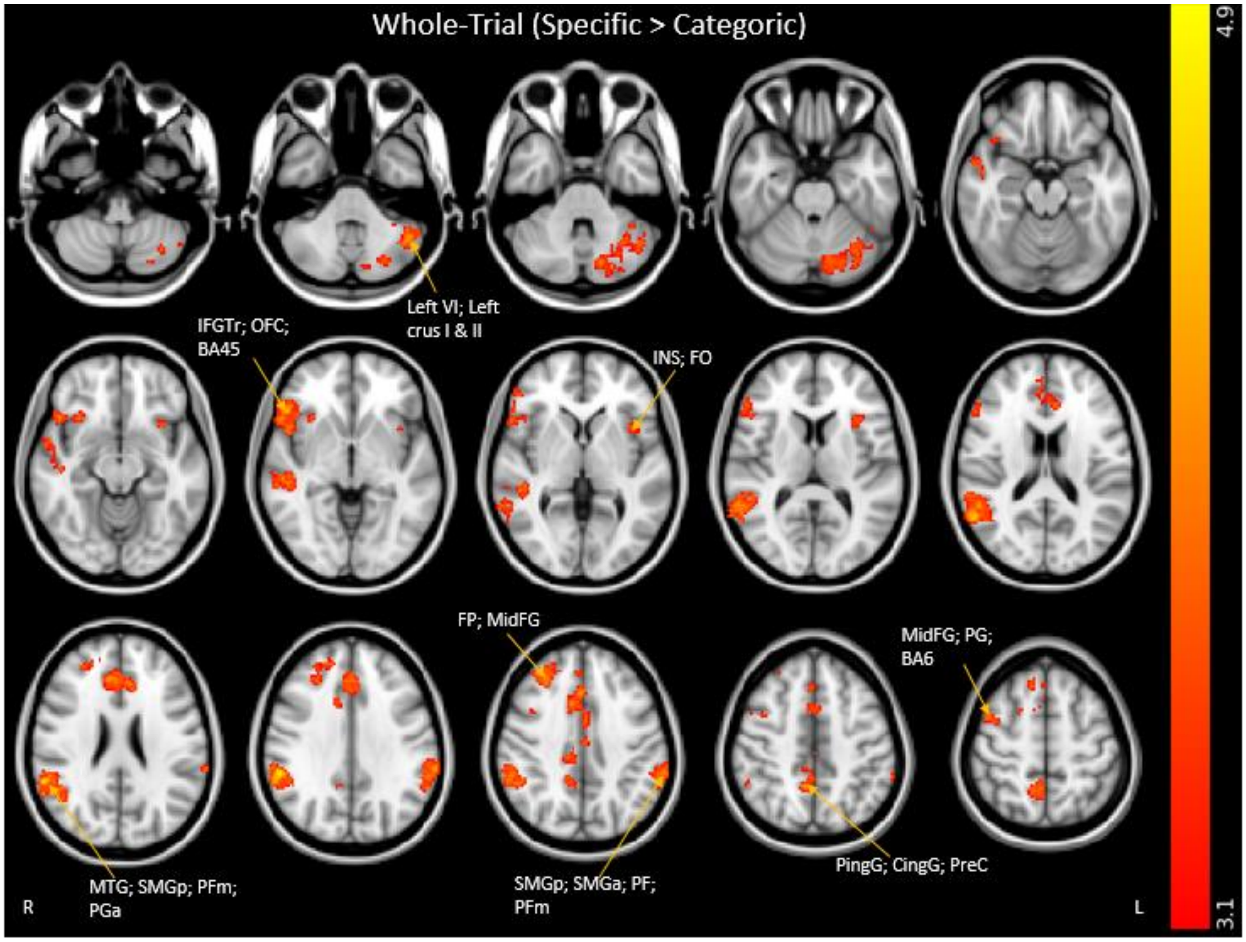

Figure 5.5. Whole-brain mixed-effects analysis of the main effect of memory condition. BOLD activity more strongly associated with specific, compared to categoric retrieval for the whole model (search + elaboration). Arrows indicate peak activity of clusters, as shown in Table 5.2 with MNI coordinates.

Cluster Index	Voxels	Z score	MNI X (mm)	MNI Y (mm)	MNI Z (mm)	Atlas label(s)
8	2132	4.36	8	-50	44	Paracingulate Gyrus (18.6%); Cingulate Gyrus, anterior division (19.6%); Precuneous Cortex (11.5%)
7	2128	5.1	60	-46	26	Middle Temporal Gyrus, temporooccipital part (11.1%); Supramarginal Gyrus, posterior division (14.7%); Angular Gyrus (21.0%); GM Inferior parietal lobule PFm R (17.0%); GM Inferior parietal lobule Pga R (14.3%)
6	1295	4.37	-44	-56	-42	Left VI (15.1%); Left Crus I (51.6%); Left Crus II (21.5%)
5	877	4.55	46	22	-8	Inferior Frontal Gyrus, pars triangularis (18.1%); Frontal Orbital Cortex (14.6%); GM Broca's area BA45 R (26.1%)
4	491	4.2	32	34	40	Frontal Pole (42.0%); Middle Frontal Gyrus (15.4%)
3	462	4.4	-62	-42	42	Supramarginal Gyrus, anterior division (26.5%); Supramarginal Gyrus, posterior division (25.7%); GM Inferior parietal lobule PF L (41.4%); GM Inferior parietal lobule PFm L (18.8%)
2	189	4.13	46	4	52	Middle Frontal Gyrus (38.1%); Precentral Gyrus (18.8%); GM Premotor cortex BA6 R (14.1%)
1	156	3.85	-40	12	-2	Insular Cortex (39.2%); Frontal Operculum Cortex (19.4%)

Table 5.2. Clusters with peak co-ordinates of regions activated during specific whole-trial, compared to categoric whole-trial. Cluster forming threshold Z>3.1 and (corrected) P < .05. Only structures to which the cluster had a >5% chance of belonging to are represented in this table.

Elaboration Model. Regions which were significantly more active during specific, compared to categoric elaboration are shown in Figure 5.6 and Table 5.3. Results from this contrast (specific > categoric) appear to qualitatively overlap with results from the same contrast conducted for the ‘whole-trial’ model. The retrieval of specific (episodic) AMs during the elaboration phase was associated with greater activity in the middle temporal gyrus, supramarginal gyrus, precuneus, inferior parietal lobe (namely right PGa, bilateral PF and PFm), cerebellum, right Broca’s area, and regions in the frontal cortex, including frontal pole and middle frontal gyrus. Of particular interest to the main hypotheses of this chapter, when contrasting specific > categoric BOLD activity, both 'whole-trial' and 'elaboration' models revealed greater AG, specifically right PGa, and precuneus activity for specific, compared to categoric memory retrieval.

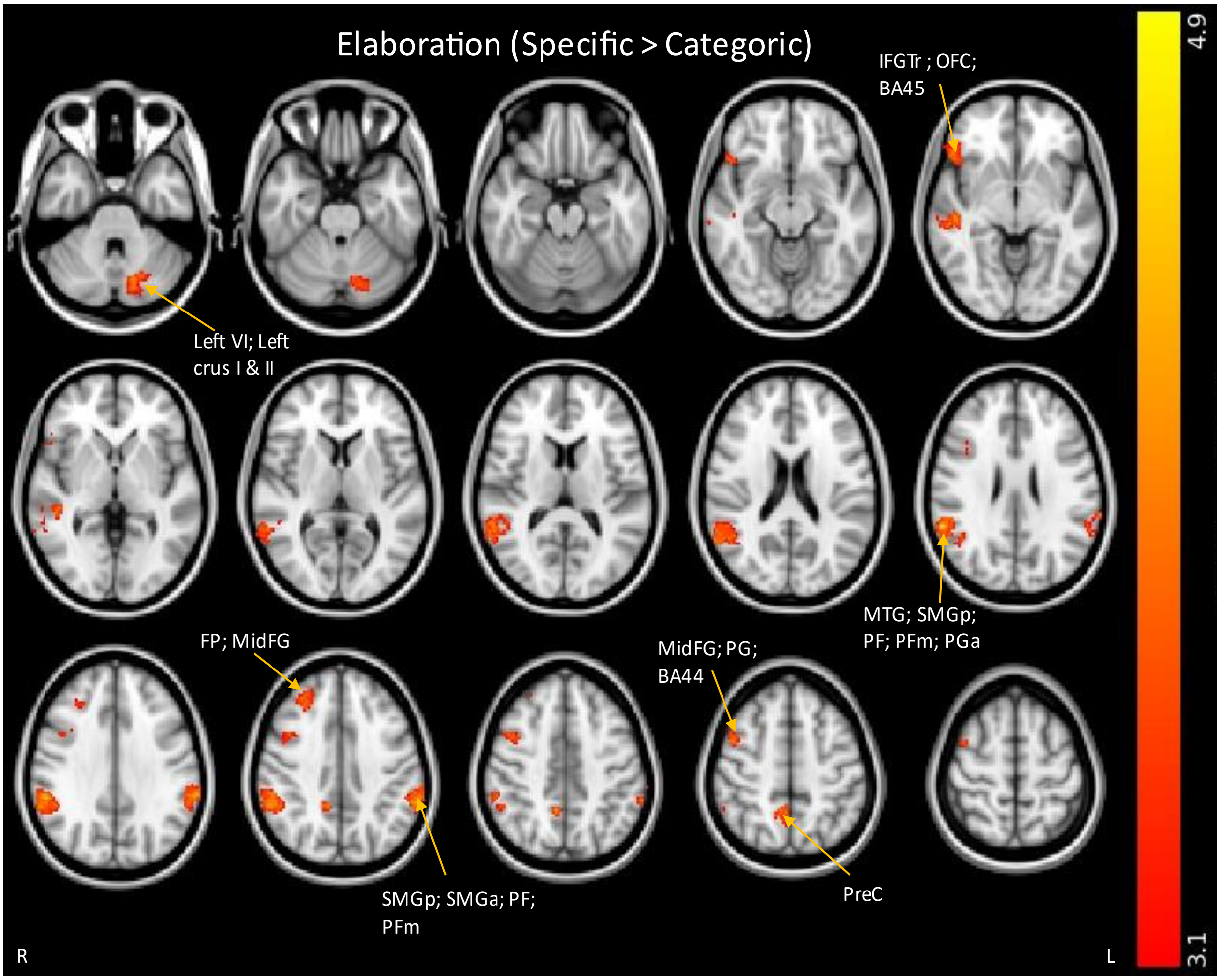

Figure 5.6. Whole-brain mixed-effects analysis of the main effect of memory condition. BOLD activity more strongly associated with specific, compared to categoric retrieval for the elaboration model (elaboration phase only). Arrows indicate peak activity of clusters, as shown in Table 5.3 with MNI coordinates.

Cluster Index	Voxels	Z score	MNI X (mm)	MNI Y (mm)	MNI Z (mm)	Atlas label(s)
7	1628	4.84	60	-46	28	Middle Temporal Gyrus, temporooccipital part (10.5%); Supramarginal Gyrus, posterior division (17.0%); Angular Gyrus (25.5%); GM Inferior parietal lobule PF R (10.0%); GM Inferior parietal lobule PFm R (21.7%); GM Inferior parietal lobule Pga R (17.6%)
6	443	4.45	-60	-42	40	Supramarginal Gyrus, anterior division (27.3%); Supramarginal Gyrus, posterior division (26.2%); GM Inferior parietal lobule PF L (41.8%); GM Inferior parietal lobule PFm L (17.5%)
5	372	4.39	-14	-72	-30	Left VI (13.9%); Left Crus I (43.5%); Left Crus II (31.3%)
4	234	4.03	46	4	52	Middle Frontal Gyrus (34.2%); Precentral Gyrus (17.9%); GM Broca's area BA44 R (11.1%)
3	197	4.02	46	22	-8	Inferior Frontal Gyrus, pars triangularis (17.7%); Frontal Orbital Cortex (24.3%); GM Broca's area BA45 R (17.8%)
2	179	4.04	24	44	40	Frontal Pole (31.7%); Middle Frontal Gyrus (25.6%)
1	169	4.17	8	-50	48	Precuneous Cortex (63.8%)

Table 5.3. Clusters with peak co-ordinates of regions activated during specific elaboration, compared to categoric elaboration. Cluster forming threshold Z>3.1 and (corrected) P < .05. Only structures to which the cluster had a >5% chance of belonging to are represented in this table.

Memory Retrieval and Details during Elaboration phase

A group analysis of elaboration where the level of details recalled for each trial was included as a parametric regressor at the first level, was conducted. Group averages for the parametric (details) contrasts for both specific and categoric elaboration were estimated (Table 5.10 of Supplementary Material). We also assessed the main effect of memory type, by contrasting activity for specific greater than categoric retrieval and vice versa, for the parametric contrast (details). Table 5.4 demonstrates the significantly stronger positive association between activity recorded during specific elaboration and self-reported details, compared to categoric elaboration. These regions included the precuneus cortex, cuneal cortex, subregions of the superior parietal lobule (right 7A, 7M and 7P), as well as subregions of the cerebellum (Figure 5.7). No clusters with Z score higher than 3.1 were found for the contrast categoric > specific.

Cluster Index	Voxels	Z score	MNI X (mm)	MNI Y (mm)	MNI Z (mm)	Atlas label(s)
3	459	4.14	18	-64	28	Precuneous Cortex (37.5%); Cuneal Cortex (18.1%)
2	154	3.86	6	-64	62	Precuneous Cortex (59.0%); GM Superior parietal lobule 7A R (22.0%); 7M R (11.1%); 7P R (21.4%)
1	151	4.04	-24	-42	-44	Left VIIIa (16.4%); Left VIIIb (12.4%); Left X (14.9%)

Table 5.4. BOLD activity for specific, compared to categoric memory retrieval, with details as a regressor. Clusters were determined by Z<3.1, and a corrected cluster significance threshold of P = 0.05. For each region of activation, the coordinates of the peak within each structure is reported, as indicated by the highest Z-score.

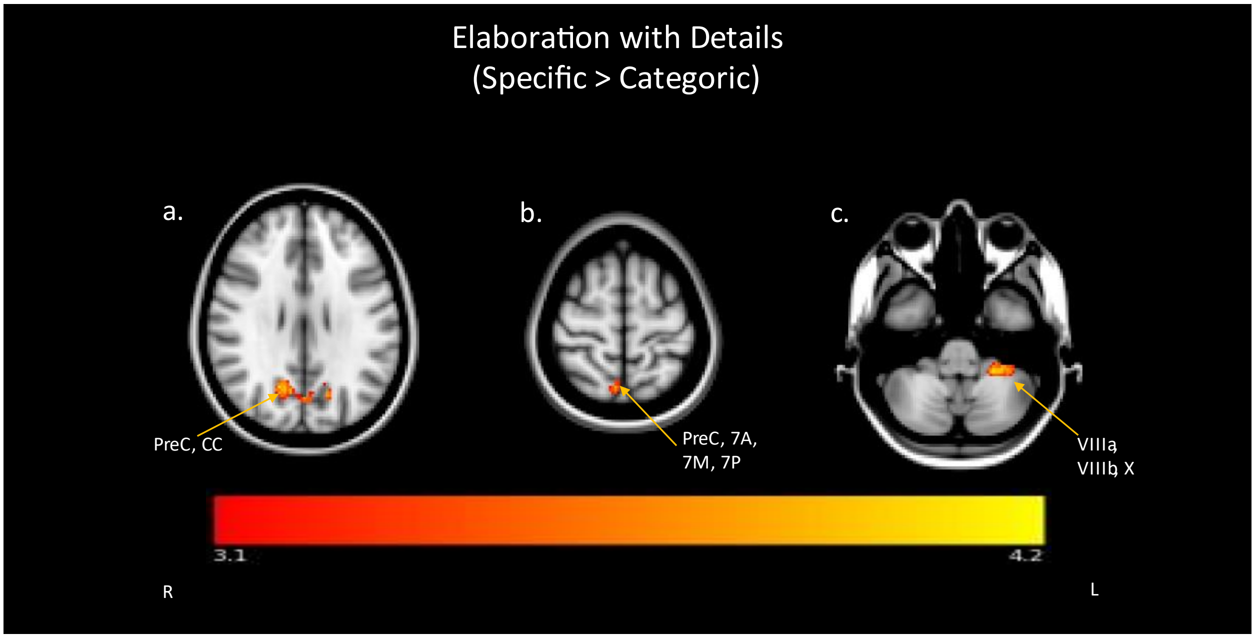

Figure 5.7. BOLD activity associated with specific elaboration (with details as regressor), compared to categoric elaboration. Peak co-ordinates are reported, a. = precuneus and cuneal cortex (CC). b. = precuneus, right superior parietal lobule (7A, 7M and 7P); c. = left VIIIa, left VIIIb and left X in the cerebellum.

5.3.3 Mask Analyses

In line with our hypotheses, we wanted to investigate whether the AG is sensitive to the richness of the content that is being retrieved during elaboration and whether its subregions (PGa and PGp) would show different involvement. We also had prior hypotheses of a positive relationship between AG and details, irrespective of whether the memory was episodic or semantic in nature. We first assessed main effects of memory conditions by contrasting specific vs categoric elaboration. To assess more specifically the involvement of AG in the retrieval of rich AMs, we assessed the group relationship between activity and the number of details retrieved for each memory type separately. For completeness, we also contrasted specific Vs categoric conditions to assess any differences in the relationship between activity and details between memory types. AG masks were created for each subregion separately (left and right PGa and PGp). These were then combined to provide a more general overview of the role of the AG in rich memory retrieval and create a left and right AG mask. In line with extensive evidence demonstrating key involvement of both the hippocampus and precuneus in the retrieval of AM, we also included masks for these two brain areas (left and right hippocampus and precuneus).

Parametric and non-parametric (permutation-testing) analyses were conducted for left and right AG (as a whole), left and right PGa and PGp, hippocampus, and precuneus masks. Where contrasts were significant ($p < .05$) only for the non-parametric analysis, this was reported due to the increased robustness of this test. Where discrepancies arose between the parametric and non-parametric masked analysis, the non-parametric was reported. From here on, all results are outcomes from non-parametric analyses. Where there is agreement between the two types of analyses, this will be indicated in the tables with a *.

Differences Between Memory Types: Specific Vs Categoric

When assessing whether activity is differentially recruited for specific, compared to categoric memories, no differentiation was seen for the categoric > specific contrast. In contrast, greater activity was observed during specific elaboration, compared to categoric elaboration for right AG (including PGa and PGp) and precuneus (Table 5.5).

Contrast	Mask	Voxels	P value	MNI X (mm)	MNI Y (mm)	MNI Z (mm)
Categoric > Specific	No masks reached significance					
Specific > Categoric	Left AG	-	-	-	-	-
	Right AG	508	0.004 *	58	-52	16
	Left Pga	-	-	-	-	-
	Right Pga	426	0.002 *	58	-52	16
	Left PGp	-	-	-	-	-
	Right PGp	31	0.025 *	52	-70	20
	Right PGp	31	0.029 *	50	-60	20
	Left HP	-	-	-	-	-
	Right HP	-	-	-	-	-
	Precuneus	24	0.038 *	8	-48	42

Table 5.5. Main effects of memory condition during elaboration. Significant results only seen for the specific > categoric masked analyses contrasts.* represents agreement of significant results between parametric and non-parametric masked analyses.

Memory Retrieval and Details during Elaboration phase

To test our hypothesis of whether the AG is sensitive to the richness of retrieved content, activity for the parametric regressor (details) was averaged across the group. Results from non-parametric analysis can be seen in Table 5.6 and Figure 5.8. For categoric AMs, a significant positive relationship with number of details was observed in the left AG, specifically left PGp, and bilateral hippocampus. For specific AMs, a significant positive relationship with number of details retrieved was seen for bilateral AG, specifically, bilateral PGp activity and right PGa activity, as well as in bilateral hippocampus and precuneus.

Contrast	Mask	Voxels	P value	MNI X (mm)	MNI Y (mm)	MNI Z (mm)
Categoric Details	Left AG	57	0.024 *	-48	-70	20
	Left AG	31	0.028 *	-32	-88	34
	Right AG	-	-	-	-	-
	Left Pga	-	-	-	-	-
	Right Pga	-	-	-	-	-
	Left PGp	204	0.015 *	-48	-70	20
	Right PGp	-	-	-	-	-
	Left HP	128	0.01 *	-32	-20	-16
	Right HP	71	0.014 *	28	-18	-14
	Precuneus	-	-	-	-	-
Specific Details	Left AG	414	0.006 *	-36	-84	28
	Right AG	884	0.001 *	46	-80	18
	Left PGa	-	-	-	-	-
	Right PGa	227	0.012 *	48	-48	26
	Left PGp	451	0.004 *	-36	-86	26
	Right PGp	685	0.001 *	44	-82	20
	Left HP	416	< 0.001 *	-34	-34	-8
	Right HP	355	0.001 *	32	-14	-18
	Precuneus	3615	< 0.001 *	18	-58	12

Table 5.6. Main effects of memory condition during elaboration, with details as regressor.* represents agreement of significant results between parametric and non-parametric masked analyses.

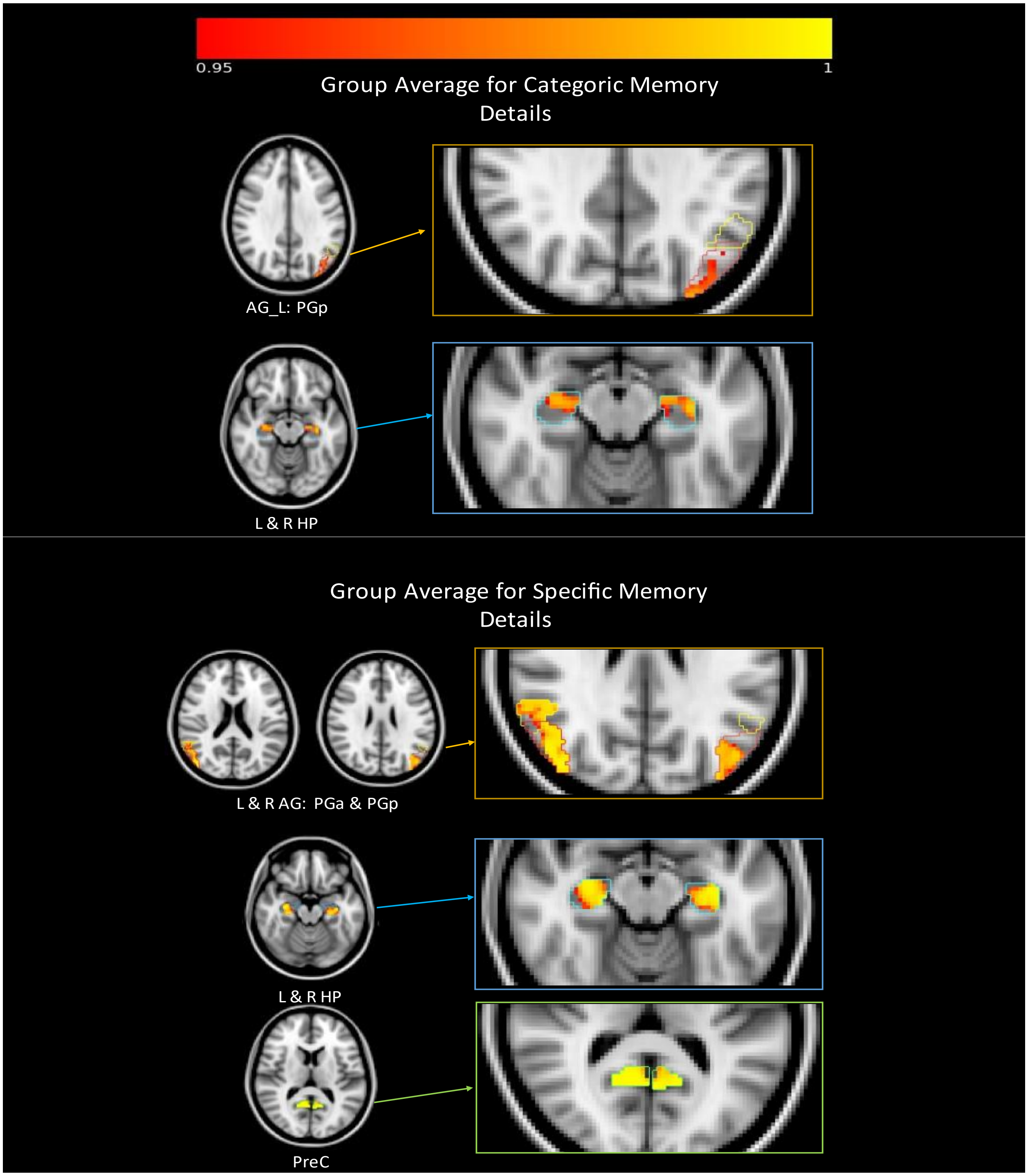

Figure 5.8. Main effect of memory condition during elaboration, with details as regressor (TFCE corrected *p* < .05, p-value colour bar shown). Mask outline is also presented, with AG mask subdivided into PGa and PGp. Non-parametric masked analyses reached significance for bilateral AG (left PGp, right PGa & PGp), bilateral hippocampus and precuneus for the specific condition. Significant results only seen for left AG (specifically PGp) and bilateral hippocampus for the categoric condition.

Finally, when assessing whether activity based on the level of details recalled was differentially recruited for specific, compared to categoric memories, no differentiation was seen for the categoric > specific contrast. A stronger positive relationship between the BOLD activity recorded during specific elaboration and details was seen compared to the equivalent contrast for categoric elaboration for the right AG (including PGa and PGp), left hippocampus and precuneus (see Figure 5.9 and Table 5.7). For comparison, at the whole-brain level, only the precuneus and left cerebellum were identified as being more positively associated with details in the comparison specific > categoric.

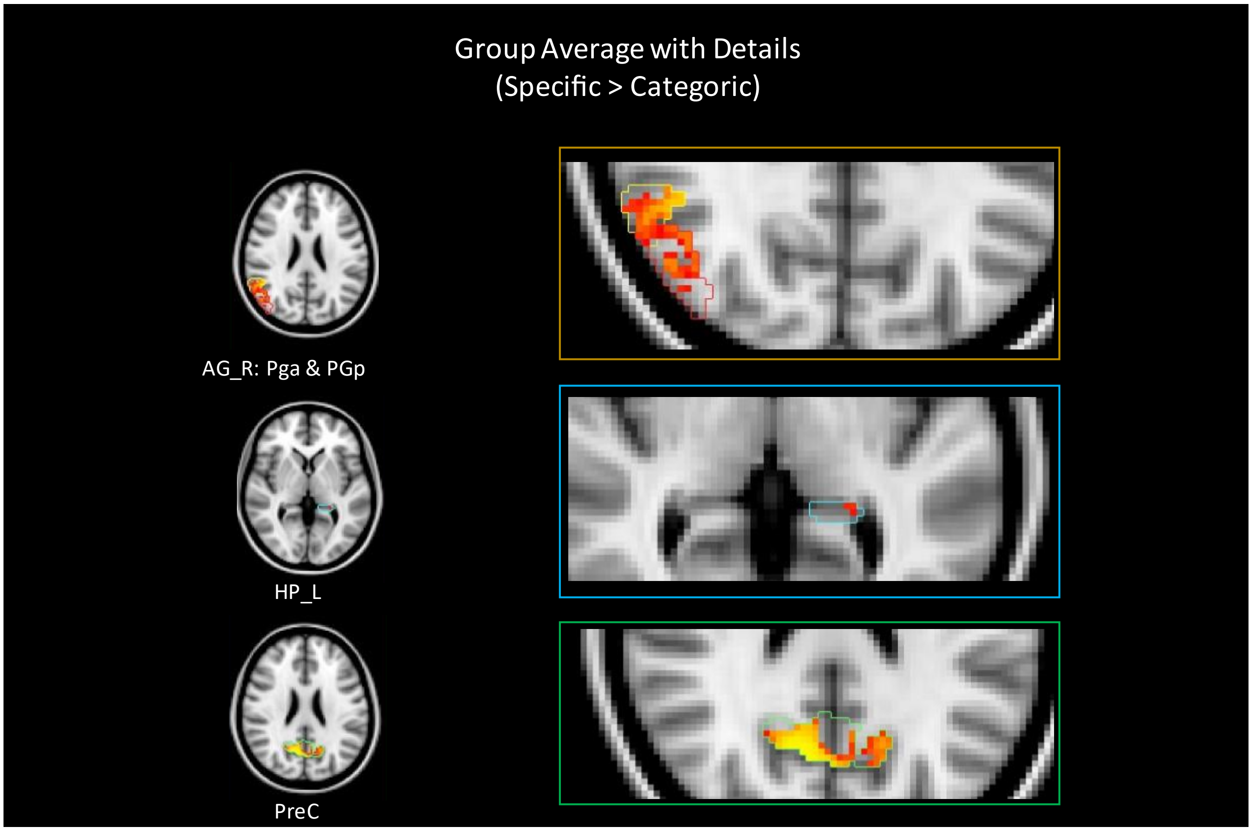

Figure 5.9. Main effect of memory condition (specific > categoric), with details as regressor (TFCE corrected $p < .05$, p-value colour bar shown). Mask outline is also presented, with AG mask subdivided into PGa and PGp. Non-parametric masked analyses reached significance for right AG (PGa and PGp), left hippocampus and precuneus.

Contrast	**Mask**	**Voxels**	**P value**	**MNI X (mm)**	**MNI Y (mm)**	**MNI Z (mm)**
Categoric > Specific	No masks reached significance					
Specific > Categoric	Left AG	-	-	-	-	-
	Right AG	392	0.012	48	-50	24
	Left Pga	-	-	-	-	-
	Right Pga	199	0.01 *	48	-50	24
	Left PGp	-	-	-	-	-
	Right PGp	187	0.01 *	42	-68	28
	Left HP	6	0.041 *	-24	-38	2
	Right HP	-	-	-	-	-
	Precuneus	1987	0.002 *	10	-66	24

Table 5.7. Main effects of memory condition, with details as regressor. Significant results only seen for the specific > categoric masked analyses contrasts.* represents agreement of significant results between parametric and non-parametric masked analyses.

5.4 Discussion

The goal of this study was to investigate the involvement of the AG during the elaboration of episodic (specific events) and categoric memories. This is one of the few studies assessing activity within subregions of the AG; PGa and PGp. Our main hypothesis was that we would see differences in BOLD activity of PGa and PGp for both episodic and categoric retrieval. We also predicted to see AG activity to be sensitive to the richness of the memory (measured through self-reported details), irrespective of whether the memory was more episodic or semantic in nature (specific Vs categoric events). Consistent with our hypotheses, our whole-brain analyses demonstrated activity overlapping with left AG for both specific and categoric retrieval, compared to the control, and greater right PGa activity for specific, compared to categoric retrieval. Our mask-based analyses assessed our predictions directly, revealing a positive relationship between left AG activity and details during categoric retrieval, this was restricted to area PGp, with no significant relationship seen for our left PGa mask. When assessing retrieval of specific memories, with the regressor ‘details’, we found a significant relationship between left and right AG (specifically left PGp and right PGa and PGp) and details. Our memory condition contrast demonstrated how right PGa and PGp are modulated by the amount of details retrieved for specific memories, compared to categoric ones.

Autobiographical Memory Retrieval

We first investigated the activity of brain regions involved in the retrieval of AM by comparing whole-brain activity elicited by the memory condition as compared to the control task. For both specific and categoric memories, we observed a network of brain consistent with the core recollection network (Cabeza & St Jacques, 2007; Moscovitch, 2016; Svoboda et al., 2006; St Jacques, 2012), namely, the medial prefrontal cortex, posterior cingulate/retrosplenial cortex, precuneus, angular gyrus, lateral temporal cortex (middle and superior temporal gyrus), para-hippocampal gyrus and hippocampus. To assess differences between episodic and categoric retrieval, the two memory conditions were contrasted in a separate whole-brain analysis. Consistent with previous research (Ford et al., 2011; Holland et al., 2011), the retrieval of specific (episodic) AMs was associated with greater activity of precuneus, middle temporal, middle frontal and frontal pole regions. Interestingly, we also found greater activity for episodic, compared to categoric retrieval in left and right supramarginal gyri, right angular gyrus and Broca's area, and left cerebellum. Qualitatively, these effects were very similar for the 'whole-trial' and 'elaboration' models. Supporting prior findings, activity in the cerebellum was consistently seen in the memory versus control and specific versus categoric contrasts, for the whole-brain analyses (Addis et al., 2016).

In line with our hypotheses, whole-brain analyses revealed greater activity in the left AG for both specific and categoric retrieval, compared to the control. Clusters also included the hippocampus and precuneus for both contrasts. When comparing differences between specific and categoric trials, higher activation was seen during specific, compared to categoric retrieval in the AG, with specific overlap seen for right PGa. These findings were consistent for both the whole-trial and elaboration phase analyses. The results of these whole brain analyses, indicating the involvement of the AG in both specific and categoric memory retrieval, as well as differential roles for the subregions PGa and PGp formed a solid basis on which the mask analyses could be conducted.

Mask analysis of Specific and Categoric Memories during Elaboration

To investigate our hypotheses directly, we conducted a series of non-parametric mask analyses, specifically assessing activity in left and right PGa and PGp, hippocampus and precuneus. Evidence has shown how the two AG cytoarchitectonic subregions (Caspers et al., 2006) differ functionally and anatomically (Uddin et al., 2010), suggesting differentiated involvement in cognitive processes. Bellana et al. (2023) found that left AG activity was sensitive to both successful recollection and access to prior knowledge, demonstrating the involvement of the region in both episodic and semantic tasks. However, these findings were restricted to the PGp subregion. When contrasting activity between episodic and categoric elaboration, greater activity was seen for specific AM only for the right AG (including PGa and PGp).

To assess more specifically whether AG activity is sensitive to richness, we included self-reported detail responses (1-4) as a regressor to the elaboration phase of both memory conditions (this was done at the first-level). Studies have demonstrated AG involvement and sensitivity to the amount of content and vividness of a memory both in episodic (Berryhill et al., 2007; Berryhill, 2012; Simons et al., 2010; Tibon et al., 2019) and semantic (Ferreira et al., 2015) tasks (Renoult et al., 2019; Rugg & King, 2018; Rugg, 2022). Consistent with these findings, we demonstrated a positive relationship between AG activity and the amount of detail retrieved for both episodic (specific events) and categoric memories. Specifically, only the left PGp activity met our significance corrected threshold of $P < .05$ for both episodic and categoric retrieval, demonstrating a positive relationship between PGp and amount of details retrieved, irrespective of memory type. Contrastingly, right AG activity was seen only for the specific memory condition, with a significant association seen for both right PGa and PGp. This comparison was further investigated by contrasting episodic to categoric elaboration, with details as a regressor. Here we found a stronger positive relationship with the amount of details retrieved in the right AG (both PGa and PGp) for episodic, compared to categoric elaboration.

These findings are also consistent with the limited existing evidence distinguishing activity of PGa and PGp during retrieval. When selecting their ROIs, Bellana et al. (2023) created a reverse inference meta-analytic map using Neurosynth using the term ‘episodic memory’. Of the voxels overlapping with the left AG, the vast majority fell within the PGp area. As justified by the meta-analysis, Bellana et al., (2023) restricted most analyses to PGp. This study has helped clarify the roles of both PGa and PGp in declarative memory for both semantic and episodic memories by assessing BOLD activity for both PGa and PGp. It could be argued that the activity often associated with the left AG (for both specific/episodic and categoric/semantic retrieval) might be mostly derived from area PGp. This would be consistent with evidence demonstrating a strong functional and anatomical connection between PGp and hippocampus, and PGp and the default mode network (Uddin et al., 2010). The behavioural findings presented in this chapter add to this interpretation as they demonstrated no significant difference in number of details being retrieved across conditions, suggesting that functional results would not have been affected by potential differences in quality and content of memories between the two conditions (i.e., had we seen significantly higher detail scores for episodic, compared to categoric memories).

For a more complete description of the brain regions of the core recollection network sensitive to retrieval richness, we also included the hippocampus and precuneus in our mask analyses. These regions' involvement in AM has been widely and consistently recognized (Bird et al., 2012; 2015; Cabeza & St Jacques 2007; Maguire & Mummery, 1999; Moscovitch, 2016). Our results demonstrated no significant difference in hippocampal activity when contrasting specific versus categoric elaboration. Evidence has also demonstrated their association with richness and amount of details retrieved during AM retrieval (Addis et al., 2004; Daselaar et al., 2008). When assessing hippocampal and precuneus sensitivity to richness, our results showed a significant positive relationship between BOLD activity in the left and right hippocampus for both specific and categoric AM retrieval, but the precuneus was only observed for specific memories. When assessing whether activity based on level of details was differentially recruited for specific, compared to categoric memories in these two regions we found a stronger positive relationship between activity during specific elaboration in the left hippocampus and precuneus, consistent with the findings of previous studies investigating AM elaboration (Addis et al., 2004; Holland et al., 2011).

Limitations and Future Directions

Due to time restraints and technical difficulties, which meant we would have had to remove thirteen participants, we were unable to assess findings from the post-scan task in relation to BOLD activity during elaboration. Future studies could include the self-reported measure of visual perspective as a regressor, similarly to how we analysed the effect of details on activity. With the collection of more data, we hope to assess the relationship between our selected regions and perspective in future. As I discuss in previous chapters, previous evidence has shown involvement of both the AG and precuneus in the switching of perspective during retrieval (for a review see St Jacques, 2022). Consistent with Rice and Rubin's (2009) ideas, our post-scan perspective scale ranged from 1 – 5, accounting for the possibility that perspective can be shifted within the same retrieved event and is therefore not necessarily binary (i.e., Field Vs Observer). We also did not compare activity between search and elaboration of memories. Though this has been investigated using a similar paradigm in the past (Addis et al., 2007), we felt the large, significant difference between search and elaboration duration would have been a substantial confound in the interpretation of our results.

Conclusion

In summary, we demonstrate evidence supporting the involvement of the left AG in the retrieval of rich memories. In particular, we demonstrate how this involvement is specific to the left PGp region, irrespective of whether the condition is episodic or categoric, but there seems to be a significant difference and greater association between episodic retrieval and right AG, comprising both PGa and PGp. These findings add to limited existing knowledge of the functional differences between subregions of the AG, as well as demonstrate activity of the left AG for both episodic driven and semantically driven tasks.

5.5 Supplementary Material

Table 5.8. List of abbreviations as seen in Figures of main text, with respective brain regions:

INS	Insular Cortex
IFGTr	Inferior Frontal Gyrus, pars triangularis
OFC	Frontal Orbital Cortex
FO	Frontal Operculum Cortex
FP	Frontal Pole
MidFG	Middle Frontal Gyrus
MTG	Middle Temporal Gyrus
SMGp/a	Supramarginal Gyrus, posterior division/anterior
PFm	Inferior Parietal lobule, PFm
Pga	Inferior Parietal lobule, Pga
PF	Inferior Parietal lobule, PF
PingG	Paracingulate Gyrus
CingG	Cingulate Gyrus
PreC	Precuneus
PG	Precentral Gyrus
STGp	Superior Temporal Gyrus, posterior division
PHG	Parahippocampal Gyrus
Cllm	Cerebellum
TH	Thalamus
CC	Cuneal Cortex

Table 5.9. Whole-trial model of main effects of memory condition, compared to control. This is a more extensive representation of the data seen in Table 5.1 as atlas labels are not thresholded to >5%.

Brain regions activated during Categoric AM retrieval, compared to the control task (letter change task)

Cluster Index	Voxels	Z score	MNI X (mm)	MNI Y (mm)	MNI Z (mm)	Atlas label(s)
8	11672	6.86	-52	34	8	Frontal Pole (12.4%); Superior Frontal Gyrus (7.7%); Middle Frontal Gyrus (9.0%); Inferior Frontal Gyrus, pars triangularis (3.6%); Inferior Frontal Gyrus, pars opercularis (2.3%); Precentral Gyrus (1.0%); Paracingulate Gyrus (2.7%); Frontal Orbital Cortex (3.7%); GM Broca's area BA44 L (4.2%); GM Broca's area BA45 L (6.3%); GM Premotor cortex BA6 L (4.7%)
7	10433	7.48	-10	-60	8	Intracalcarine Cortex (7.6%); Cingulate Gyrus, posterior division (2.8%); Precuneous Cortex (8.1%); Cuneal Cortex (2.4%); Parahippocampal Gyrus, posterior division (4.1%); Lingual Gyrus (11.5%); Temporal Fusiform Cortex, posterior division (2.8%); Temporal Occipital Fusiform Cortex (1.1%); Supracalcarine Cortex (3.3%); GM Hippocampus cornu ammonis L (4.5%) & R (2.1%); GM Hippocampus dentate gyrus L (2.3%); GM Hippocampus subiculum L (3.5%)& R (2.2%); GM Visual cortex V1 BA17 L (9.5%) & R (6.9%), V2 BA18 L (7.0%), & R (5.1%), V3V L (1.8%); WM Callosal body (5.4%); WM Optic radiation R (3.2%)& L (6.1%); Left I-IV (1.7%); Left V (1.3%); Right IX (3.0%);Left Hippocampus (4.3%) & Right Hippocampus (2.0%)
6	4314	6.43	44	-70	-40	Occipital Fusiform Gyrus (1.0%); Right VI (8.1%); Right Crus I (32.5%); Right Crus II (27.5%); Right VIIb (3.9%)
5	1633	6.33	-38	-76	36	Angular Gyrus (2.6%); Lateral Occipital Cortex, superior division (47.6%); GM Anterior intra-parietal sulcus hIP1 L (1.1%); GM Inferior parietal lobule PFm L (1.3%); GM Inferior parietal lobule Pga L (14.5%); GM Inferior parietal lobule PGp L (30.4%)
4	950	5.06	-4	-14	12	WM Callosal body (12.4%); WM Fornix (4.1%); WM Superior occipito-frontal fascicle L (1.0%); Left Thalamus (22.4%); Left Caudate (25.8%)
3	559	6.07	-4	60	-4	Frontal Pole (33.3%); Frontal Medial Cortex (24.8%); Paracingulate Gyrus (9.4%)
2	273	4.18	-62	-44	-4	Superior Temporal Gyrus, posterior division (6.6%); Middle Temporal Gyrus, posterior division (30.1%); Middle Temporal Gyrus, temporooccipital part (13.8%); Supramarginal Gyrus, posterior division (2.6%)
1	247	4.18	-54	-6	-16	Superior Temporal Gyrus, anterior division (8.8%); Superior Temporal Gyrus, posterior division (10.5%); Middle Temporal Gyrus, anterior division (15.0%); Middle Temporal Gyrus, posterior division (18.7%)

Brain regions activated during Specific AM retrieval, compared to the control task (letter change task)

Cluster Index	Voxels	Z score	X (mm)	Y (mm)	Z (mm)	Atlas label(s)
3	34088	7.53	-24	-34	-18	Frontal Pole (4.9%); Superior Frontal Gyrus (3.5%); Middle Frontal Gyrus (3.6%); Inferior Frontal Gyrus, pars triangularis (1.4%); Intracalcarine Cortex (1.8%); Paracingulate Gyrus (2.1%); Cingulate Gyrus, posterior division (1.1%); Precuneous Cortex (2.8%); Frontal Orbital Cortex (1.4%); Parahippocampal Gyrus, posterior division (1.3%); Lingual Gyrus (3.4%); Temporal Fusiform Cortex, posterior division (1.3%); GM Broca's area BA44 L (1.7%); GM Broca's area BA45 L (2.4%); GM Hippocampus cornu ammonis L (1.3%); GM Hippocampus subiculum L (1.1%); GM Visual cortex V1 BA17 L (2.2%) & R (1.6%); GM Visual cortex V2 BA18 L (1.6%) & R (1.1%); GM Premotor cortex BA6 L (2.0%); WM Callosal body (1.6%); WM Optic radiation L (1.5%); Right VI (1.7%); Right Crus I (5.0%); Right Crus II (3.8%); Left Thalamus (1.8%); Left Hippocampus (1.2%)
2	3350	6.52	-32	-80	40	Superior Temporal Gyrus, anterior division (1.4%); Superior Temporal Gyrus, posterior division (6.2%); Middle Temporal Gyrus, anterior division (1.9%); Middle Temporal Gyrus, posterior division (6.6%); Middle Temporal Gyrus, temporooccipital part (2.8%); Supramarginal Gyrus, posterior division (2.3%); Angular Gyrus (4.6%); Lateral Occipital Cortex, superior division (27.4%); GM Inferior parietal lobule PFm L (1.3%); GM Inferior parietal lobule Pga L (8.3%); GM Inferior parietal lobule PGp L (17.0%)
1	419	5.25	-4	56	-6	Frontal Pole (30.1%); Frontal Medial Cortex (26.6%); Paracingulate Gyrus (15.9%)

Table 5.10. Details Model (elaboration phase). Whole-brain BOLD activity for categoric and episodic elaboration with details as a regressor.

Specific Elaboration

Cluster Index	**Voxels**	**Z score**	**MNI X (mm)**	**MNI Y (mm)**	**MNI Z (mm)**	**Atlas label(s)**
10	18795	5.35	-4	-70	24	Precuneous Cortex (13.9%)
9	2354	4.66	16	-50	-48	Left VI (19.1%); Right VIIIa (10.2%)
8	508	4.36	28	-60	-22	Right VI (58.8%); Right Crus I (25.4%)
7	472	4.2	-62	-42	24	Supramarginal Gyrus, anterior division (18.4%); Supramarginal Gyrus, posterior division (20.9%); Parietal Operculum Cortex (15.0%); GM Inferior parietal lobule PF L (43.8%); GM Inferior parietal lobule PFcm L (20.4%); GM Inferior parietal lobule PFm L (15.0%)
6	463	4.15	-44	-78	16	Lateral Occipital Cortex, superior division (59.0%); GM Inferior parietal lobule PGp L (43.3%)
5	345	4.42	56	-44	22	Middle Temporal Gyrus, temporooccipital part (10.7%); Supramarginal Gyrus, posterior division (24.5%); Angular Gyrus (22.2%); GM Inferior parietal lobule PFm R (18.4%); GM Inferior parietal lobule Pga R (15.2%)
4	272	4.04	40	10	8	Insular Cortex (20.3%); Central Opercular Cortex (19.4%)
3	222	4.04	-30	46	24	Frontal Pole (57.9%)
2	204	4.44	50	-4	-18	Temporal Pole (12.6%); Superior Temporal Gyrus, anterior division (14.2%); Middle Temporal Gyrus, anterior division (10.1%)
1	164	3.97	60	-28	38	Supramarginal Gyrus, anterior division (24.0%); Parietal Operculum Cortex (24.9%); GM Inferior parietal lobule PF R (24.6%); GM Inferior parietal lobule PFcm R (29.8%); GM Inferior parietal lobule PFop R (15.5%); GM Secondary somatosensory cortex / Parietal operculum OP1 R (22.8%)
Categoric Elaboration						
1	192	3.91	-14	20	4	Left Caudate (50.4%); Left Putamen (10.8%)

Chapter 6 - General Discussion

6.1 Thesis Overview

At the heart of this thesis are the questions, what makes our memories rich and vivid, allowing us to feel as though we are re-living an event, and what is the corresponding neural activity associated with these highly detailed memories. Two main areas were assessed from a behavioural standpoint: the effect of multisensory environments and visual perspective on objective and subjective aspects of retrieval (Chapters 2 and 3). For the neuroimaging part of this thesis, I focused specifically on the role of the AG in the retrieval of rich memories (Chapter 5). This final chapter will review results from the three experimental chapters (Chapters 2, 3 and 5), discuss the theoretical implications of the results gathered, as well as outline the studies' limitations, important methodological considerations, and consider future directions.

6.2 Summary of Findings

Chapter 2 reported the piloting of a new stimulus set, comprising a set of videos, filmed from a field view, and depicting everyday life events. Following quality checks, free recall and recognition performance were assessed to select a subset of videos which would be later used in Experiment 2. In this second study, I investigated differences in the subjective and objective retrieval of memories, across different modalities, comparing retrieval of unisensory versus multisensory settings, as well as retrieval differences for visual, compared to auditory information. Participants reported a higher sense of presence for multisensory, compared to unisensory stimuli, and significantly lower confidence and vividness scores for audio-only videos, compared to other modalities. Using a newly developed scoring system, free recall interviews were scored and analysed. We found that participants were significantly better at retrieving details for audio-only events, compared to other modalities (visual-only and audio-visual). It is unclear whether these results demonstrate a true preference for audio-only environments or a task difficulty effect, with greater ease for the audio-only videos, which contained fewer details than the visual and audio-visual ones. Only when comparing visual and audio-visual memory performance did we observe higher retrieval accuracy for multisensory stimulus presentation. In line with this task difficulty interpretation, when retrieving multisensory events, participants were much better at accurately recalling visual, compared to auditory details. Moreover, when analysing free recall performance, we found that audio-only videos contained the lowest number of descriptive details (lowest richness), compared to other modalities. Interestingly, pairing visual information with sounds did not increase the richness of descriptions, with visual-only videos being associated with the highest number of descriptive details produced across the three modalities. When considering the type of sensory information being described for the multisensory stimuli, we observed that participants were significantly better at providing visual, compared to auditory descriptions.

Experiments in Chapter 3 followed a very similar procedure to those in Chapter 2, but the focus here was on the effect of perspective on subsequent retrieval performance. Experiment 3 from this chapter reported the piloting of another set of video stimuli, filmed from an observer perspective. These were filmed either with a moving or static camera frame. Experiment 4 compared the accuracy of correctly recognising a video as being filmed from either a field or observer perspective and included the videos of Experiment 3, as well as those from Chapter 2. The results of this study allowed me to select a subset of observer moving and field videos, which were later used for Experiment 5. Finally, experiment 5 assessed subjective and objective retrieval differences between the two perspectives. We found that participants had a higher sense of presence when watching videos from a field perspective, compared to an observer one, but no differences in the reported confidence and vividness between the two modalities. Using the same scoring system as in Experiment 2, we also found no effect of perspective on objective memory performance. However, when assessing the effect of perspective and type of detail retrieved on memory accuracy, we observed a significant interaction. Participants were significantly better at retrieving visual than auditory information for both field and observer videos but were also significantly better at retrieving auditory details for observer videos, compared to field. When assessing the richness of memories, we found that participants freely recalled a greater number of descriptive details when retrieving observer videos, compared to field ones, but were also more likely to wrongly remember certain details for observer videos. Finally, both Experiment 2 and Experiment 5 failed to demonstrate a significant relationship between subjective scores (at encoding and retrieval) and objective measures of retrieval (free recall; see discussion below).

Chapter 4 reviewed the literature on the role of the AG in episodic memory retrieval and discussed existing theories explaining the involvement of the AG in the retrieval of highly detailed, multisensory, and egocentric memories. Here I proposed that the role of the AG is more closely related to the richness of the recollected memory, rather than to remembering multisensory events per se, or to retrieval from an egocentric perspective. Nonetheless, if the level of activity in the AG follows the amount of content being retrieved, we would expect to see the involvement of this brain region in the retrieval of memories rich in multisensory details and associated with higher vividness scores. I also argued that this sensitivity to the richness of retrieved content should be observed irrespective of the type of memory information, namely whether it is more semantic or episodic in nature.

Chapter 5 tested the proposal of Chapter 4 that the angular gyrus would be sensitive to the richness of recollected information and amount of details retrieved in an fMRI study, comparing retrieval of specific (episodic) and categoric (repeated/semantic) autobiographical memories. To assess the richness of memories, we used self-reported scores of amounts of details remembered. In line with our predictions, we found that activity in the left AG (restricted to area PGp) increased with the amount of details being retrieved, both for specific and categoric memories. When comparing specific versus categoric retrieval, we observed stronger parametric modulation of right PGa and PGp with the amount of details retrieved for specific than for categoric memories.

6.3 Integrating Findings and Relation to the Broader Literature

Cognitive Correlates of Rich and Vivid Memory for Real World Events

Our sense of re-living and ability to mentally travel back in time relies heavily on the richness of the visual imagery being retrieved (Zaman & Russell, 2022) and each experience must hold a viewpoint in one’s mind's eye, both when first experienced and when subsequently remembered (St. Jacques, 2021). These two aspects of memory retrieval are at the centre of the behavioural studies conducted in this thesis, comparing the effects of unisensory versus multisensory processing, and of field versus observer perspective on subjective and objective aspects of memory retrieval.

Taking inspiration from the VR literature, studies in Chapters 2 and 3 explored differences in reported sense of presence ratings for different events and the relationship between presence and retrieval performance. To our knowledge, this measure has not been assessed outside the VR field but can provide useful insight into the immersiveness of ecologically valid stimuli, and its impact on retrieval performance. Two key features that have been shown to contribute to a heightened sense of presence are the field of view from which an individual experiences the VR environment, and the presentation of coherent multisensory information (Coelho et al., 2006; Makowski et al., 2017; Smith, 2019). More specifically, studies have demonstrated how experiencing an environment from a field perspective (Denisova & Cairns, 2015; Iriye & St Jacques, 2021; Kallinen et al., 2007) and the use of realistic multisensory inputs (Iachini et al., 2019; Makowski et al., 2017; Witmer & Singer, 1998) can increase the sense of presence reported by participants. Consistent with these findings, we found higher sense of presence ratings reported for field, compared to observer videos, as well as for multisensory, compared to unisensory videos. Interestingly, no difference was seen between audio-only and visual-only videos, consistent with an association between presence and multisensory environments.

Less is known about the relationship between presence and memory performance, with few studies having assessed this relationship directly, and reporting either a positive relationship between these two measures (Davis et al., 1999; Lin et al., 2002; Mawkoski et al., 2017) or no relationship at all (Buttussi & Chittaro, 2018; Dinh et al., 1999). A higher sense of presence could increase our selective attention to a virtual environment and decrease external distractions, resulting in a positive relationship between presence and memory performance. However, those features which give us a more immersed experience (i.e., rich perceptual details, ambient sounds) could also lead to divided attention within the virtual environment, thereby nullifying this relationship (Smith, 2019). Our results consistently failed to show this relationship. In behavioural experiments of Chapters 2 and 3, presence ratings were not significant predictors of recall accuracy. However, it is difficult to use Smith's (2019) explanation for both experiments. In experiment 2, the inclusion of sounds in the multisensory condition led to higher presence scores but may have resulted in participants dividing attention and becoming distracted by the presentation of sounds. This reasoning however cannot be used to explain the results of Experiment 5, where participants were exposed to multisensory details for both perspectives but reported higher presence for field, compared to observer videos, with no relationship seen between presence and retrieval performance.

Interestingly, we also did not find a relationship between subjective measures of retrieval (confidence and vividness) and objective memory accuracy, though positive relationships with retrieval success have previously been reported for both vividness ratings (D’Angiulli et al., 2013; Jackson & Schacter, 2004; Alghamdi & Rugg, 2020) and confidence judgements (Yonelinas, 1994, 2001). The key differences between these studies and the studies reported in this thesis are the type of stimuli being presented and the memory tests used. For instance, while our experiments used complex and rich video stimuli, past studies have mainly focused on the use of word lists and picture-word pairs (Alghamdi & Rugg, 2020; D’Angiulli et al., 2013; Jackson & Schacter, 2004; Yonelinas, 1994), and have used source memory tests or R/K paradigms (Alghamdi & Rugg, 2020; Jackson & Schacter, 2004; Yonelinas, 1994; 2001) rather than free recall tests. It could be argued that our findings are linked to the increased complexity of the stimuli being shown and increased difficulty in freely recalling events, compared to recognition or source memory tests, resulting in a decoupling of the correlation between subjective and objective measures. However, Oedekoven et al., (2017) did find a robust relationship between vividness, and memory performance in young adults, using a video stimulus set, similar vividness measure (1-6 Likert scale) and free recall test, suggesting that the relationship between vividness and retrieval can be observed in the context of real-world events and measuring recall performance.

Despite not finding a positive relationship between subjective and objective measures of memory retrieval, we did see differences in confidence and vividness scores when comparing ratings for unisensory and multisensory videos. Both confidence and vividness scores were significantly higher for the retrieval of visual-only and audio-visual videos, compared to audio-only stimuli. Similar results were also seen when comparing the measure of 'richness' (number of descriptive details) between modalities, with highest richness scores seen for visual videos and lowest for audio-only videos. Consistent with these findings, Rubin et al., (2003) showed how highly re-lived AMs were associated with the retrieval of vivid visual images. Vividness ratings have typically been defined as representing the richness of the memory, and the sense of re-experiencing the original event (Rubin & Kozin, 1984; Talarico, et al., 2004; Folville et al., 2021). From our results it would seem the richness of retrieval is associated with the presence of visual details, irrespective of whether these are accompanied by congruent sounds or not, but that this sense of re-experiencing significantly decreases when we experience events without visual information, as seen with the audio-only stimuli.

Differences in confidence and vividness reports were not seen for the comparison of field versus observer videos. To date, only one study has shown a reduction in vividness ratings for observer events, compared to field ones, when perspective was manipulated at encoding (Bergouignan et al., 2014). Consistent with our results, these differences have not been supported by more recent studies, demonstrating no differences in confidence (Leynes et al., 2017) and vividness scores (Iriye & St. Jacques, 2021) when comparing field and observer perspectives. Our findings add to the limited research existing on the manipulation of visual perspectives and its impact on subjective and objective measures of memory retrieval. It seems that the reductions in vividness seen following a shift from a field to observer perspective (Butler et al., 2016;

Verghaegen et al., 2018) might be representing a loss of visual information, resulting from the added difficulty in remembering a memory from a novel perspective, rather than an intrinsic difference in the phenomenological experience associated with observer memories.

With regards to objective measures of retrieval performance, results from Chapter 3 show no differences in recall accuracy (details recalled/total details) between field and observer videos. Once again, studies manipulating perspective at encoding have shown contradictory effects on retrieval accuracy, with some demonstrating poorer recognition performance and retrieval of fewer details for observer, compared to field views (Bergouignan et al., 2014; Leynes et al., 2017) and another study showing no differences between the two perspectives in the number of details freely recalled by participants (Iriye & St. Jacques, 2021). Consistent with these latter findings (Iriye & St. Jacques, 2021), the results of Chapter 3 show that encoding events from an observer perspective does not seem to reduce our ability to retrieve details pertaining to that event.

Experiment 5 (Chapter 3) also goes a step further in assessing differences in the type of details being retrieved, as well as the richness of memories, measured through the number of additional descriptive details. Our results demonstrated higher accuracy for visual, compared to auditory details for both video modalities (field and observer) and increased retrieval of auditory details for observer videos, compared to field ones. Thinking back to the points discussed by Smith (2019), it could be argued that the increased immersiveness of field videos, illustrated by higher presence scores, may have led to dividing attention and resulted in allocating more attention to the visual details of the video and less to surrounding sound. In comparison, observer videos could result in viewing an environment as more of a ‘whole’/external viewpoint and could have increased retrieval accuracy for peripheral information. The increased attention to details shown in observer videos, compared to field ones is also seen when assessing the richness of memories. Participants freely recalled more descriptive details, both auditory and visual, for observer compared to field videos, suggesting again that adopting an observer viewpoint may help retrieve in a perceptually rich way.

Finally, an improved performance for the retrieval of visual, compared to auditory information was also seen in the results from Chapter 2. When shown multisensory (audio-visual) environments, participants were significantly better at recalling visual, compared to auditory information. This is consistent with studies demonstrating a human propensity to be more attentive to visual items and have a higher capacity to retain visual information (Colavita, 1974; Brady et al., 2008; Koppen & Spence, 2007). This idea was also supported by findings of higher richness (number of descriptive details retrieved) for visual-only videos, and lowest for audio-only. However, surprisingly, encoding multisensory videos was not associated with higher richness, compared to a unisensory format. Also, not in line with our predictions, results demonstrated higher free recall scores for audio-only stimuli and lowest for visual-only videos. These findings contradict prior research which consistently shows better memory performance for multisensory, compared to unisensory stimuli (Bonnici et al., 2016; Lehmann & Murray, 2005; Murray et al., 2004; Schroeder & Marian, 2016; Thelen et al., 2014). One main explanation for why our results may differ is the stark difference in the total number of details associated with each sensory modality. A negative correlation was shown between the total number of details present in each video modality and accuracy scores, suggesting that these findings may relate more to task difficulty. Despite this negative correlation and a significant difference in the number of details presented between visual and audio-visual videos, participants demonstrated better memory performance for audio-visual videos, compared to visual ones, suggesting some preference for multisensory, compared to unisensory environments.

Neural Correlates of Rich and Vivid Autobiographical Memory

The main goal of Chapter 5 was to investigate the involvement of the AG, specifically PGa and PGp subregions, during the elaboration of episodic (specific) and semantic (categoric) AMs. Over the last two decades, consensus has built recognising the AG as a key brain region involved in the successful recollection of memories, becoming part of the 'core recollection network' (Rugg & Vilberg, 2013). Key theoretical accounts explaining the role of the AG in the retrieval of episodic memories were reviewed in Chapter 4. Though conceptually distinct, these theories can all be somewhat integrated by associating the AG's involvement in memory with retrieval success. For instance, the convergence of multimodal features, or selectivity of the AG for highly vivid, egocentric memories could all be linked to this region's sensitivity to the amount of content and richness of the memory being retrieved. This role also seems to apply irrespective of whether the memory content is more episodic or semantic in nature. Prior research has linked AG involvement and sensitivity to rich, successful recollection of a memory both in episodic (Berryhill et al., 2007; Berryhill, 2012; Simons et al., 2010; Tibon et al., 2019) and semantic (Ferreira et al., 2015) tasks (Renoult et al., 2019; Rugg & King, 2018; Rugg, 2022). However, these two types of memory have typically been studied in isolation.

The study outlined in Chapter 5 specifically investigated the role of the AG in the retrieval of both episodic (measured through specific AM) and semantic (categoric AM) memories, within the same experimental paradigm. This study's novelty rests in the differentiation of the role of AG subregions, PGa and PGp in the retrieval of rich memories, measured by the amount of details participants reported remembering. Though these subregions have been identified for some time (Caspers et al., 2006), we have very limited knowledge regarding their potentially differentiated role in memory retrieval, with few studies investigating this question directly (Bellana et al., 2023; Kuhnke et al., 2023). Furthermore, there seem to be inconsistencies in how PGp and PGa are subdivided, either based on their cytoarchitectonic structure (Bellana et al., 2023) or as ventral and dorsal regions of the AG (Kuhnke et al., 2023). Our study sets out to investigate the role of PGa and PGp separately, using the Juelich Histological Atlas (as part of FSL) which separates brain regions based on their differences in cytoarchitecture (as used in Bellana et al., 2023).

Consistent with our predictions that we would find a positive relationship between activity in the AG and richness of the retrieved memories, irrespective of whether they are more episodic or semantic in nature, we observed left AG activity for both types of AMs. Focusing more specifically on the differential role of PGa and PGp, this relationship was seen for both memory types only for area PGp. When contrasting specific, versus categoric memories, we found a positive relationship with the amount of details retrieved in the right AG (both PGa and PGp) for specific but not categoric AMs.

These results provide evidence to suggest AG involvement in both episodic and semantic memory retrieval, and that this activity is in fact positively associated with the richness and amount of content being retrieved. We were also able to demonstrate differentiated activity and involvement of PGa and PGp in memory retrieval. Namely, only left PGp seems to be modulated by richness, irrespective of the type of memory being remembered. Conceptually, this could be explained by evidence showing a strong functional and anatomical connection between PGp and the default mode network, including the hippocampus, supporting the involvement of this region in recollection (Uddin et al., 2010). However, there does also seem to be some differences between specific and categoric retrieval, with activity of both right PGa and PGp being associated with the amount of details recalled for specific memories, but not for categoric ones.

6.4 Limitations and Future Directions

The first two pilots of Chapters 2 and 3 (Experiments 1 and 3), conducted on Qualtrics did not include breaks or distraction tasks between the encoding and retrieval phases. Though this could have been implemented had all videos been shown at encoding separately, I was concerned with the difficulty of the task due to the large number of video stimuli they were asked to watch. For instance, in Experiment 1 of Chapter 2, participants were asked to encode and retrieve 21 videos in total. To conduct a within-subjects design, participants would have been asked to watch all 21 videos and retrieve them following title cues in a separate retrieval phase. I believed this setup would have increased the likelihood of seeing floor effects, as it would have been too challenging for participants to retrieve all 21 stimuli. Reassuringly, our results demonstrated no ceiling effects despite not having included breaks or distraction tasks.

These were also the first two studies to be conducted as part of the PhD project and to be adapted for an online environment during the first COVID-19 lockdown. The inexperience with online setups can be seen in these two studies, such as controlling for the time taken to complete the task and ensuring participants did not pause during the experimental task. One way I attempted to mitigate the issue of unaccounted breaks during the completion of the task was to instruct participants to only leave the environment temporarily and in between blocks. This was to ensure participants did not take breaks between the encoding and retrieval phases of each video ‘block’, but rather waited for the retrieval phase to end if a break was necessary. The progress in designing online studies can be seen in the behavioural experiments in Chapters 2 and 3 (Experiments 2 and 5), where the Gorilla task was conducted in the same fashion as an in-lab experiment by providing instructions verbally, through a Teams call that lasted the whole duration of the experiment and for which it was possible to strictly control for the duration of the task and breaks. Conducting the experiment via a Teams call also ensured some control over the environment of the participant, such as limiting distractions and background noises (i.e., asking participants to move rooms if they were surrounded by other people, or if the TV was on in the background).

Focusing specifically on studies presented in Chapter 3, which examined the effect of perspective on retrieval, it could be argued that none of the videos are truly encoded from a ‘Field’ perspective, making it difficult to compare behaviour between first-person and third-person perspective videos. Unlike autobiographical memories or even VR environments (Iriye & St Jacques 2021; St. Jacques et al., 2011), using a video stimulus set could reduce the distinction between either perspective. This conceptual limitation in the design was addressed by conducting two pilot studies which compared the ability to accurately define a video as being filmed from a field or observer perspective. Interestingly, participants were highly accurate in determining whether a video was filmed from a field or an observer perspective. Based on the results from these pilot studies, we were able to select a subset of videos, identified as field or observer, without the confound of movement (i.e., resulting from the comparison of static observer and moving field videos). I would argue the identifiable distinction between the two perspectives still makes this a useful stimulus set for the investigation of perspective and memory while being able to assess objective accuracy which would not typically be possible in a design using autobiographical memories.

A further limitation of the stimulus set is the large unbalance of auditory, compared to visual details. This particularly applies to the analysis of Experiment 2, Chapter 2, where the number of freely recalled details against the total was significantly higher for audio-only events, compared to visual-only and audio-visual ones. Due to the stark difference between total details available between conditions, it could be argued that these effects represent a task difficulty difference, where retrieving auditory details was easier as there were very few details, compared to the other modalities. Though this imbalance between auditory and visual information is representative of our real-life environment, future studies could remove the confound of task difficulty by creating and filming videos, for which the number of auditory details is manipulated. By using YouTube videos, I had little control over this difference in the total number of sensory details present. Perhaps performing and filming events would allow more freedom and standardisation. For instance, by filming more visually bare environments (room with few objects) and having an actor perform actions that are likely to produce different auditory details. Hands on manipulation like this would ensure environments could still be representative of everyday life (unlike adding additional ambient sounds to an existing video) while reducing the difference in total details present between sensory modalities.

While collecting data for Experiment 5, (Chapter 3) participants were shown all videos again at the end of the free recall phase to provide perspective judgements. This brought about discussions with participants about the details they had forgotten or remembered differently and why (e.g., memory errors resulting from an association between the video and a prior personal event), as well as what hobbies and individual differences they thought were linked to their verbal proficiency (i.e., writers and avid readers). These discussions made me raise two questions: firstly, the importance and extent to which individual differences between participants, for instance with regards to occupation and hobbies they partake in, could result in differences in retrieval performance. Secondly, the extent to which vocabulary ability affects mental imagery and our ability as researchers to measure retrieval performance while using free recall tests if response to these is dependent on the ability for a participant to describe what they remember. For both questions, it would be interesting in future research to include questionnaires evaluating not only vocabulary ability but also the lifestyle of participants, from educational background to hobbies and interests, as a way of measuring the relationship between these individual differences and the ability to describe episodic memories. Further, it would be interesting to create novel designs or use alternative memory test measures to assess retrieval, which may not be as reliant on vocabulary ability as a free recall test.

For instance, Iriye and St Jacques (2021) asked participants to draw maps of the layout of the VR environment experienced. In direct relation to the current study, participants could be presented with the video again, following the free recall test and be asked to describe and rate to which extent their mental imagery of the event differed from the encoded video. It could also yield valuable information to use modified recognition tasks, such as where participants are shown video segments of a previously experienced event against similar environments filmed by someone else (Misra et al., 2018); or a spot the difference task for scenes from the video (including both visual items and sounds), as well as recognition tests whereby sounds are not presented in written format, i.e., ‘rain’ but rather for which participants are presented with sounds, both present during the video, as well as lures of differing similarity and asked to select which of the sounds they believed were present at encoding. These measures could help investigate to what extent our increased ability to retrieve visual information is simply due to a greater aptitude and retention ability, as well as to what extent are findings from the current studies a result of increased difficulty in describing auditory, compared to visual items.

Finally, with regards to Chapter 5, we were unable to assess results from the post-scan task. This was in part due to technical difficulties which led to thirteen participants not completing post-scan questions for all of the cue words presented during scanning, and in part due to time restraints which meant I was not able to analyse these findings. It would have been especially relevant to this thesis to use the measure of visual perspective as a parametric regressor. As discussed in Chapter 1, prior studies have shown the involvement of the AG and precuneus in holding an egocentric field of view and updating to a novel perspective during retrieval (Freton et al., 2014; Hebscher et al., 2018; Russell et al., 2019; St Jacques et al., 2017; 2018). Future analyses of this dataset could investigate this relationship further, using a similar mask-based approach as was conducted in Chapter 5. A natural shift to an observer perspective is typically linked to more remote memories (Verhaeghen et al., 2018). It would be interesting to investigate whether this is represented in the current dataset, and whether the link between observer memories and reduced amount of details retrieved is mediated by the remoteness of memories as previously suggested (Rice & Rubin, 2009), or whether this is an inherent phenomenological aspect of holding an observer viewpoint.

6.5 Conclusion

The research presented in this thesis provides both a behavioural and neuroimaging perspective of components that affect the richness of our memories. Following the creation of a new stimulus set of real-world events, we demonstrate an increased sense of presence for events rich in realistic multisensory details and viewed from a field perspective, as well as a preference and greater ability in retrieving visual perceptual details, compared to auditory ones. We do not reliably find evidence for better memory performance of multisensory compared to unisensory stimuli and the richness of memories was also not positively affected by the encoding of multisensory, compared to unisensory videos. Encoding an event from either a field or observer perspective does not seem to affect retrieval performance, however, the richness of memories retrieved was higher for videos filmed from an observer, compared to field perspective. Finally, we provide further evidence of the role of the AG in the retrieval of episodic and semantic memories. Our findings show how activity in left PGp is positively associated with the richness of our memories, irrespective of the type of memory being recalled. We also demonstrate how the subregions of the AG respond differently, with only left PGp being modulated by richness for both specific (episodic) and categoric (semantic) memories and right AG (both PGp and PGa) showing this relationship for specific but not categoric AMs.

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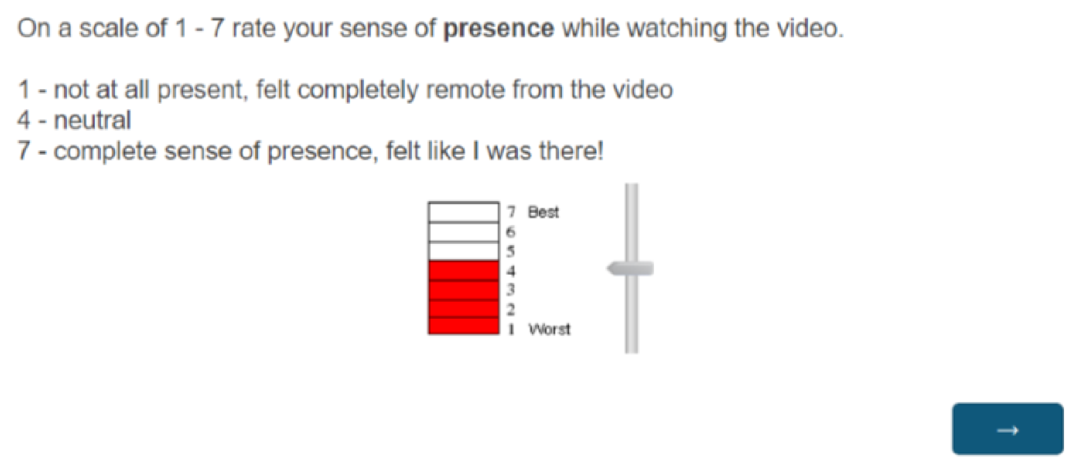
Appendices

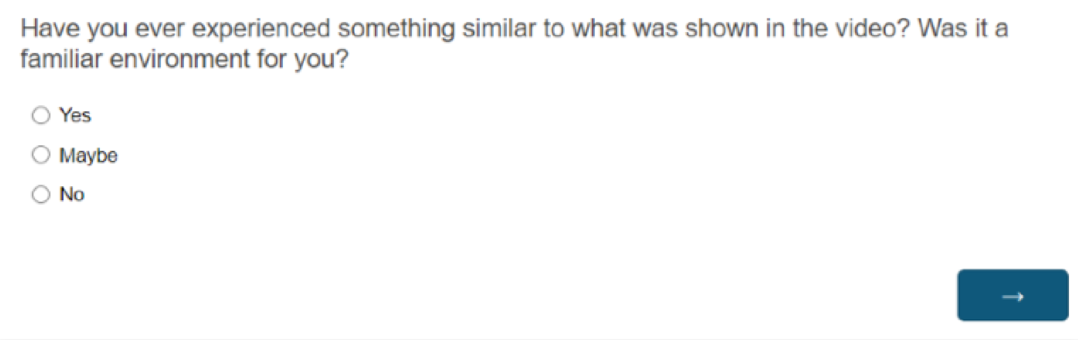
Appendix A: Screenshots of questions from Experiment 1 and Experiment 3

Screenshots from the Qualtrics pilot outlined in the Experiment 1 section of Chapter 2. The study was conducted to assess the quality of a new stimulus set. The same procedure and set-up was used for Experiment 3 of Chapter 3, where the quality of third-person perspective videos was assessed. This also included a perspective judgement task, shown in the Procedure section of Experiment 3. Screenshots are in order of presentation.



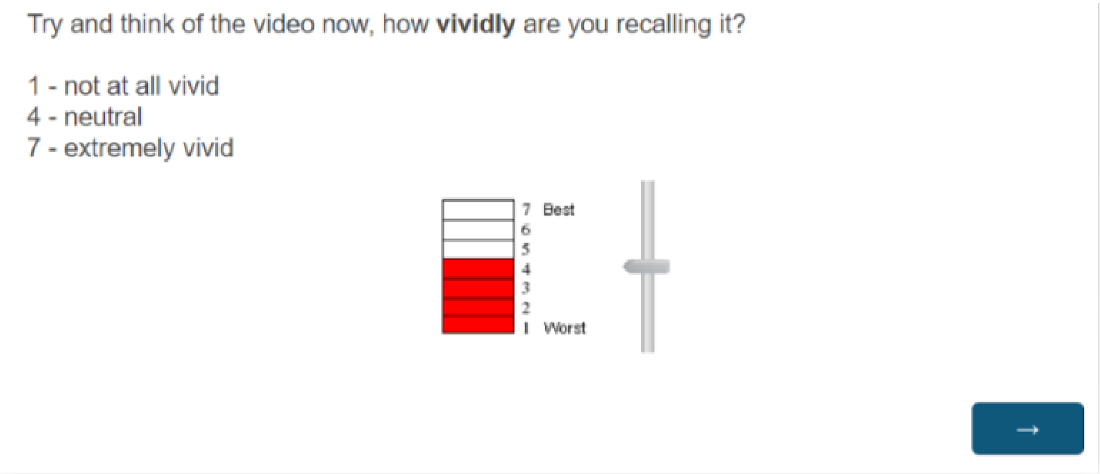
On a scale of 1 - 7 rate your sense of **presence** while watching the video.

1 - not at all present, felt completely remote from the video
4 - neutral
7 - complete sense of presence, felt like I was there!



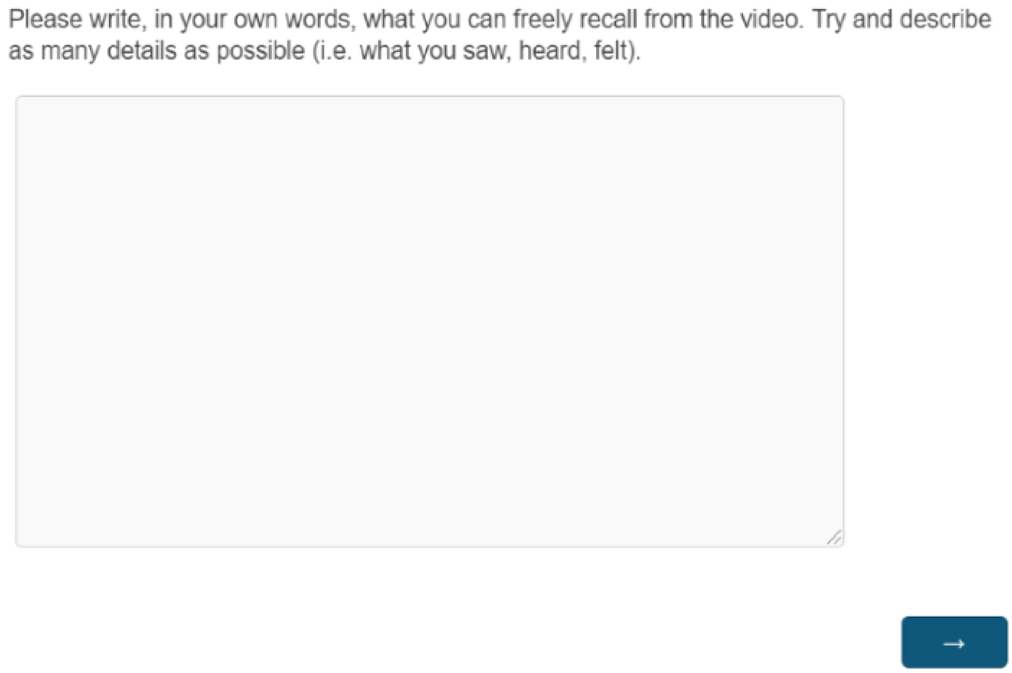
Have you ever experienced something similar to what was shown in the video? Was it a familiar environment for you?

○ Yes
○ Maybe
○ No

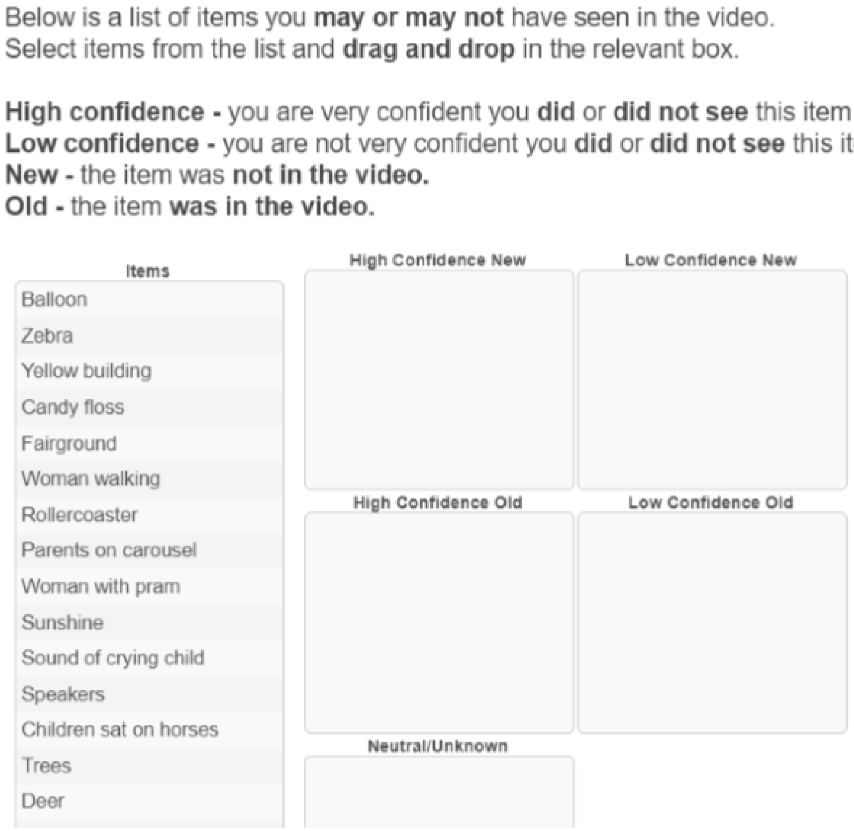


Try and think of the video now, how **vividly** are you recalling it?

1 - not at all vivid
4 - neutral
7 - extremely vivid



Please write, in your own words, what you can freely recall from the video. Try and describe as many details as possible (i.e. what you saw, heard, felt).



Below is a list of items you **may or may not** have seen in the video.
Select items from the list and **drag and drop** in the relevant box.

High confidence - you are very confident you **did** or **did not see** this item before.
Low confidence - you are not very confident you **did** or **did not see** this item before.
New - the item was **not in the video.**
Old - the item **was in the video.**

Items
- Balloon
- Zebra
- Yellow building
- Candy floss
- Fairground
- Woman walking
- Rollercoaster
- Parents on carousel
- Woman with pram
- Sunshine
- Sound of crying child
- Speakers
- Children sat on horses
- Trees
- Deer

Appendix B: Chapter 2 selection of videos calculations

Videos were ranked based on the accuracy shown for free and recognition tests for each sensory modality (i.e. high accuracy in retrieving auditory details). The rank number within each modality was summed and divided by 6 to calculate the average standing of each list. (See Appendix B). This average standing was then compared across memory test results to ensure the final selection included videos as highly ranked for each modality as possible (as close to 1 out of 21 for audio, and the same for visual), while also ensuring the average standing was similar between memory tests (i.e. average standing of 5 out of 21 videos for auditory free recall, and 4 out of 21 for recognition). A final list of videos, combined from the two memory test accuracy scores was created.

Formulas:
Calculation of rank, measured against list under ‘stimuli’.
=SUMIFS(AK$3:AK$23,$AJ$3:$AJ$23,AJ30)

Sum of values for top six audio-only stimuli (measured against word list in column AN).
=SUMIFS(AK30:AK50,$AN$30:$AN$50,AK29)

Average calculated for ranking of all six stimuli, taking the sum from the calculation above and dividing by 6.
=AK28/6

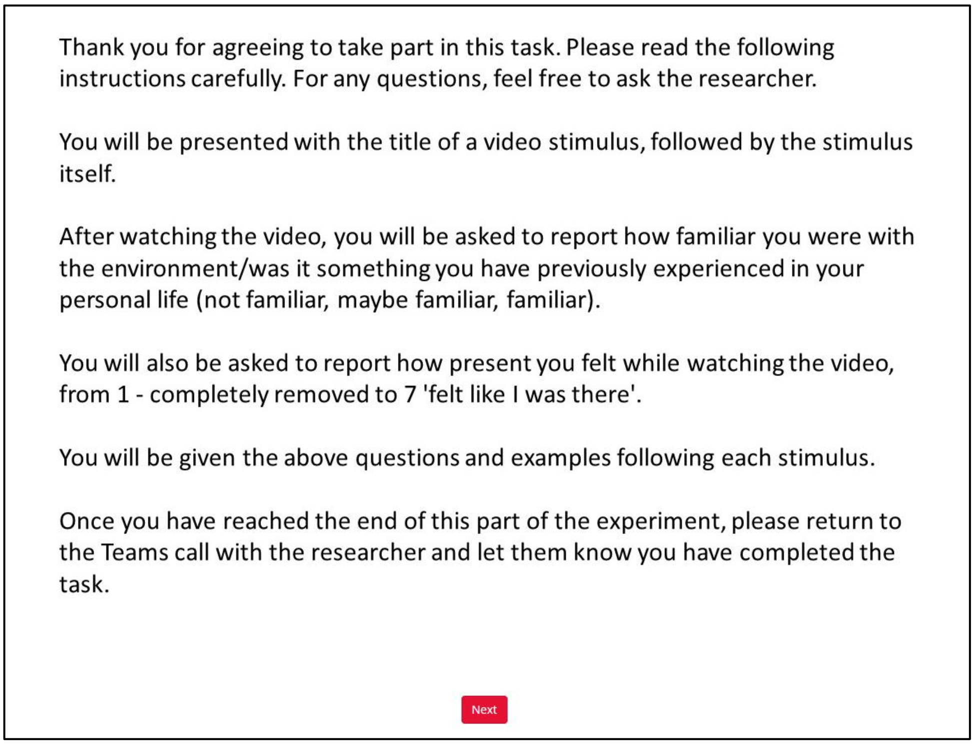
Cued	5.333333333	6.50	8.50	
Recognition	32	39	51	
Stimuli	**Audio**	**Visual**	**Multi**	
American Football	1	9	12	Audio
Jump	2	4	9	Multi
City Walk	3	6	8	Multi
Ducks	4	2	5	Multi
GoKarting	5	18	21	Audio
Volleyball	6	19	20	Audio
Carousel	7	14	17	Audio
Surf	8	16	18	
Eggs	9	10	10	Multi
Alps	10	8	6	Multi
Horse	11	3	2	Visual
Ice Hockey	12	1	1	Visual
Mountainbike	13	15	16	Audio
Rollercoaster	14	13	13	Multi
Shopping Centre	15	17	14	
Baseball	16	5	3	Visual
Skiing	17	7	4	Visual
Car	18	12	11	Visual
Dog Grooming	19	11	7	Visual
Marathon	20	20	15	
Woodwork	21	21	19	

Audio	
American Football	*Carousel*
GoKarting	*Mountainbike*
Volleyball	Alps
Carousel	*American Football*
Surf	Jump
Mountainbike	Rollercoaster
Multi	
Jump	*City Walk*
City Walk	*Ducks*
Ducks	Car
Eggs	Baseball
Alps	GoKarting
Rollercoaster	Skiing
Visual	
Horse	Volleyball
Ice Hockey	Shopping Centre
Baseball	*Horse*
Skiing	Marathon
Car	*Ice Hockey*
Dog Grooming	Eggs

Free	4.6666666667	4.5000000000	10.3333333333	
Recall	28	27	62	
Stimuli	**Audio**	**Visual**	**Multi**	
City Walk	1	1	1	Multi
Carousel	2	14	16	Audio
Mountainbike	3	8	10	Audio
Alps	4	18	20	Audio
American Football	5	15	17	Audio
Jump	6	12	13	Audio
Ducks	7	10	12	Multi
Rollercoaster	8	19	19	Audio
Volleyball	9	2	2	Visual
Shopping Centre	10	4	4	Visual
Horse	11	6	7	Visual
Car	12	11	9	Multi
Surf	13	21	21	
Marathon	14	7	8	Visual
Ice Hockey	15	5	5	Visual
Baseball	16	13	11	Multi
Dog Grooming	17	20	18	
GoKarting	18	16	14	Multi
Skiing	19	17	15	Multi
Woodwork	20	9	6	
Eggs	21	3	3	Visual

Appendix C: Screenshots of questions from Experiment 2 and Experiment 5

Screenshots of task used for Experiment 2 and Experiment 5, in Chapters 2 and 3. The study was conducted on Gorilla and Teams. Experiment 5 also contained a perspective judgment task conducted in Qualtrics. Screenshots are in order of presentation.



Thank you for agreeing to take part in this task. Please read the following instructions carefully. For any questions, feel free to ask the researcher.

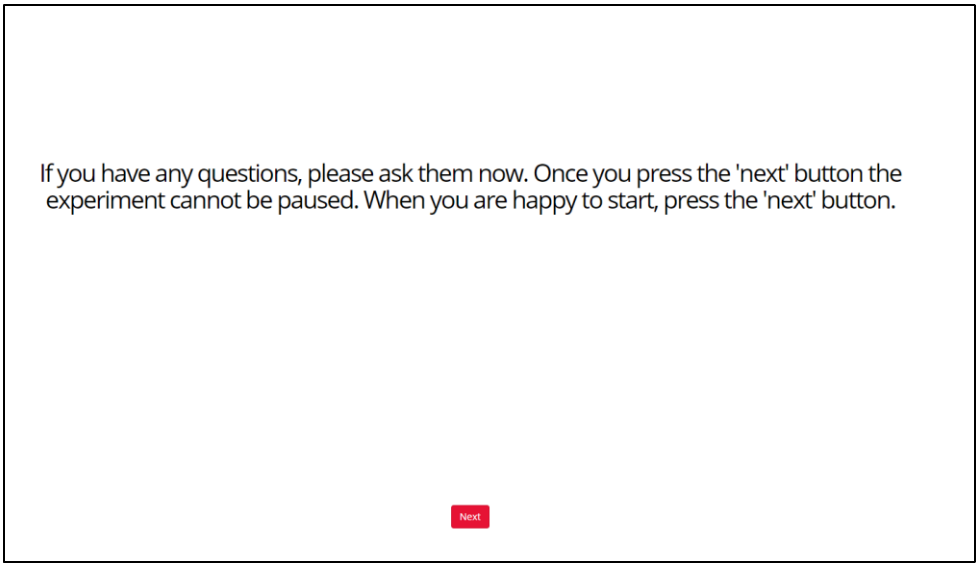
You will be presented with the title of a video stimulus, followed by the stimulus itself.

After watching the video, you will be asked to report how familiar you were with the environment/was it something you have previously experienced in your personal life (not familiar, maybe familiar, familiar).

You will also be asked to report how present you felt while watching the video, from 1 - completely removed to 7 'felt like I was there'.

You will be given the above questions and examples following each stimulus.

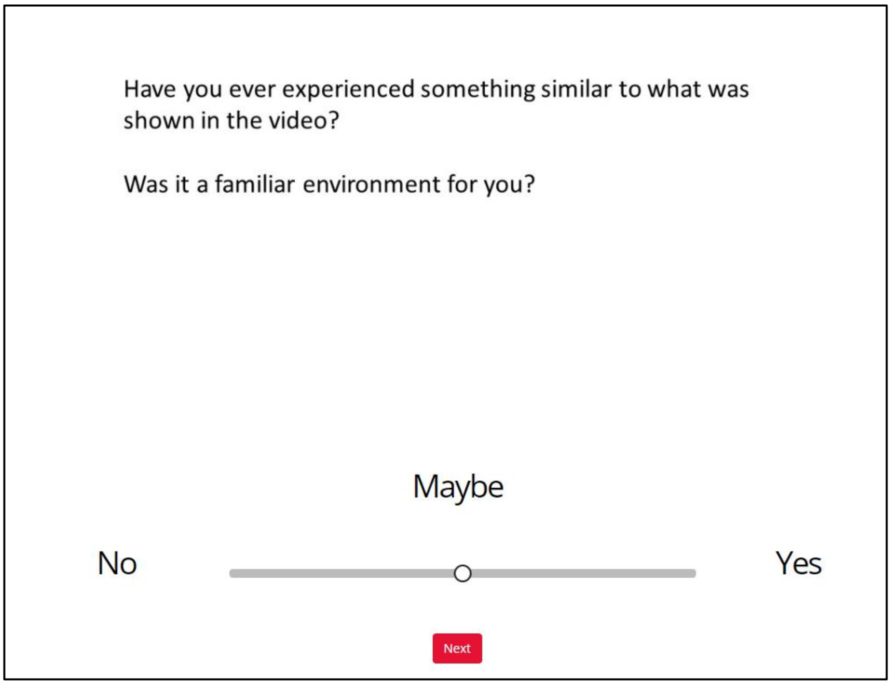
Once you have reached the end of this part of the experiment, please return to the Teams call with the researcher and let them know you have completed the task.



If you have any questions, please ask them now. Once you press the 'next' button the experiment cannot be paused. When you are happy to start, press the 'next' button.

Volleyball

+



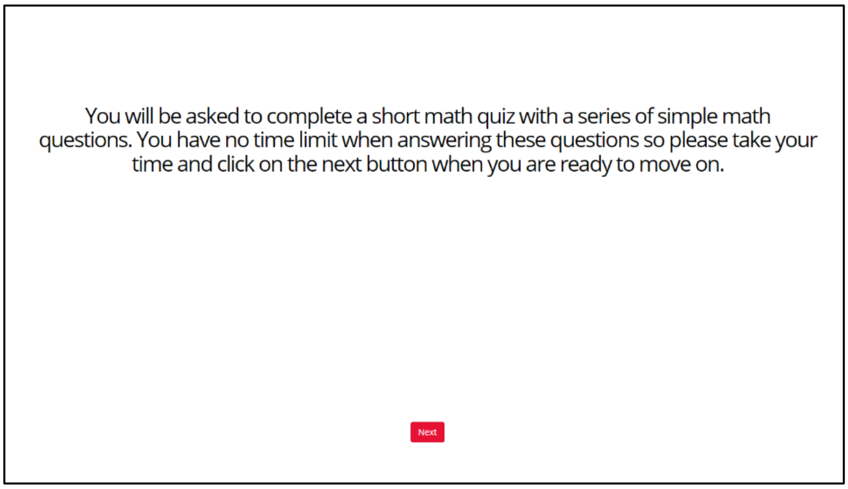
Have you ever experienced something similar to what was shown in the video?

Was it a familiar environment for you?

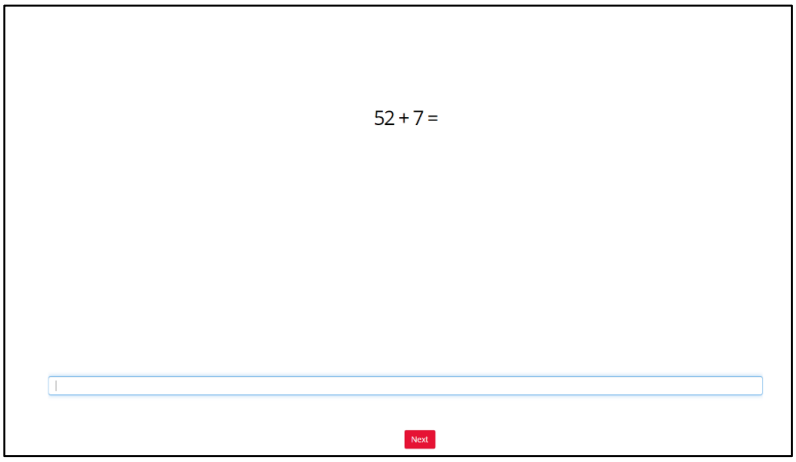
Please state how present you felt in the video:

1 - 'Felt completely remote'

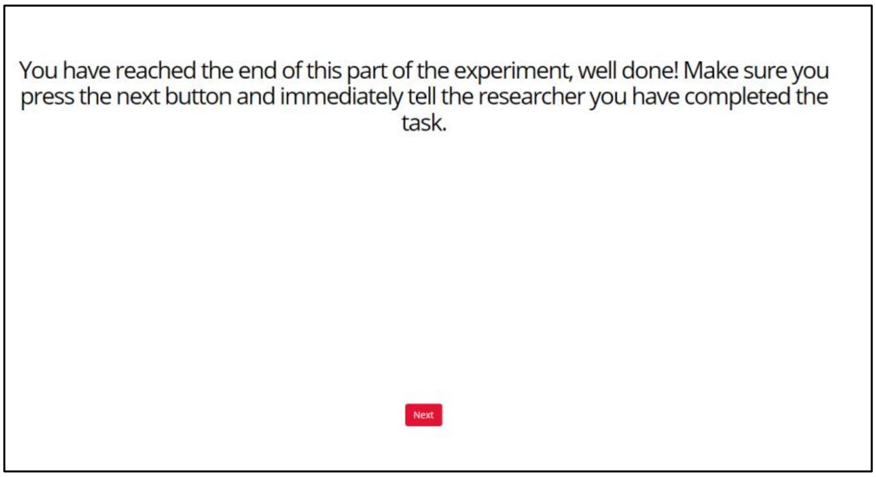
7 - 'Felt like I was there'



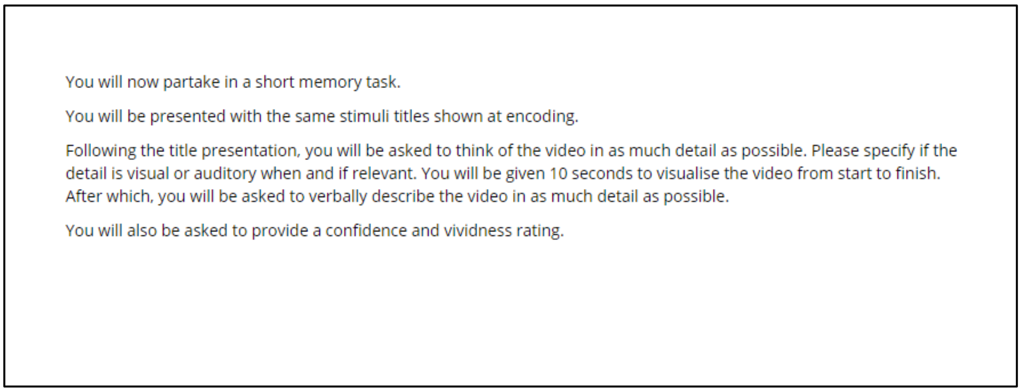
You will be asked to complete a short math quiz with a series of simple math questions. You have no time limit when answering these questions so please take your time and click on the next button when you are ready to move on.



52 + 7 =



You have reached the end of this part of the experiment, well done! Make sure you press the next button and immediately tell the researcher you have completed the task.

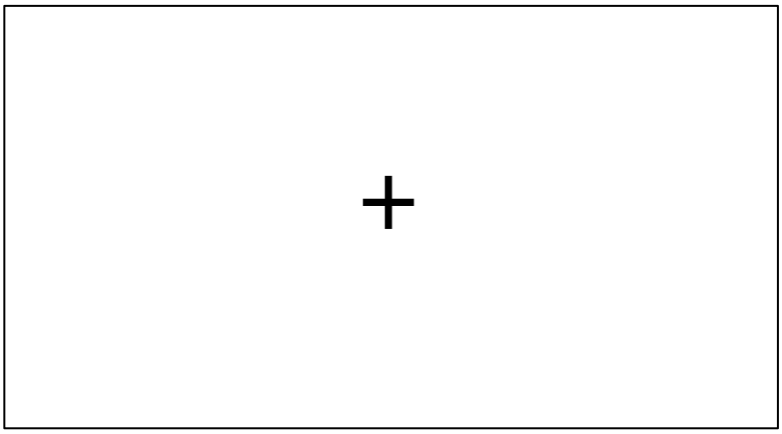


You will now partake in a short memory task.

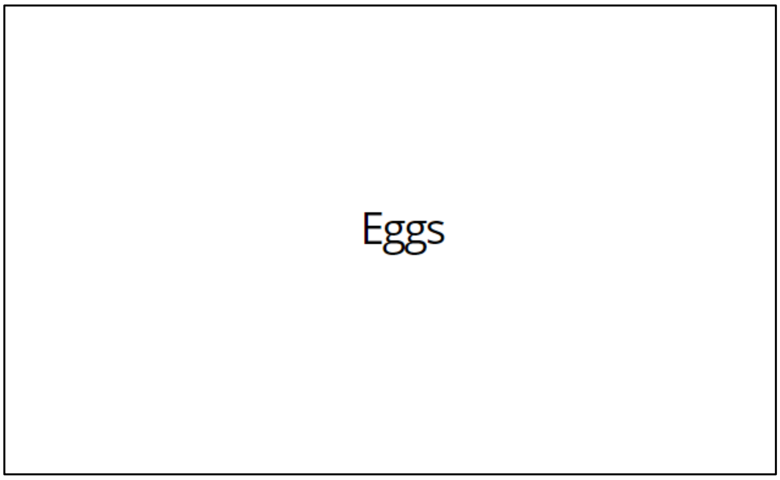
You will be presented with the same stimuli titles shown at encoding.

Following the title presentation, you will be asked to think of the video in as much detail as possible. Please specify if the detail is visual or auditory when and if relevant. You will be given 10 seconds to visualise the video from start to finish. After which, you will be asked to verbally describe the video in as much detail as possible.

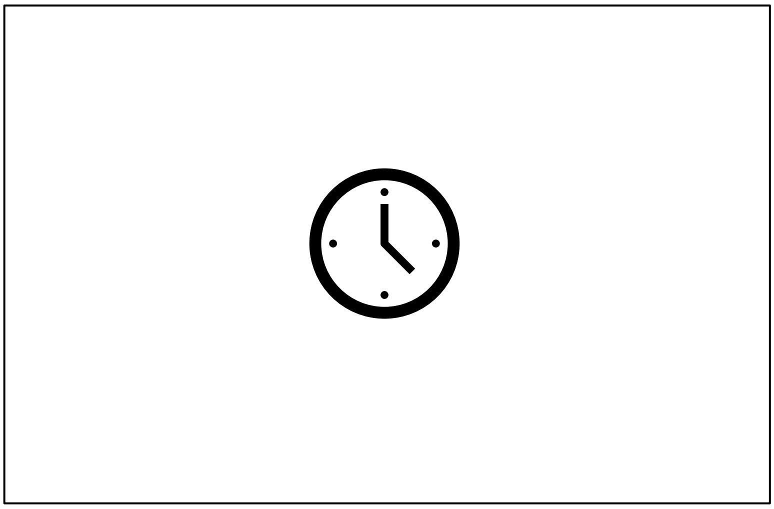
You will also be asked to provide a confidence and vividness rating.



+



Eggs



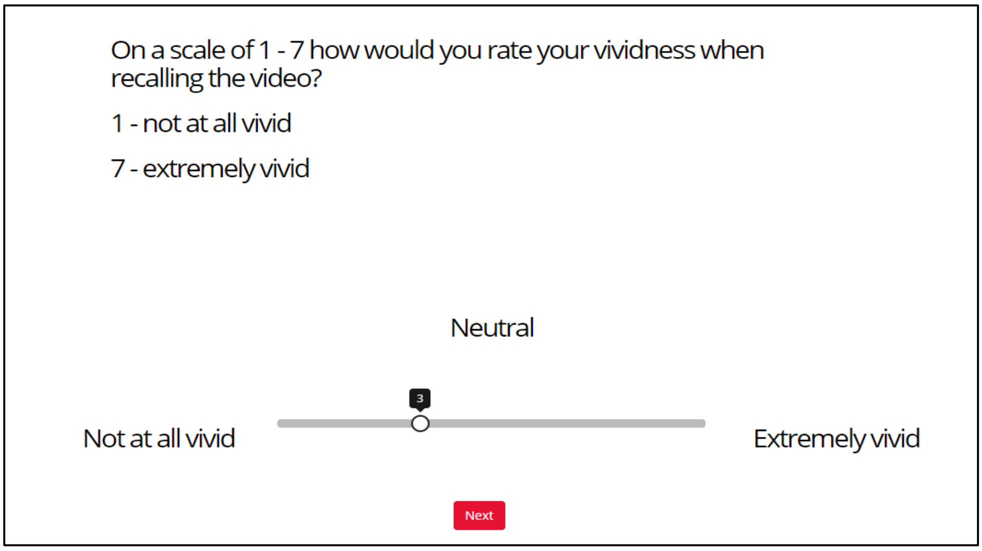
Please provide as much detail as possible of the video associated with the title you have just seen.

How confident are you of your response?

1 - Not at all confident

2 - Somewhat confident

3 - Very confident



On a scale of 1 - 7 how would you rate your vividness when recalling the video?

1 - not at all vivid

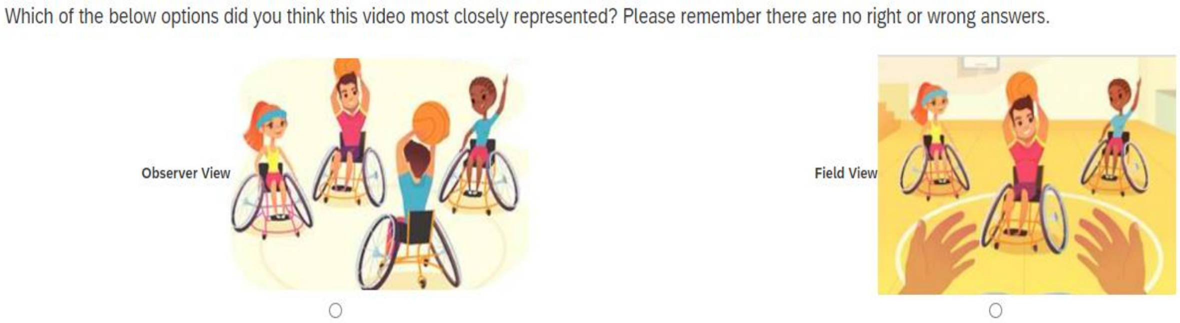
7 - extremely vivid

Neutral

Not at all vivid

Extremely vivid

Perspective Judgement Task; only used for Experiment 5, Chapter 3:



Which of the below options did you think this video most closely represented? Please remember there are no right or wrong answers.

Observer View ○

Field View ○