Selective Attention During Encoding Mediates Memory Representation

by

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Abstract

Attention selects the information we remember, yet the specific mechanism by which attention influences our memory remains unclear. This investigation examined a novel interpretation of how attention and memory interact: whether semantic vs. perceptual attention biases the encoding of precise-integrated representations that constrain the detail of our memories. I present two studies that examine how semantic vs. perceptual attention to illustration features impacts representation. Participants attended to perceptual or semantic features at encoding, then performed a surprise memory test for the illustrations. Study 1 showed that perceptual attention led to precision from experiences with the attended feature. Study 2 examined if perceptual attention facilitated precision for the attended feature, or overall. Memories showed precision from perceptually similar experiences and integration with semantically similar experiences, irrespective of attention state. Further work is needed to determine whether mnemonic precision and integration is biased across semantic and perceptual attention tasks.

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Chapter 1
The Interaction Between Attention and Memory

Attention allows us to prioritize the information we later remember. The information attended to during memory encoding can determine which experiences and features we later recognize (i.e., recognition memory; Boronat & Logan, 1997; Gardiner & Parkin, 1990; Naveh-Benjamin, Craik, Perretta, & Tonev, 2000; Turk-Browne, Golomb, & Chun, 2013) and subsequently remember long-term (Hawley & Johnston, 1991; Kellogg, 1980; Reinhart & Woodman, 2014). Therefore, understanding how attention impacts recognition memory is fundamental to clarifying how we build upon our prior experiences and knowledge. Many theories suggest different mechanisms behind the impact attention at encoding has on recognition memory—ranging from processing enhancement effects (Broadbent, 1957; Tipper & Driver, 1988) to the implications of attending to different levels of information (Brainerd & Reyna, 1990; Craik & Lockhart, 1972). Despite the abundance of theories on how attention impacts remembering, it remains unclear what mechanisms contribute to the specific impact attention has on our ability to encode and remember experiences.

Building on prior work that suggests the level of information attended to at encoding will impact remembering, the present investigation examined how attending to either semantic or perceptual features at encoding influences the detail of the encoded experience. I will first review past literature on how attention at encoding impacts subsequent memory behaviours. I will then propose a mechanism through which attention to semantic vs. perceptual features at encoding impacts memory: selective attention to either feature may bias the encoding of precise vs. integrated memory representations that constrain the detail of the remembered experience. Lastly, I will present two studies that examined whether selective attention to semantic vs. perceptual features impacts the precision-integration of the experiences we encode and remember.

1 Background

1.1 Attentional Filtering During Memory Encoding

Prior work suggests that attention acts through two main streams to impact what we encode and remember: (1) by allocating cognitive resources towards processing the attended information

(Head & Helton, 2014; Lavie, Hirst, De Fockert, & Viding, 2004), and (2) selecting the information that is encoded into long-term memory (Hawley & Johnston, 1991; Kellogg, 1980; Rosen, Stern, Michalka, Devaney, & Somers, 2015). While it is clear that attending to information impacts the sensory processing of the information at hand, it is less clear how attention at encoding benefits later memory for the attended information. Earlier theories on attention and memory suggest that attention at encoding allows for the enhanced cognitive processing of selected information, consequently leading to better memory for the attended information (Broadbent, 1957; Norman, 1968). In support of this theory, empirical studies have shown that attended information possesses a multitude of memory benefits in comparison to unattended information (see Aly & Turk-Browne, 2017; Muzzio, Kentros, & Kandel, 2009 for reviews). The most prominent theory of attention and memory encoding suggests that attention acts as a “filter”, allowing only attended information to receive enhanced processing and subsequent storage into short-term memory storages like working memory (Broadbent, 1957). Attended information transferred to working memory then has to potential to be stored into long-term memory storages (i.e., long-term memory; Atkinson & Shiffrin, 1968) and retrieved long-term.

Engaging in selective attention, or attending to specific information while ignoring the rest, has been used to test the attentional filter theory. One of the first paradigms to employ selective attention at encoding was the dichotic listening task (Cherry, 1953), where participants heard different auditory stimuli (typically speech) in each ear and were cued to attend to and repeat the auditory information presented in one ear while ignoring information presented in the other ear. Consistent with predictions from the attentional filter theory, results from these tasks showed that information participants were cued to attend to was remembered more than unattended information (Bryden, 1971; Colflesh & Conway, 2007). Using this paradigm with a variety of different auditory stimuli (e.g., emotional prosody and non-verbal sounds; Erhan, Borod, Tenke, & Bruder, 1998; King & Kimura, 1972), the attended information memory benefit has been seen for the recognition of different types of cued verbal information. However, our understanding of how selective attention impacts memory in the dichotic listening task is limited to memory for a single modality (i.e., auditory information) and does not reveal how memory for other modalities is impacted by attentional focus.

The dichotic listening task does not describe how attention influences our memory for complex, non-auditory experiences. For example, in many instances, there will be features—such as different aspects like the scene, objects, participants, colour scheme, and situation theme— of the experience that hold greater relevance to the task at hand than others. Tasks similar to the dichotic listening paradigm are not applicable in these scenarios since the unattended and attended information are different stimuli entirely. Because of this limitation, it is unclear how allocating attention to different features of the same experience impacts later memory for the entire experience. Furthermore, since selective attention tasks typically manipulate attention to different stimuli entirely, the attentional effects on memory these studies demonstrate may be confounded by differences among the processing of attended vs, unattended information. To examine how attention impacts memory irrespective of processing differences, memory for a single experience that contains both attended and unattended features must be examined.

How does attention to specific features within a complex stimulus impact memory for the stimulus as a whole? To investigate how attending to select features of an experience impacts memory for the entire experience, some paradigms have employed the use of composite stimuli: an image of one object overlaid on top of the image of another object. By using composite stimuli, the visual input remains the same while the perceiver's attentional focus can be manipulated. Studies that have used composite stimuli have shown that attended features are remembered better than unattended features. For example, studies that used composite face and scene images have shown that while both the face and scene images are perceived and encoded by the participant, the object the participant is cued to attend to (i.e., face) is remembered more than the unattended object (i.e., scene) within the composite picture (Yi & Chun, 2005). These studies demonstrate that when the stimulus the participant encodes is constant, there continues to be a memory benefit for attended features within the same stimulus (Walker, Low, Cohen, Fabiani, & Gratton, 2014; Yi, Kelley, Marois, & Chun, 2006; Yi, Woodman, Widders, Marois, & Chun, 2004). However, these findings lead to the question, what is occurring at encoding for attended vs. unattended information to show a memory benefit?

1.2 Semantic and Perceptual Attention at Encoding

In contrast to previous theories that address attention to different *content* and their consequent memory benefits, some influential cognitive theories suggest that the *level* of content information attended to at encoding may impact the likelihood of remembering. Specifically, attention to either (1) semantic qualities that represent abstract information such as themes and meaning (i.e., gist), or (2) perceptual qualities that represent concrete, physical characteristics such as shape and colour, may influence long-term memory (Brainerd & Reyna, 1990; Craik & Lockhart, 1972). Importantly, these theories suggest that not only does the content that is attended to at encoding impact what is remembered, but the level of content information that is focused on can influence the likelihood of remembering. What these theories differ on is whether attending to semantic or perceptual features of the information at encoding leads to better memory. The levels of processing (LOP) theory suggests that attending to semantic features at encoding leads to better memory (i.e., more items recognized at recall; Craik & Lockhart, 1972), while the fuzzy-trace theory proposes attending to perceptual features will lead to better memory (i.e., accurate remembering; Reyna & Brainerd, 1995). Empirical work motivated by these theories support both claims, providing mixed results for what attribute must be attended to at encoding to lead to better memory (Ally & Budson, 2006; Curran & Doyle, 2011; Ecker, Zimmer, & Groh-Bordin, 2007; Gallo, Meadow, Johnson, & Foster, 2008; Job, Rumiati, & Lotto, 1992; Lockhart, 2002; Sheridan & Reingold, 2012).

1.2.1 The Levels of Processing Theory: Attending to Semantics Allows for Better Remembering

LOP theory proposes that attending to semantic features at encoding will lead to better memory. Specifically, LOP theory suggests that engaging in "deep processing" by attending to semantic cues at encoding will lead to better recall of targets than "shallow processing", associated with attending to surface, perceptual cues at encoding (Craik & Lockhart, 1972). According to the framework, memory trace stability is dependent on the depth of processing engaged at encoding, with deeper processing and greater semantic conceptualization of the encoded information leading to a higher likelihood of remembering—also known as the LOP effect (Challis et al., 1996).

A classic example of studies motivated by the LOP theory are list learning paradigms. In these studies, participants are instructed to attend to semantic aspects (e.g., category association) or perceptual aspects (e.g., font size) of different words, resulting in the incidental encoding of these words through deep and shallow processing, respectively (Craik & Tulving, 1975). In line with the LOP theory's predictions, attending to semantic aspects of words leads to greater memory for target words in comparison to attending to shallow, perceptual features. Other empirical studies have also show that attending to semantic features benefits subsequent memory in child (Ackerman, 1981; Johnson & Pascual-Leone, 1989; Owings & Baumeister, 1979; Weiss, Robinson, & Hastie, 1977), older adult (Fu, Maes, Varma, Kessels, & Daselaar, 2017; Jacoby, Shimizu, Velanova, & Rhodes, 2005), clinical (e.g., autism spectrum disorders and schizophrenia; Brebion et al., 2000; Harris et al., 2006; Kubicki et al., 2003; Toichi & Kamio, 2002), and healthy, adult populations (Craik & Lockhart, 1972). The LOP effect continues to be replicated years later (Galli, 2014; Schott et al., 2013), and with non-verbal stimuli such as colour masks (Breitmeyer, Ro, & Singhal, 2004) and sounds (Gloede, Paulauskas, & Gregg, 2017), suggesting that attending to semantic vs. perceptual features at encoding may lead to better memory for non-verbal information as well.

Whether attending to semantic vs. perceptual features benefits visual information remains unclear. Of the few studies that have examined the LOP effect among visual information, there appears to be a continued memory benefit for attending to semantic vs. perceptual aspects at encoding. For example, one study that examined memory for pictures of objects asked participants to view objects while engaging in either perceptual processing by discriminating between large and small-sized images, low-level semantic processing by deciding if the picture represented a word that rhymed with another word, or high-level semantic processing by incorporating consecutive pictures in sentences. The study found better memory for objects encoded with semantic vs. perceptual processing, but surprisingly no difference in memory performance for images in the high- and low-level semantic processing conditions (D'Agostino, O'Neill, & Aivio, 1977). Contrary to one of the principals of LOP theory that describes better memory being dependent on the depth of processing used, the described study did not show memory performance differences among deeper levels of semantic processing. However, semantic attention overall showed a subsequent memory benefit.

1.2.1.1 Questions Remaining for LOP theory

Although LOP theory introduces the notion that the level of information attended to at encoding will impact subsequent memory, there are many aspects of the interaction between attention and memory the theory does not address. LOP theory emphasizes that the depth of processing engaged at encoding impacts memory, and thus, uses attentional tasks that engage different levels of processing and difficulty—with the semantic attention tasks chosen demonstrating greater task difficulty and complexity than the shallow perceptual tasks. Prior work has shown that it typically takes longer to determine the appropriate category a target word belongs to in comparison to determining the colour of a word, an easier categorization to make (Kiefer, 2001). Semantic and perceptual categorization time differences are also seen among visual stimuli: individuals are faster at categorizing visual stimuli of common objects and living things according to perceptual similarity than semantic similarity (Job et al., 1992). Therefore, the semantic and perceptual attention tasks used by studies that show the LOP effect may be unmatched in processing time and difficulty. Since LOP theory only alludes to the benefits of depths of processing relative to semantic vs. perceptual tasks, the memory benefit seen for semantic attention at encoding may be the by-product of greater task processing—and consequently, greater encoding time—during semantic attentional tasks, and not because of attention to semantic information itself. It is unknown whether attending to semantic vs. perceptual features during tasks matched in difficulty and complexity will also show a memory advantage for encoding through semantic attentional states.

Another aspect of memory the LOP theory does not address is whether deeper, semantic attentional processing impacts our ability to remember the specific details a part of the experiences we encode. Although LOP studies have shown that attending to semantic vs. perceptual features of items results in better remembering, there is limited research on whether this better memory consists of recognizing the specific details within an encoded experience. Prior work has shown that when individuals are asked to recollect studied items, they tended to rely on their memory for the abstract information associated with the studied item (i.e., gist), instead of recollecting the details of the experience (Koutstaal & Schacter, 1997; Reyna, Holliday, & Marche, 2002). Therefore, attending to semantic features at encoding may only benefit memory for gist, as opposed to memory for the precise details of the experience. The occurrence of biased gist-based memory is not limited to verbal information and may explain the semantic attention benefit seen for visual information as well. For example, Koutstaal & Schacter (1997) found that when participants were presented with illustrations of objects during an incidental encoding task, repeated exposures to gist-related exemplars led to participants falsely remembering new objects of the same kind as having been studied at encoding. This finding suggests that participants encoded and remembered the gist-related features of the object instead of specific item details. Will semantic attention at encoding lead to better memory for solely the gist of the experience, or does memory for the entire experience (including the idiosyncratic details) benefit?

1.2.2 The Fuzzy-Trace Theory of Memory: Attending to Perceptual Information Allows for Accurate Remembering

In contrast to the LOP theory, the fuzzy-trace theory proposes that attending to perceptual features at encoding leads to a greater likelihood of *accurately* remembering details of the encoded experience, in comparison to attending to semantic features (Brainerd & Reyna, 1990). Broadly, the fuzzy-trace theory of memory stems from a developmental perspective but has strong applications to adult memory and reasoning behaviours. The core framework of the theory is that encoded information can be stored in one of two types of memories: (1) gist memories—also called fuzzy traces—that hold the meaning and individual's interpretation of the target experience, or (2) verbatim memories that contain perceptual details about the target experience. Importantly, fuzzy and verbatim traces store different types of features, with fuzzy traces containing abstract, relational themes vs. verbatim traces holding concrete, perceptual features. The theory suggests that verbatim traces are typically more beneficial for detailed memory, while fuzzy traces aid in inference and logical reasoning abilities that require applying past experiences and memories flexibly (Brainerd & Reyna, 2004).

1.2.2.1 Fuzzy and Verbatim Trace Encoding

Differences between the encoding mechanisms that form fuzzy and verbatim traces reflect how these memories represent vastly different types of information. Fuzzy traces tap into automatic encoding processes, while verbatim traces require goal-directed motivation (Brainerd & Reyna, 2004). In order to encode fuzzy traces, the individual must extract and add information pertaining to how they conceptualize the target situation—a process called gist extraction. During automatic gist extraction, individuals recognize the shared semantic themes and relations among different situations, connecting stored fuzzy traces with the meaning and interpretation of the new experience. Considering the diverse interpretations one experience can elicit across individuals, many different fuzzy traces can be created from one target experience. In contrast, the encoding of verbatim traces is facilitated when the individual is focused on extracting the surface representation of the target experience. Consequently, verbatim traces consist of specific, invariant representations of the target experience (Brainerd & Reyna, 2004).

Although the encoding mechanisms that form gist and verbatim traces are different, prior work has shown that fuzzy and verbatim traces can be encoded in parallel and from the same experience (Reyna et al., 2002). However, while both fuzzy and verbatim traces can be encoded, it has been shown that task demands may bias the type of memory trace encoded and stored (Brainerd & Reyna, 2004). Situations that require detailed memory representation may bias the encoding of verbatim vs. gist traces, while spontaneous knowledge acquisition may favour the automatic encoding of gist traces. Presently, there is limited work on the situational constraints that bias the encoding of fuzzy and verbatim traces, though some studies that examine whether participants can successfully track statistical regularities (e.g., probability decision-making tasks) show that individuals continue to rely on gist extraction for encoding (Reyna & Brainerd, 1995) despite verbatim encoding being more beneficial to task performance. These results suggest that participants may show a bias towards gist extraction, even when it is not the optimal encoding strategy. With respect to how selective attention to semantic vs. perceptual features may impact the encoding of different memory traces, it is unclear how attention to either feature promotes the encoding of fuzzy and verbatim traces.

1.2.2.2 False Memory Susceptibility Among Fuzzy and Verbatim Traces

In relation to how fuzzy and verbatim traces impact remembering, fuzzy traces also demonstrate greater susceptibility to memory distortion and false memories than do verbatim traces (Reyna et al., 2002). Studies motivated by the fuzzy-trace framework have shown that similar experiences (i.e., lures) associated with fuzzy traces are more likely to be falsely remembered as “old” than lures related to verbatim traces (Brainerd & Reyna, 2004). A common trend among studies that investigated the emergence of false memories is that falsely remembered information typically reinstated the gist of the encoded fuzzy trace. A few examples that demonstrate the prevalence of gist-related false memories include: falsely remembering words semantically related to target words (Roediger & Mcdermott, 1995), falsely recognizing objects within the same object category as the target object (Koutstaal & Schacter, 1997), and incorporating false semantically related information when retelling stories (Donread, 1996) and eye-witness testimonies (Brainerd & Reyna, 2002). Collectively, the listed phenomenon show that gist-related information is easily incorporated with the encoded target experience. Crucially, these findings suggest that overall attention to information at encoding is not always beneficial for accurate remembering, and that level of information that is attended to will facilitate subsequent memory benefits.

Why are there more gist-related false memories than verbatim-related false memories? The fuzzy-trace theory proposes that since fuzzy traces contain general information about the target experience, many different lures can overlap with the fuzzy trace and become incorporated into the representation. In contrast, verbatim traces are specific and therefore unlikely to overlap with lure information, allowing the representation to remain preserved. As a consequence of frequent fuzzy trace reinstatement, fuzzy traces demonstrate greater endurance over time than verbatim traces. Therefore, while fuzzy traces are susceptible to distorting the details of the memory, they may be beneficial for long-term memory retrieval that relies on trace accessibility over remembering the fine-grain details of the experience. Since fuzzy traces are general and can overlap with many different retrieval cues, they are more accessible at retrieval than verbatim traces, but at the cost of remembering accurate details of the experience. Greater distortion among fuzzy traces is what motivates the fuzzy-trace theory to suggest that verbatim traces are transient representations of accurate memory, while fuzzy traces are representations that are easily manipulated and distorted, but accessible long-term (Reyna et al., 2002).

1.2.2.3 Questions Remaining from the Fuzzy-Trace Theory

Contrary to one of the main tenets of fuzzy-trace theory, recent research suggests that verbatim traces are not completely impervious to memory distortion. Re-exposure to features of the target experience can lead to misinformation effects if subtle changes to the encoded experience are introduced during re-exposure to the target experience. For example, when individuals were presented with new lists of words that shared details with correctly recalled target words, they falsely remembered encoding the new list along with the target words (Marche & Brainerd, 2012). Therefore, verbatim traces may also demonstrate distortion under specific constraints.

1.3 Attention Mediates Hippocampal Memory Representation

Although the fuzzy-trace and LOP theories propose that the type of feature attended to at encoding will impact subsequent memory, these perspectives on attention and memory are rooted in behavioural research and do not define the neural mechanisms behind the impact attending to these features have on our ability remember. Neural evidence of the relationship between attention and memory encoding processes may shed light on mechanistic causes behind the behavioural memory benefits seen for attending to different types of features. Recent work has shown that selective attention to different types of information at encoding (i.e., attentional states) can modulate activation in the hippocampus (Aly & Turk-Browne, 2016; Muzzio, Levita, et al., 2009) — a region of the brain crucial for forming and storing detailed episodic memories (Scoville & Milner, 1957). Therefore, attentional modulation of the hippocampus may impact the memory formed and stored at encoding.

Functional magnetic resonance imaging (fMRI) work has shown that the hippocampus can form and store memories representations that vary in detail (Schlichting, Mumford, & Preston, 2015)). In particular, anterior vs. posterior regions of the hippocampus show evidence for forming memories that show (1) integration, facilitating connections among related experiences to extract their common features, and (2) differentiation, which aids in distinguishing among related experiences to preserve the unique event details, respectively. Therefore, different hippocampal biases at encoding may impact the type of representation formed.

One potential way attention to semantic vs. perceptual features at encoding may impact memory is by biasing the type of representation formed for the encoded experience, and consequently, subsequent memory behaviours. Attentional modulation of the hippocampus and subsequent member behaviours has been seen in both animal (Muzzio, Levita, et al., 2009) and human models (Aly & Turk-Browne, 2016). Studies with rodents have shown that activation patterns within hippocampal cells at encoding can predict later recall of the attended information (Fenton et al., 2010; Muzzio, Levita, et al., 2009; Rowland & Kentros, 2008). For example, when mice were cued to attend to spatial or olfactory cues, greater distinctness of the patterns of hippocampal activation seen within the mice during spatial and olfactory attentional states led to better memory for the attended information (Muzzio, Levita, et al., 2009). Similar findings have also been seen with humans, with one study by Aly & Turk-Browne (2016) showing that the distinctness of hippocampal activation patterns during painting vs. room layout attentional encoding states predicted successful remembering of the attended information. Although attention states are represented in the hippocampus, it is unknown how these states bias anterior vs. posterior hippocampal representation.

Given the evidence of attentional modulation of the hippocampus and memory behaviors, different attentional states may engage different hippocampal encoding mechanisms. Attending to semantic features may engage anterior hippocampus regions that form integrated memories, while attention to perceptual features may recruit posterior hippocampus encoding schemes that form precise memories. Therefore, different attentional state may impact the region of the hippocampus that participants in encoding the experience, and thus, whether the memory formed either (1) emphasizes common features across related experiences (integration) or (2) maintains idiosyncratic details to differentiate between related experiences (precision; Preston & Eichenbaum, 2013).

2 The Present Investigation

This investigation examined how attention to semantic vs. perceptual features at encoding impacts the type of memory representation formed. As previously described, I propose that the mechanism through which attention impacts memory is by biasing the encoding of memories that vary along a spectrum of precise to integrated. Specifically, attending to semantic features will facilitate the formation of integrated memories that emphasize shared themes across experiences, while attending to perceptual features will form precise memories that preserve the idiosyncratic details of the experience.

The present investigation examined several novel aspects of how semantic and perceptual attention intersect with memory that have yet to be tested. First, unlike how LOP theory uses semantic and perceptual attention tasks to investigate the impact processing load has on memory, this investigation examined how semantic and perceptual attention impacted subsequent memory for the encoded experience. While the LOP theory suggests attending to semantic information will lead to a greater likelihood of remembering the encoded information, the framework was motivated by examining how processing differences account for memory, and thus, chose semantic attentional tasks that demonstrate higher processing demands than the shallow processing perceptual attention tasks used. This investigation examined the isolated impact attention to semantic vs. perceptual features has on memory while equating factors like task difficulty. Therefore, semantic and perceptual tasks matched in difficulty were chosen as the attentional manipulations, allowing for any subsequent memory benefits seen to be solely the by-product of attention to semantic or perceptual features, and not due to processing differences.

Furthermore. semantic and perceptual attentional conditions used in the past rarely consist of attending to different features within the same stimulus. To account for any information differences that may impact memory, our task incorporated semantic and perceptual attention conditions that require attending to features of the same type of complex visual stimulus (i.e., detailed illustrations).

Studies motivated by the LOP and fuzzy-trace theory do not explicitly clarify how attention to semantic vs. perceptual features biases memory representation of complex, detailed experiences. Typically studies within the LOP and fuzzy-trace frameworks examine item memory for verbal words or basic objects a part of different attention conditions, and not how attention to either semantic or perceptual features impacts the detailed remembering of the same stimulus. To capture how attention to semantic vs. perceptual features at encoding impacts memory for complex experiences, we used stimuli that are rich in detail and contain both semantic and perceptual features (i.e., illustrations). Fairytale illustrations were chosen as task stimuli because they depict both semantic and perceptual complex features (i.e., story theme and artistic style) while showcasing scenes, characters, concepts, and imagery that are closer to the real-world experiences we encode into episodic memory. In contrast to unitary objects, fairytale illustrations display juxtaposed objects and items that collectively depict a cohesive story theme and artist style. Importantly, fairytale story knowledge is abstract enough to not be rooted in a single, specific experience as other complex visual stimuli like movies are—there are many different depictions of a single fairytale story so that individuals can have abstracted away from remembering the specific depiction of the story to remembering the general store structure.

Lastly, the type of remembering facilitated by attention to semantic vs. perceptual features is unclear. Although LOP theory proposes better memory when attending to semantic features, and the fuzzy-trace theory suggests better memory when attending to perceptual features, these theories assess and operationalize better memory differently. LOP theory considers the recognition of items that can be supported by remembering gist-related concepts as better memory (Craik & Lockhart, 1972). Therefore, recognition tests that do not examine the precise detail of the encoded memory coincide with the predictions put forth by LOP theory. In contrast, fuzzy-trace theory considers remembering specific details of the past experience as better memory (Brainerd & Reyna, 1990). When items that contain multiple details are tested at retrieval, focusing on perceptual features aids in remembering the encoded items and their precise details. To account for any discrepancy among what different studies consider to be better memory, this investigation examined how attention to semantic and perceptual features impacts the detail of the memory that is encoded, and how the precise or integrated nature of the memory facilitates this detailed remembering. Specifically, this investigation tested whether semantic vs. perceptual attention at encoding impacts the degree of precision or integration the encoded representation demonstrates. Examining how encoded representations are differentiated from highly similar experiences (i.e., lures) will reveal how the resulting precise and integrated representations constrain our accurate memory for complex experiences.

2.1 Objective

The objective of the current investigation was to examine how selective attention to semantic vs. perceptual features at encoding impacts the type of memory representation formed, and consequently, the subsequent memory behaviours demonstrated. Specifically, the research questions were whether attending to semantic vs. perceptual features of illustrations (1) results in a greater likelihood of remembering complex visual illustrations and (2) impacts the precision-integration of the illustration memories.

2.2 General Predictions

Memory representation will vary as a function of the attentional state at encoding. Selective attention to semantic features will form illustration memories that show integration with existing story knowledge, leading to a tendency to falsely endorse semantic lures as old. In contrast, attending to perceptual features will form precise memories that maintain the unique details of the experience, preventing perceptual lures from being endorsed as old.

Chapter 2
Study 1

Study 1 investigated whether detailed memory for illustrations occurs from semantic attentional states (as LOP theory suggests) or perceptual attentional states (as fuzzy-trace theory suggests) at encoding. Participants first performed an incidental encoding task while selectively attending to the semantic (i.e., story) or perceptual (i.e., artist style) features of different illustrations. Immediately after, participants performed a surprise memory test for the illustrations presented at encoding. This study examined whether illustration memories show integration and precision from related experiences and the importance of the attentional state at encoding in facilitating mnemonic integration and precision processes. Illustrations memories will be examined for their integration vs. precision from highly similar experiences that share features: Study 1 tested discrimination of encoded illustrations from (1) lures portraying the same story drawn by different artists or (2) lures portraying the same artist style but different stories. Specifically, this study assessed whether attending to semantic features at encoding leads to integration with experiences that share semantic features vs. attending to perceptual features, which may lead to precision from experiences that share perceptual features. Lastly, this study also tested whether illustrations that share features and occur sequentially in time become not just integrated into existing semantic or perceptual experiences, but also bound with one another in memory.

3 Predictions

It is predicted that selective attention to semantic vs. perceptual features of illustrations will yield better memory for the illustrations. However, selective attention to semantic features will form illustration memories that show integration with existing story knowledge, resulting in new illustrations depicting the same semantic features seen at encoding being endorsed as “old”. In contrast, attending to perceptual features will form precise memories for the illustrations, preventing new illustrations that share the same repeated information from being endorsed as “old”.

4 Method

4.1 Participants

A sample size of 44 adult undergraduate participants (mean age = 19.05 years old, SD = 3.10 years, 30 females, 14 males) was chosen *a priori* based on a power calculation with an effect size of d = 0.45 estimated based on prior published work (Aly & Turk-Browne, 2016). Participant inclusion criteria included the following: individuals between the ages of 17-35 years old, normal or corrected to normal vision (including normal colour vision), normal or corrected to normal hearing, no prior diagnosis of mental illness or neurological disorder (e.g., depression, epilepsy, stroke, traumatic brain injury), and an accuracy for detecting cued repeats higher than 0.66 during the encoding phase. A cued-repeat detection accuracy higher than 0.66 was chosen as the inclusion metric based on pilot data from a separate group of participants (N=14), the majority of whom were able to perform the task above the threshold. Fifty-five participants were recruited (M = 18.96 years old, SD = 2.84 years, 15 males, 40 females) with 11 individuals excluded because they did not meet cued-repeat detection accuracy threshold (N = 10) or were not within the chosen age range (N = 1). The experimental protocol was approved by the University of Toronto Research Ethics Board. All participants provided written consent.

4.2 Stimuli

Fairytale images that varied in semantic (i.e., story theme) and perceptual features (i.e., artist style) were used during the encoding and retrieval phase. Using online databases and image cataloguing sites (i.e., SurLaLune, Society of Children's Book Writers and Illustrators, Pinterest, and Tumblr), 576 coloured fairytale images were collected. All illustrations were cropped to a 4:5 ratio, standardized for luminance and cleared of artist signatures and other identifying features (i.e., borders and text).

4.2.1 Encoding Phase Stimuli

Of the 576 illustrations collected, 288 illustrations were used in the encoding phase. Out of the 288 encoding phase illustrations, 144 of these illustrations shared either semantic or perceptual features: pairs of illustrations that were either drawn by the same artist and portrayed different stories (perceptual repeat) or portrayed the same story and different artistic styles (semantic repeat). The remaining 144 illustrations portrayed unique stories and artist styles (fillers). Using the repeat and filler illustrations collected, 36 blocks of illustrations were created so that each block contained one semantic repeat, one perceptual repeat and four filler images (eight images). Although all filler illustrations presented unique stories and artist styles, each block was designed so that fillers and semantic repeats presented artistic styles that were visibly different from other artistic styles presented in the block. This ensured that within each block, perceptual repeats were the only images that were perceptually similar (Figure 1A).

4.2.2 Retrieval Phase Stimuli

All illustrations shown during the encoding phase and an additional 288 illustrations not shown at encoding were presented during the retrieval phase (Figure 1B).

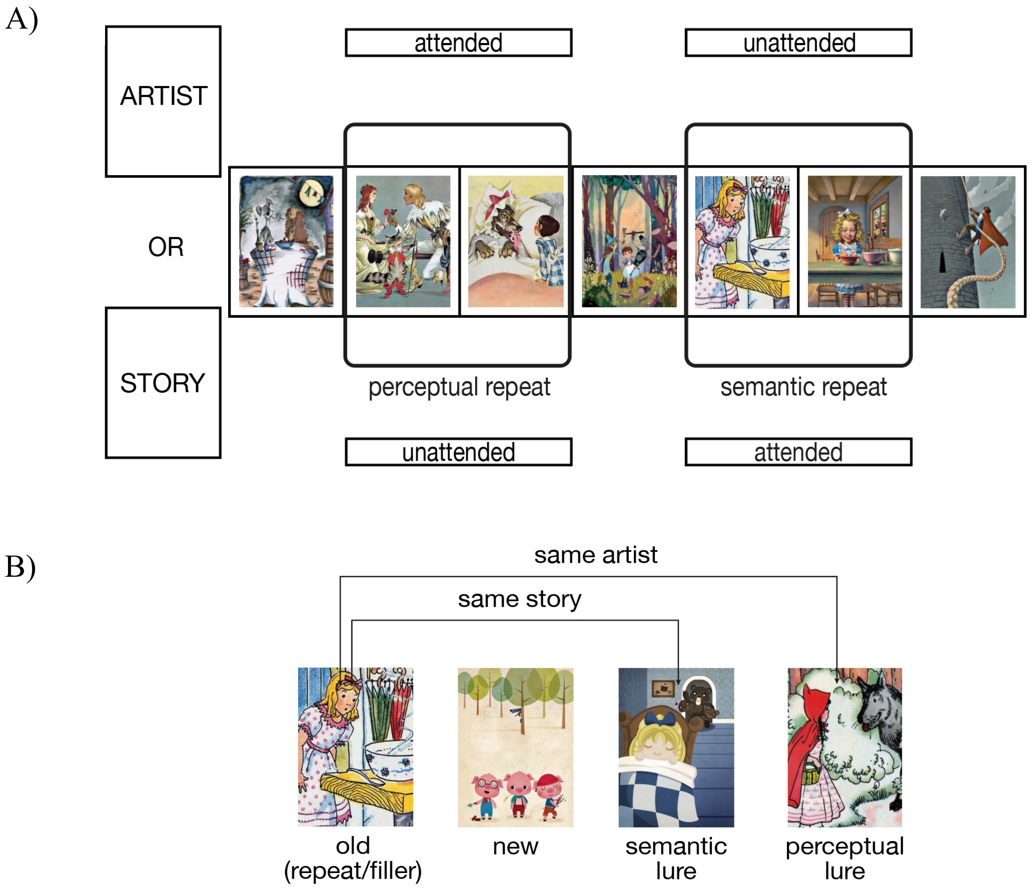


Figure 1. General Design for both Study 1 and Study 2: A) Encoding: Semantic repeats consisted of two illustrations that shared semantic features (i.e., story), while perceptual repeats were two illustrations that shared perceptual features (i.e., drawn by the same artist; same artist style). The remaining illustrations depicted independent stories and artist styles. There were 8 illustrations per block. During the ARTIST task, participants were instructed to attend to the artist style of each illustration, responding to perceptual repeats. During the STORY task, participants are told focus on the story each illustration depicts, responding to semantic repeats. B) Retrieval: The different images types presented at retrieval included old (repeats and filler), semantic lures (same story; different artists, perceptual lures (same artist; different stories), and new (unrelated stories and artist styles).

To examine how selective attention to semantic vs. perceptual features impacts mnemonic discrimination from similar experiences, each semantic repeat had two illustrations that portrayed the same story (semantic lures), while each perceptual repeat had two illustrations that depicted the same artist style (perceptual lures), presented at retrieval (Figure 2). In Study 1, there were 288 images from encoding, 72 semantic lures, 72 perceptual lures, and 144 illustrations portraying stories and artist styles not presented at encoding (new).

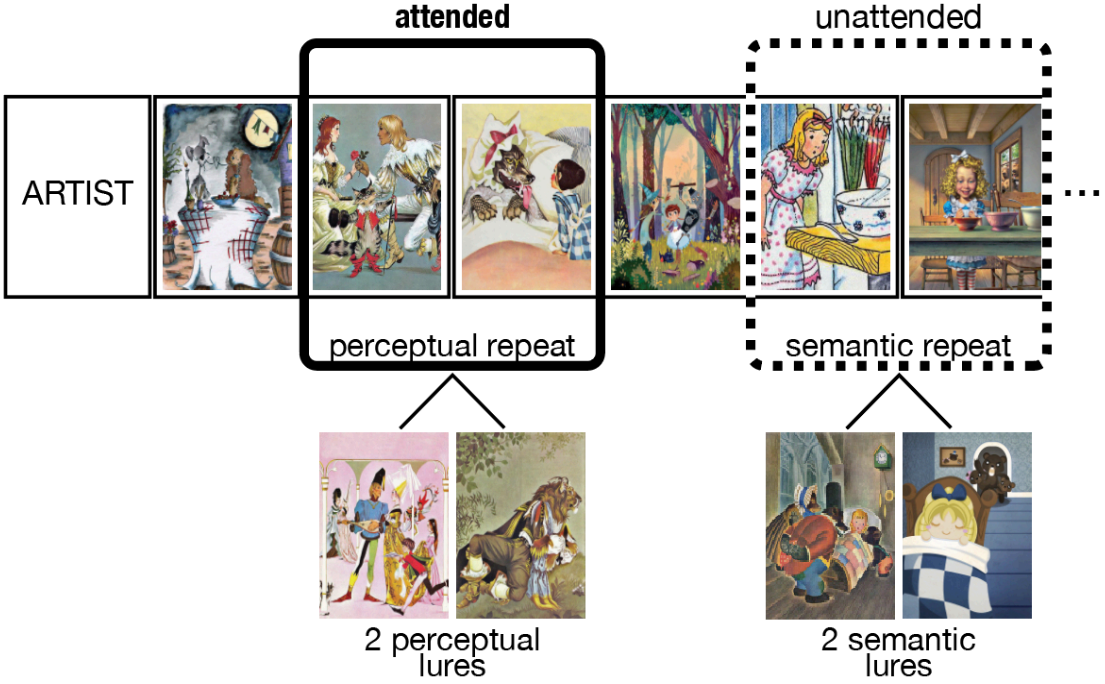


Figure 2. Study 1-Retrieval Image Type Structure: Depiction of the relationship between the illustrations presented at retrieval in Study 1. Each repeat (both cued/attended and uncued/unattended repeats) had either 2 semantic lures or 2 perceptual lures presented at retrieval.

4.3 Tasks

4.3.1 Encoding Phase

During the encoding phase, participants performed a modified version of a 1-back task where they were cued to attend to either semantic (i.e., story) or perceptual (i.e., artistic style) features of different blocks of illustrations, responding to repeats on the cued dimension. This task was used to have participants engaged in semantic vs. perceptual attentional states when encoding the same type of stimuli (i.e., illustrations). At the beginning of each illustration block, participants saw a screen that displayed “ARTIST” or “STORY”, which cued attention to the perceptual (perceptual attention condition), or semantic (semantic attention condition) features of the illustrations within the block, respectively. During the ARTIST task, participants were instructed to detect when two illustrations drawn by the same artist were presented consecutively (perceptual repeat), while during the STORY task, participants detected illustrations that portrayed the same story presented consecutively (semantic repeat). Participants were instructed to respond to whether the illustration presented on the screen was a repeat on the cued dimension with key press "2", or not a repeat with key press "1". For each participant, half of the illustration blocks were in the semantic attention condition (18 blocks), and half within the perceptual attention condition (18 blocks); therefore, all participants received blocks from both attention conditions. Importantly, the types of images within each attention block was held constant while the attentional condition varied, allowing for the isolation of the specific effects the attentional state the participant engaged in had on subsequent memory. In between performing the attention tasks, participants occasionally performed a baseline task that was cued with a screen that displayed "DOTS". During the baseline task, participants were instructed to respond to where the dot was located on the three-section rectangle using key press "1", "2", and "3" to indicate left, middle, and right, respectively. Importantly, baseline task blocks helped maintain the participant's interest throughout the encoding task and offered opportunities to rest between attention blocks.

The encoding phase was broken into six runs, allowing participants the chance to take short breaks between runs. Each run contained three semantic attention blocks, three perceptual attention blocks, and four baseline task blocks. A baseline task block was presented after every two attention blocks and at the start and end of each run. Baseline blocks contained eight images per block as well. Each image was presented for 2500 ms with a 500 ms inter-stimulus interval (ISI). Cue screens were presented for 2000ms with a 500 ms inter-stimulus interval (ISI). The entire task lasted approximately 30 mins (Figure 1A).

4.3.2 Retrieval Phase

Immediately after the encoding phase, participants performed a surprise memory test. This memory test examined whether illustrations showed different memory behaviours (i.e., remembering vs. forgetting) when encoded during semantic vs. perceptual attentional states. The memory test presented the following types of images, one at a time, and in an intermixed order: encoding phase images (288 old, including both fillers and repeats), images depicting the same semantic features (72 semantic lures) or perceptual features (72 perceptual lures) as encoded images, and images with unique semantic and perceptual features not presented at encoding (144 new). Participants were asked to judge whether each image presented was old (i.e., was presented at encoding) with keypress "1", or new (i.e., not presented at encoding) with keypress "2".

Each image was presented for 500 ms, followed by a 1000 ms response window and 500 ms ISI (Figure 3). Participants could respond while the image was presented on the screen, or during the response window. The retrieval phase was broken into three runs, allowing participants the chance to take breaks between runs. Each run contained 96 old, 24 semantic lures, 24 perceptual lures, and 48 new images, and was approximately 5 mins. The entire memory test was 15 mins long.

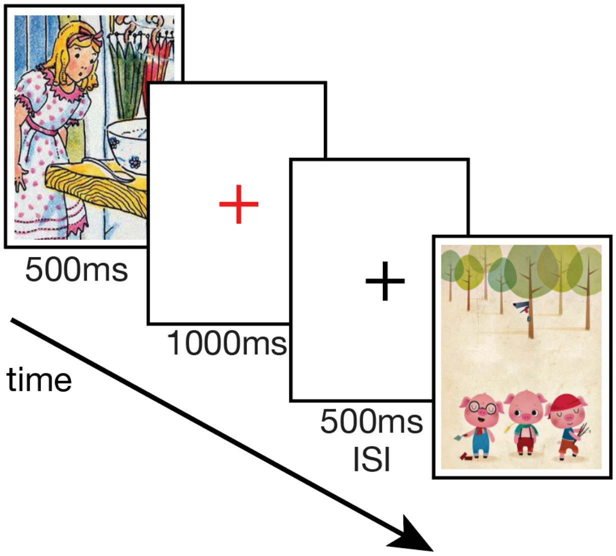


Figure 3. Retrieval Trial Timing: At retrieval, participants were presented images sequentially and in an intermixed order, with each image shown for 500 ms followed by a 1000 ms response window, and a 500 ms black fixation cross ISI.

To examine whether memories for illustrations with repeated semantic and perceptual features are bound together in memory across time, unbeknownst to participants, repeats from the encoding phase appeared during retrieval either in the same order as seen during encoding (intact) or paired with an image from a different block (matched). Half of the semantic and perceptual repeats were presented in the same order seen during encoding (intact pairs). The remaining repeat images were matched with a repeat image from another block (matched pairs).

All other images were presented in a random order. Faster reaction times to the second image of an intact pair would suggest that these repeats are bound together in memory. All participants received the same number of intact, matched, and random trials. Assignment of the repeat images to intact vs. matched pairs was counterbalanced across participants. Images not a part of intact or matched pairs were presented randomly.

4.3.3 Post Task Procedure

After the completion of the encoding and retrieval phases, participants completed a follow-up questionnaire. Specifically, participants were provided with a list of the names of the stories included in the encoding phase and asked to indicate which stories they were familiar with. Participants were also asked to list any artists they recognized from the encoding task. Lastly, the questionnaire asked participants open-ended questions about their subjective experience with the experiment, such as their level of fatigue and the strategies they used to perform the tasks.

4.4 Analysis Plan

4.4.1 Encoding Measures

The objective of the modified 1-back ARTIST and STORY task was to ensure that participants engaged in semantic and perceptual attentional states at encoding. The analyses performed were to confirm whether participants could effectively perform the task and attend to the cued feature. The ability to sustain attention to the cued feature was indexed by the participant’s ability to respond (1) “repeat” to cued repeats and (2) “not a repeat” to filler illustrations.

4.4.2 Retrieval Measures

The retrieval phase was used to examine the precise and integrated nature of illustration memories formed during semantic and perceptual attentional states. To examine the impact of attentional states on illustration memory representation, comparisons were made for (1) general recognition of illustrations, and (2) mnemonic discrimination of studied illustrations from lure illustrations. D’ scores were used for each mnemonic measure to correct for response biases (see Green & Sweets 1966 for signal detection theory). Importantly, the discrimination of old illustrations from highly similar lures indexed the degree of precision-integration the resulting illustration memories demonstrated.

(1) General recognition memory for illustrations was assessed by evaluating memory for filler illustrations that portrayed non-repeated semantic and perceptual features in comparison to false alarms to illustrations that presented unrelated semantic and perceptual features (new). This analysis was done by calculating d' for old fillers vs. new illustrations:
    (1) ((z(hit rate to fillers) – z(false alarm rate to new))
(2) To examine the precision-integration of illustration memories and how this impacts the tendency to mistake highly similar lures as having been studied at encoding, discrimination of old repeats from lures portraying the same repeated feature was measured. This analysis was done by calculating d' for old repeats vs. lures:
    (1) (z(hit rate to semantic repeats) – z(false alarm rate to semantic lures))
    (2) (z(hit rate to perceptual repeats) – z(false alarm rate to perceptual lures))

Low mnemonic discrimination (low d' scores) served as an indicator of integration along the repeated feature. High mnemonic discrimination (high d' scores) indicated mnemonic precision of the illustration memory from experiences that shared the repeated feature.

5 Results

5.1 Encoding Phase Results

I first compared the proportion of repeat responses to repeats on the cued dimension—i.e., semantic repeats in the semantic attention condition, and perceptual repeats in the perceptual attention condition—vs. filler illustrations. Participants responded "repeat" more to cued repeats vs. filler illustrations ($t(43) = 12.161$, $p < 0.0001$, Cohen's $d = 9.05$), suggesting that the attentional manipulation was effective.

Next, repeat detection between the attention conditions was examined to see if repeat responses differed as a function of attention condition. There was a significant interaction between the attention condition and repeat type ($F(1,43) = 715.86$, $p < 0.0001$, $\eta = 0.84$). Participants responded "repeat" more to repeats on the cued dimension vs. repeats on the uncued dimension in both attention conditions (semantic attention: $t(43) = 18.34$, $p < 0.0001$, Cohen's $d = 4.11$; perceptual attention: $t(43) = 23.61$, $p < 0.0001$, Cohen's $d = 4.99$), suggesting that the repeat detection tasks were matched in difficulty. Interestingly, there was a trend between the proportion of false alarms to uncued repeats in the semantic vs. perceptual attention condition (t(43) = 1.74, p = 0.09), suggesting that participants may have had difficulty maintaining a semantic attentional state at encoding (Figure 4).

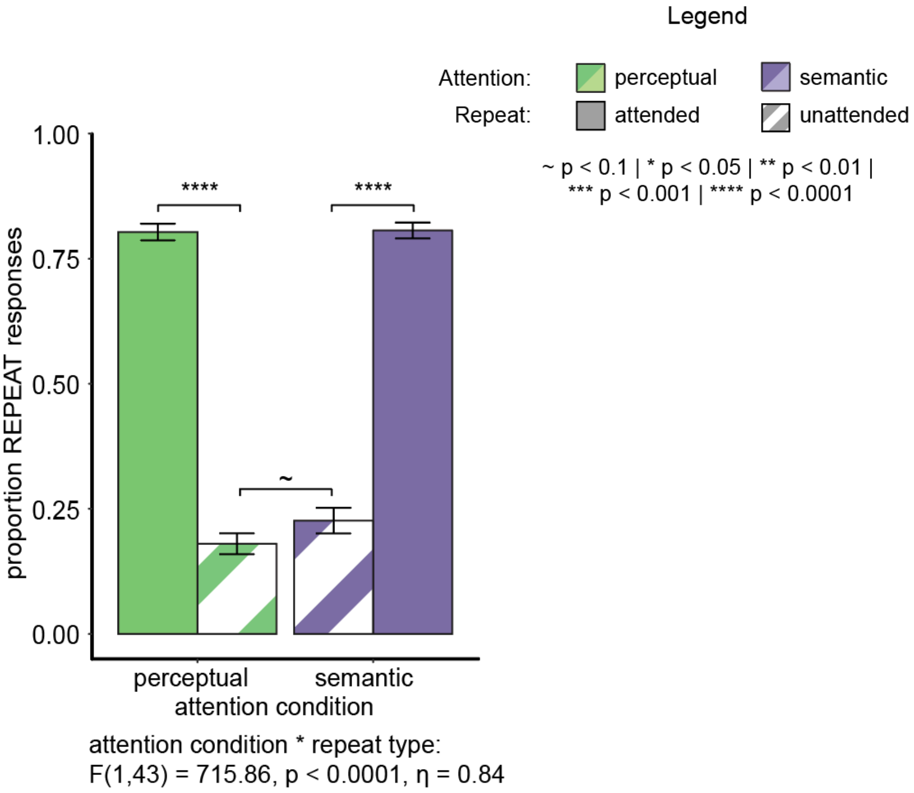


Figure 4. Study 1-Repeat Detection: The proportion of repeat responses to cued and uncued repeats from the perceptual vs. semantic attention condition. Participants responded “repeat” more to cued vs. uncued repeats, with a trend of more false alarms in the semantic vs. perceptual attention condition.

5.2 Retrieval Phase Results

First, comparisons were made to confirm that participants could remember the encoded illustrations irrespective of the attentional manipulation. Responses to lures were also examined to determine whether semantic and perceptual lures showed a greater likelihood of being endorsed as “old” than new illustrations. A repeated measures ANOVA was used to compare the proportion of old responses to old illustrations, semantic lures, perceptual lures, and new illustrations: there was a significant effect for image type (F(1,3) = 236.02, p < 0.0001, η = 0.61). Participants responded “old” more to old illustrations vs. semantic lures (t(43) = 14.64, p < 0.0001, Cohen’s d = 2.52), perceptual lures (t(43) = 15.11, p < 0.0001, Cohen’s d = 2.43), and new illustrations (t(43) = 17.86, p < 0.0001, Cohen’s d = 3.31). Therefore, participants demonstrated memory for illustrations presented during the encoding phase. Participants also responded "old" more to semantic lures vs. new illustrations ($t(43) = 11.38$, $p < 0.0001$, Cohen's $d = 0.67$), and perceptual lures vs. new illustrations ($t(43) = 9.45$, $p < 0.0001$, Cohen's $d = 0.65$), suggesting that both lure types provided a harder mnemonic discrimination from studied illustrations than new illustrations. Both semantic and perceptual lures were matched in mnemonic discrimination difficulty ($t(43) = 0.14$, $p = 0.89$), with no significant difference in the proportion of old responses between the lure types.

5.2.1 Filler Memory Performance

Before examining whether illustration memories varied in precision and integration, general recognition memory for studied illustrations was examined. The following analyses examine whether recognition of studied filler illustrations was better when encoded during semantic vs. perceptual attentional states. High d' scores for fillers (hits) vs. new illustrations (false alarms) indicated high recognition memory, while low d' scores represented low recognition memory. Participants demonstrated better memory for fillers in the semantic vs. perceptual attention condition ($t(43) = 6.62$, $p < 0.0001$, Cohen's $d = 0.36$; Figure 5). Better memory for fillers encoded during semantic vs. perceptual attentional states was comprised of higher hits to studied fillers from the semantic vs. perceptual attention condition ($t(43) = 6.50$, $p < 0.0001$, Cohen's $d = 0.44$). Since false alarms to new illustrations could not be grouped by semantic vs. perceptual attention condition, memory performance solely reflected differences in the hit rates to studied fillers from semantic vs. perceptual attentional states. Consistent with LOP theory, attending to the semantic features of illustrations at encoding was associated with better recognition of studied filler illustrations at retrieval.

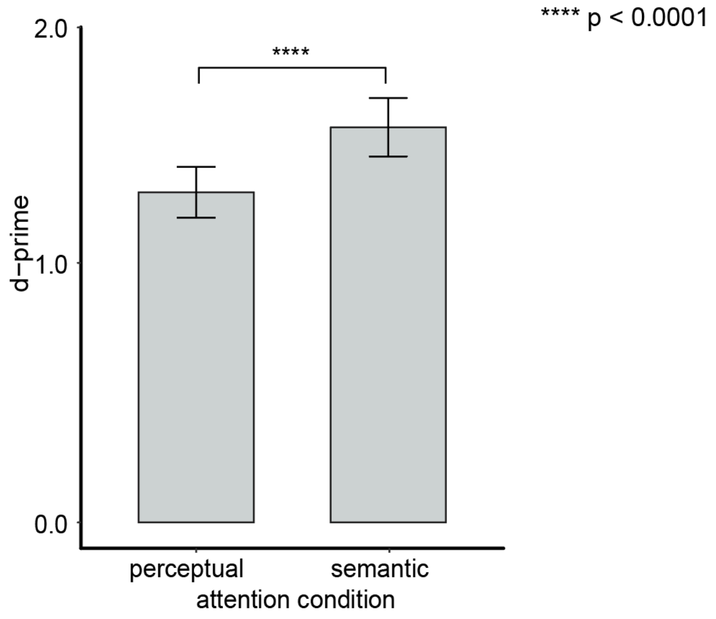


Figure 5. Study 1-Filler Memory Performance: D' for fillers vs. new illustrations as a function of attention condition. Participants showed better memory for fillers encoded during semantic vs. perceptual attentional states.

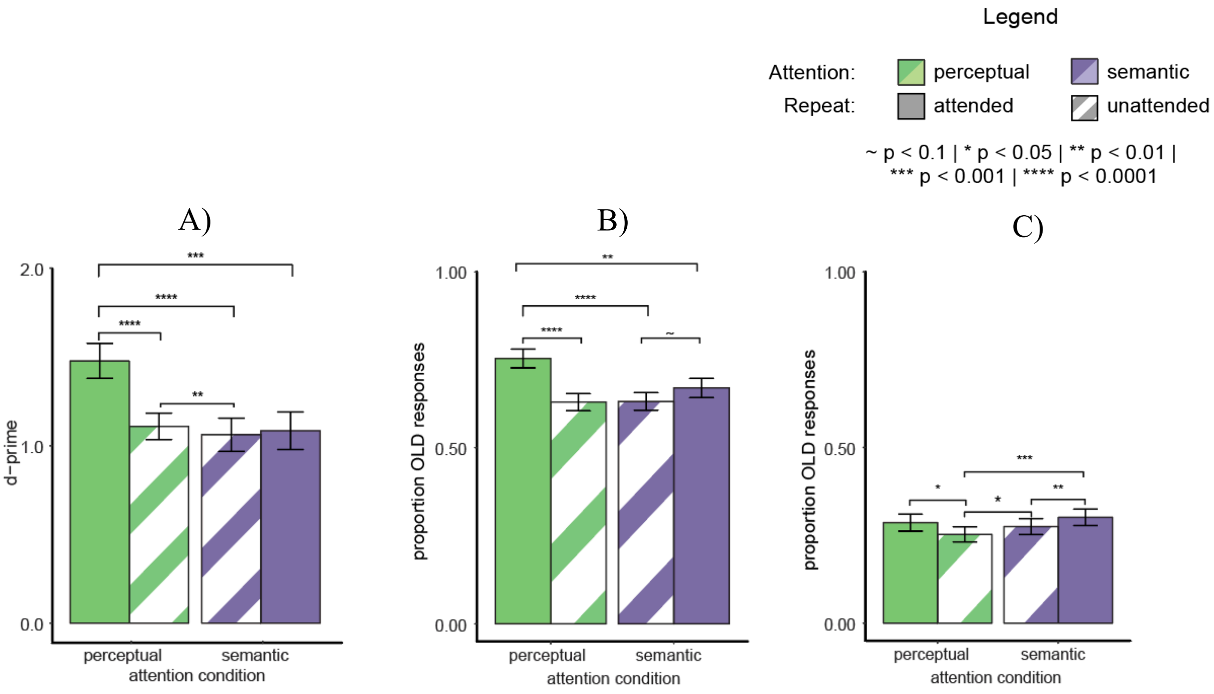
5.2.2 Discriminating Old Repeats from Related Experiences

The following analyses examined whether (1) repeat illustration memories demonstrated degrees of precision and integration with highly similar illustrations, and (2) if semantic vs. perceptual attentional states facilitated the mnemonic precision and integration of the studied repeats. However, only responses to the first image a part of each repeat were assessed. At encoding, repeat images (the second image within the repeat) were the only images to require a different response key, in comparison to the other images. Therefore, memory performance to repeat images may be confounded by associations with the infrequent use of an uncommon key press. To prevent key press memory confounds, the following analyses examined discrimination of the first image a part of each repeat. Since the first image within each repeat required the same response key as all other non-repeated images, the discrimination of these images is less impacted by memory enhancements that may have emerged at encoding due to salient opportunities to press the uncommon response key.

The precision-integration metric of interest was the discrimination of studied illustrations from highly similar illustrations, as measured with d': semantic repeats (hits) vs. semantic lures (false alarms) and perceptual repeats (hits) vs. perceptual lures (false alarms). High d' scores represented the ability to discriminate studied repeats from similar illustrations at retrieval, suggesting mnemonic precision of the encoded illustration from related experiences. Conversely, low d' scores indexed low discrimination of studied repeats from similar illustrations, suggesting integration of the encoded information. A repeated measures ANOVA with attention condition and repeat type as factors revealed a significant interaction ($F(1,43) = 13.86$, $p = 0.00056$, $\eta = 0.02$), and main effects for attention condition ($F(1,43) = 11.54$, $p = 0.0015$, $\eta = 0.03$) and repeat type ($F(1,43) = 14.48$, $p = 0.00044$, $\eta = 0.02$; Figure 6A), meaning that the ability to discriminate repeats from similar illustrations was influenced by the attentional state at encoding, and the type of repeated feature the memory contained. There was significantly higher discrimination of cued perceptual repeats from lures vs. cued semantic repeats from lures ($t(43) = 4.05$, $p = 0.0002$, Cohen's $d = 0.58$), suggesting that perceptual attentional states at encoding led to greater mnemonic precision of the attended feature than semantic attentional states. Perceptual attentional states benefited discrimination of attended features, more so than unattended features: there was greater discrimination of cued perceptual repeats from lures vs. uncued semantic repeats from lures in the same attention condition ($t(43) = 5.09$, $p < 0.0001$, Cohen's $d = 0.64$). In contrast, semantic attention did not show memory benefits for the attended feature: there was no difference in discrimination from cued semantic repeats vs. uncued perceptual repeats ($t(43) = 0.34$, $p = 0.73$). Therefore, attention at encoding did not consistently facilitate mnemonic benefits for the attended feature and appeared to only enhance detailed memory for attended perceptual repeat illustrations specifically.

Hit rates to repeats were evaluated to examine whether the perceptual attention memory benefit for attended features was primarily due to memory for repeats (hits) irrespective of their discrimination from related experiences. A repeated measure ANOVA with attention condition and repeat type as factors revealed a significant interaction ($F(1,43) = 30.60$, $p < 0.0001$, $\eta = 0.05$), and main effects for attention condition ($F(1,43) = 5.40$, $p = 0.02$, $\eta = 0.01$) and repeat type ($F(1,43) = 12.42$, $p = 0.001$, $\eta = 0.02$; Figure 6B). There were significantly more hits to perceptual vs. semantic repeats, and for repeats from the perceptual vs. semantic attention condition. Similar to the pattern of discrimination seen, there were significantly more hits to cued perceptual repeats vs. all other conditions (all $t > 3.20$, all $p < 0.003$). Therefore, mnemonic discrimination of cued perceptual repeats was reflected in participants' ability to recognize the cued perceptual repeats independently.

False alarm rates were also compared to inform whether the degree of precision and integration demonstrated among illustration memories was primarily weighed by mistaking similar lures as illustrations studied at encoding. A repeated measures ANOVA with attention condition and lure type as factors showed a significant interaction (F(1,43) = 12.17, p = 0.0011, η = 0.01), but no main effects for attention condition ((F(1,43) = 3.81 , p = 0.057), or lure type ((F(1,43) = 0.26 , p = 0.61, Figure 6C). In contrast to the high hit rate seen for cued perceptual repeats, there was a high *false alarm* rate to semantic lures similar to repeats studied during semantic attentional states. There were greater false alarms to semantic lures for repeats from the semantic vs. perceptual attention condition (t(43) = 3.66, p = 0.00068, Cohen's d = 0.15; Figure 7 C), and to lures related to uncued repeats in the semantic vs. perceptual attention condition (t(43) = 3.32 p = 0.002, Cohen's d = 0.17). This pattern suggests that false alarms to semantic lures were commonly overall, but elevated when semantic features were attended to at encoding. Therefore, attention to semantic features at encoding facilitated low discrimination (our metric of integration) of studied repeats from lures that shared the attended feature.



attention condition * repeat type:
F(1,43) = 13.86, p = 0.00056, η = 0.02

attention condition: F(1,43) = 11.54, p = 0.0015, η = 0.03

repeat type: F(1,43) = 14.48, p = 0.00044, η = 0.02

attention condition * repeat type:
F(1,43) = 30.60, p < 0.0001, η = 0.05

attention condition: F(1,43) = 5.40, p = 0.02, η = 0.01

repeat type: F(1,43) = 12.42, p = 0.001, η = 0.02

attention condition * repeat type:
F(1,43) = 12.17, p = 0.0011, η = 0.01

Figure 6. Study 1-Discriminating Old Repeats from Related Experiences: A) D' for repeats vs. lures, as a function of the attention condition. There was greater discrimination of cued perceptual repeats from lures vs. all other

conditions. B) Hit rates to repeats as a function of the attention condition. Greater hits to attended repeats in the perceptual attention condition vs. all other conditions. C) False alarms to lures as a function of the associated repeat type and attention condition. There were greater false alarms to semantic vs. perceptual lures, with elevated false alarms to attended semantic features in particular.

5.2.3 Temporal Binding of Repeats

Unknown to participants, repeats from the encoding phase appeared during retrieval either in the same sequence seen at encoding (intact) or paired with another repeat image from a different encoding block (matched). Response times to intact vs. matched pairs were examined to test whether repeats that shared features at encoding were bound together in memory across time—irrespective of their precise or integrated nature. Faster response times to the second image within each intact vs. matched pair would suggest that repeats are bound together in memory although presented consecutively at encoding. A repeated measures ANOVA with pair type (intact vs. matched) and attention condition as factors showed a significant main effect for pair type ($F(1, 43) = 13.67$, $p = 0.00061$, $\eta = 0.03$) but no significant interaction ($F(1,43) = 1.15$, $p = 0.29$) or main effect for attention condition ($F(1,43) = 0.091$, $p = 0.76$). Participants were faster to respond to intact pairs presented in the same sequence seen at encoding vs. matched pairs ($t(1,43) = 4.48$, $p < 0.001$, Cohen's $d = 0.01$; Figure 7). This suggests that repeats presented sequentially at encoding may be bound together in memory. However, there were other factors that may have impacted response times to intact vs. matched pairs. Importantly, the main effect of pair type suggests that the temporal binding of illustration memories may be the facilitated by repeated features among repeats, and not because of attentional states at encoding. The presentation of the first intact image may have facilitated faster processing of the repeated feature depicted in the second image within the pair. Furthermore, temporal binding of the repeats was tested at retrieval and may reflect recall-to-reject strategies participants used at test instead of memory binding across time. At retrieval, participants may have retrieved the studied illustration in order to determine whether the presented illustration was old or new. If this were to occur, faster response times to intact pairs may be due to consecutive exposures to the same studied feature, and not because repeats were bound together at encoding. Therefore, response times to intact vs. matched pairs may not indicate the temporal binding of memories across time and should be interpreted with caution.

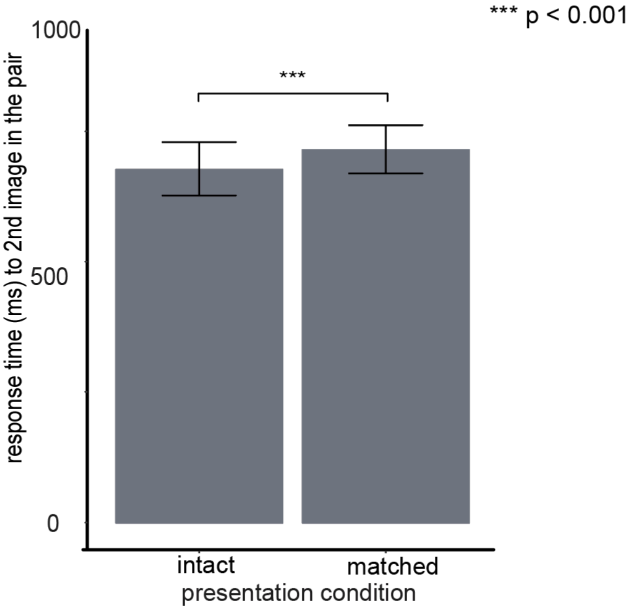


Figure 7. Study1-Temporal Binding of Repeats: Response times to intact vs. matched pairs of repeats. Participants were faster to respond “old” to intact vs. matched repeats. Note: Graphed as a function of presentation condition to highlight main effect.

6 Discussion

This study revealed a novel aspect of how attention and memory interact to influence memory behaviours: attending to semantic vs. perceptual features at encoding impacts the type of memory representation formed. Contradictory to earlier theories on attention and memory, memory benefits for the attended feature were not consistent. Specifically, attending to perceptual features formed precise memories that aided in the discrimination of memories from similar experiences that shared the attended feature. In contrast, attention to semantic features formed integrated memories that emphasized shared themes among experiences, facilitating the false recollection of illustrations that shared the attended feature. Therefore, attention to only perceptual features at encoding demonstrated a memory benefit for illustrations with the attended feature, while semantic attention did not show the same pattern.

When general recognition memory for illustrations was examined, attending to semantic vs. perceptual features at encoding led to better recognition memory. These findings coincide with prior work motivated by LOP theory which suggests that deeper processing afforded by attending to semantic vs. perceptual features facilitates better memory (Craik & Lockhart, 1972). However, when participants were required to make detailed mnemonic discriminations between studied illustrations and highly similar illustrations, perceptual attention benefited illustration memories that shared perceptual features. Semantic vs. perceptual attention at encoding instead led to worse memory for specific features of the studied illustrations, as demonstrated by participant's greater likelihood to endorse new illustrations that shared semantic features as "old".

Although semantic attention at encoding did not benefit precise memory, the dissociation of memory behaviours semantic vs. perceptual attentional encoding states demonstrated may be the product of enhanced processing of the attended information. Perceptual features are distinct and detailed in comparison to semantic features, which represent overarching themes. Attention to perceptual features may have facilitated the enhanced processing of precise perceptual details, allowing for precise memories to be formed at encoding. Semantic attention and the consequent enhanced processing of semantic features may have allowed for better memory of semantic themes that lacked detail and were integrated with prior semantic knowledge. For illustrations studied during semantic attentional states, participants' tendency to endorse semantically similar illustrations as "old" suggests better memory for semantic themes vs. the precise details of the illustrations. Therefore, the enhanced processing of attended information may have benefited memory for the attended *feature* but within this context, memory for precise details allowed for better memory of the studied *illustration*. Importantly, the general enhanced processing of features afforded by selective attention did not always result in better memory for the studied illustration, but the type of feature attended to at encoding did.

Irrespective of the attentional state engaged at encoding, memories for repeat illustrations showed temporal binding across time. However, response times to repeats are influenced by factors unrelated to memory association and therefore may not have served as the best measure of mnemonic binding across time during different attentional states. Response time patterns to repeat illustrations presented at retrieval may be due to the retrieval strategies participants used to perform the memory test. Participants may have retrieved repeat illustrations to help determine where the presented illustration (a part of the repeat) was studied at encoding. Thus, responses to the second image within each repeat may be faster because of the retrieval strategies engaged, not because of the association of these memories. Furthermore, only repeats that shared overlapping information were tested for temporal binding across time. Since repeats showed binding across time unrelated to the attentional state engaged at encoding, it's possible that the temporal binding of these illustrations may be due to the shared features repeat illustrations contained. Hence, assessing responses time to repeats failed to capture the specific impact semantic vs. perceptual attentional encoding states had on the association of memories.

Collectively, the following analyses highlight the importance of semantic vs. perceptual attentional states on memory representation. Study 1 showed that illustration memories demonstrate degrees of precision-integration as a function of attentional encoding states: memories encoded during perceptual attentional states showed precision from experiences that shared the attended feature (i.e., perceptually similar experiences), while attending to semantic features led to integration with experiences that shared semantic features.

Chapter 3
Study 2

Study 1 introduces two major questions that were addressed in Study 2. Is the perceptual attention memory benefit specific to illustrations that shared perceptual features? Furthermore, does the presence of repeated features at encoding impact whether the subsequent memory will vary in precision-integration? Repeats possessed two distinct characteristics that may have impacted the degree of precision-integration subsequent repeat illustration memories demonstrated: (1) the presence of overlapping information, and (2) task-relevant information. The overlap among encoded experiences may show different patterns of precision-integration in comparison to independent encoded experiences. Overlap across encoded experiences may cause additional competition among memories that is resolved by either emphasizing common features across related experiences (through integration) or maintaining idiosyncratic details to differentiate between related experiences (through precision; Preston & Eichenbaum, 2013). Although Study 1 included illustrations that presented independent semantic and perceptual features (i.e., fillers), whether these memories are differentiated or integrated with related experiences at retrieval was not assessed. Furthermore, participants were instructed to attend and search for cued repeats in the incidental encoding task. Therefore, differences in the memory representation of repeat illustrations may reflect mnemonic processes for goal-relevant information. The occurrence of detecting a repeat may have been a more salient experience given the task demands in comparison to the encoding of filler illustrations.

Crucially, the task was designed so that fillers were incidental to the repeat detection task performed at encoding but still encoded during semantic vs. perceptual attentional states. Any differences in the representation of fillers from semantic vs. perceptual attentional states will thus be due to the attentional manipulation, and not because of the presence of repeated information or task facilitated constraints. General recognition of fillers was better when encoded during semantic vs. perceptual attentional states. However, these independent illustrations did not have related experiences presented at retrieval to discriminate from. If illustrations highly similar to fillers are presented at retrieval, will attention to perceptual features at encoding result in greater mnemonic precision than attending to semantic features?

In addition to limiting the original investigation to whether memories for repeats demonstrated degrees of precision-integration when encoded during semantic vs. perceptual attentional states, the overall precision or integration subsequent memories demonstrated was not examined. For example, Study 1 showed that attending to perceptual information at encoding led to precise discrimination of new experiences that shared perceptual features. However, does perceptual attention at encoding impact mnemonic precision along one dimension, or is there a memory benefit for precision along *both* semantic and perceptual dimensions overall? From the results of Study 1, it is unclear whether perceptual attention biases the encoding of memories that show precision overall. Conversely, it unclear whether semantic attention at encoding facilities integration with both semantically and perceptually similar experiences. To gauge the full impact attentional states at encoding have on memory representation, is necessary to examine whether perceptual and semantic attentional states impact the precision or integration of the resulting memory overall.

Study 2 addressed the outstanding questions remaining from Study 1 by examining whether attending to semantic vs. perceptual features impacts the nature of representation for independent experiences and the precision-integration of memories overall. This investigation examined whether the presence of overlapping vs. independent information further biases precision and integration mnemonic mechanisms. Additionally, this study assessed whether illustration memories show precision or integration from similar experiences on both semantic and perceptual dimensions by including semantic *and* perceptual lures for each repeat and subset of filler illustrations.

6.1 Predictions

I predicted that memory representation will vary as a function of the attentional state at encoding and the overlap among the encoded experiences. As seen in Study 1, it is predicted that independent illustrations (i.e., fillers) will be remembered better when encoded during semantic vs. perceptual attentional states. In contrast, overlapping illustrations (i.e., repeats) will be remembered better under perceptual vs. semantic attentional states. Across both overlapping and independent experiences, semantic vs. perceptual attentional states at encoding will promote illustration memories that are integrated into existing semantic knowledge. In contrast, perceptual vs. semantic attentional states will yield memories that remain distinct from perceptually similar experiences, facilitating detailed memory representation. However, the precision-integration of illustration memories will vary as a function of overlap, with competition posed by illustrations that contain overlap yielding memory representations with enhanced precision and integration relative to independent illustrations.

7 Method

7.1 Participants

A final sample size of 44 healthy adults from our paid participant pool was selected for Study 2 (M = 21.89 years old, SD = 3.32 years, 10 males, 34 females) in order to match the sample size from Study 1. Contrary to Study 1, participants in this sample were paid 10 dollars per hour as compensation. The inclusion criteria were the same as Study 1. Seventy-one participants were recruited (M = 22.5 years old, SD = 3.71 years, 18 males, 54 females), with 27 participants excluded because they did not reach the cued repeat accuracy threshold of 0.66. All participants provided written consent and the experimental protocol was approved by the University of Toronto Research Ethics Board.

7.2 Stimuli

Some of the stimuli from Study 1 were used in Study 2 but with the addition of new illustrations that met the criteria described below. To assess the precise and integrated nature of filler memories as a function of the attentional state, each illustration block at encoding possessed critical fillers. In order to add critical fillers to each encoding block, the illustrations within each predetermined block were either redistributed or replaced with new illustrations. For each critical filler two semantically similar (filler-semantic lures; same story, different artist) and two perceptually similar (filler-perceptual lures; same artist, different story) illustrations were collected to be presented at retrieval. In addition to adding critical fillers, since in Study 1 repeats only possessed lures similar to the repeated dimension, lures for the opposite dimension were collected. In contrast with Study 1, each repeat contained two semantic lures and two perceptual lures corresponding to the first illustration a part of each repeat. The decision to collect lures associated with the first illustration within each repeat was to prevent the examined memory performance from being confounded by enhanced memory for the infrequent occurrence of a repeat illustration. Furthermore, collecting lures corresponding to the first illustration within each repeat matched the analyses performed in Study 1.

The retrieval task in this study presented the following types of images: old repeats, old fillers, semantic repeat-semantic lures, semantic repeat-perceptual lures, perceptual repeat-semantic lures, perceptual repeat-perceptual lures, critical filler-semantic lures, critical filler-perceptual lures, and illustrations with unrelated stories and artist styles (new; Figure 8).

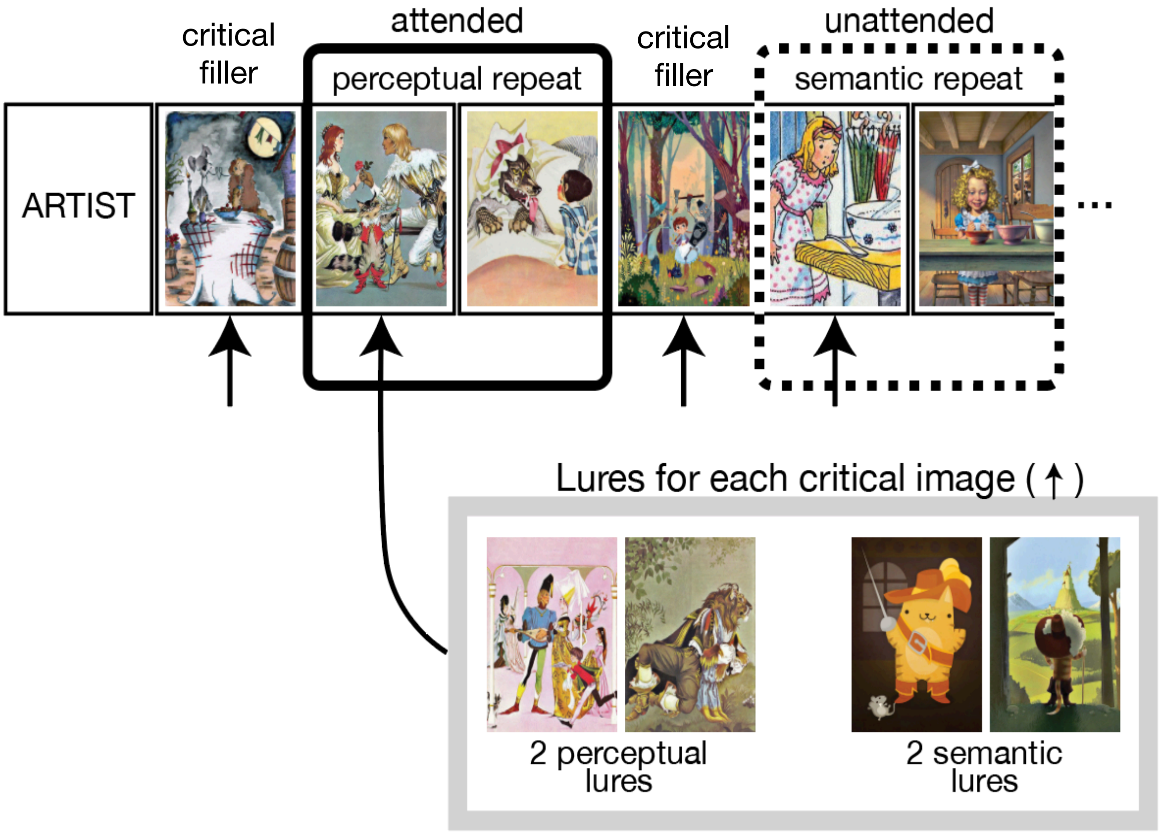


Figure 8. Study 2- Retrieval Image Type Structure: Depiction of the illustrations presented at retrieval in Study 2. Critical images are denoted with arrows and included the first image of each repeat pair as well as two designated fillers (critical fillers) per block. Each critical image had both two semantic lures and two perceptual lures presented at test. In this example, the fist image in the perceptual repeat has two perceptual lures with the same artist style, and two semantic lures depicting the same story (i.e., Puss in Boots) presented at retrieval. Each critical illustration denoted with an arrow also had two semantic lures and two perceptual lures presented at retrieval.

7.3 Task

The encoding and retrieval phases in Study 2 were similar to the encoding and retrieval tasks from Study 1. Participants performed the same modified 1-back incidental encoding task where they attended to semantic or perceptual features of blocks of illustrations responding to repeats on the cued dimension (Figure 1A). Following encoding, participants completed a surprise memory test for all the illustrations, responding “old” or “new” to each illustration presented (Figure 3). However, three major changes were incorporated into the design in order to address the research questions stated above. During the encoding phase, similar to Study 1, each block of illustrations included one semantic repeat, one perceptual repeat, and filler images. However, in this study, two of the filler images within each block were tested at retrieval for precision vs. integration along the related semantic vs. perceptual dimensions. These images were termed “critical fillers.” Critical fillers possessed the same testing structure as repeat images by having related semantic and perceptual lures but contained independent semantic and perceptual features instead. Thus, these critical fillers were comparable to repeat images when examining retrieval performance for overlapping and independent experiences.

Similar to Study 1, each block contained eight images. All blocks contained one perceptual and one semantic repeat pair (four images total). After informal conversations with colleagues revealed that the constant block structure may cause predictability in the task, 33% of blocks contained an additional repeat at the end of the block to reduce predictability and encourage attention throughout the block (junk repeats; omitted from retrieval analyses). The remaining images were fillers (two for blocks with junk repeats; four for all other blocks). Two of the fillers within each block were assigned to be critical fillers. In this study, the encoding phase consisted of nine semantic attention blocks, nine perceptual attention blocks, and 12 dot baseline task blocks. There were three runs, with each run lasting approximately 5 mins, and opportunities for the participant to rest between runs.

During the retrieval phase, participants were tested for their memory of all the illustrations presented at encoding, along with their respective lures and new illustrations. In total there were 36 old repeats images (18 old semantic repeat images, 18 old perceptual repeat images), 60 old fillers (36 critical fillers, 24 non-critical fillers), 12 junk repeat images (excluded from retrieval analyses), 72 repeat-semantic lures (36 semantic repeat-semantic lures, 36 perceptual repeat-semantic lures), repeat-perceptual lures (36 semantic repeat-perceptual lures, 36 perceptual repeat-perceptual lures), 72 critical filler-semantic lures, 72 critical filler-perceptual lures, and 144 new illustrations presented at retrieval. The retrieval phase was broken into three runs, with each run lasting 7 mins. Participants were given the chance to take short breaks between runs.

8 Results

8.1 Encoding Phase Results

Despite the addition of new filler illustrations, participants still responded repeat significantly more to repeats on the cued dimension vs. filler illustrations ($t(43) = 53.76$, $p < 0.001$, Cohen's d = 6.79), suggesting that the task changes did not negatively impact the effectiveness of the attention manipulation.

When the proportion of repeat responses was examined between attention conditions and repeat types, similar to Study 1, there was a significant interaction between the attention condition and repeat type participants responded "repeat" to ($F(1,43) = 358.47$, $p < 0.0001$, $\eta = 0.70$; Figure 9). Although illustrations from Study 1 had been redistributed to different blocks for Study 2, participants still responded repeat significantly more to repeats on the cued dimension vs. repeats on the uncued dimension (semantic attention: $t(43) = 21.29$, $p < 0.0001$, Cohen's d = 3.65; perceptual attention: $t(43) = 8.85$, $p < 0.0001$, Cohen's d = 2.54). In contrast to Study 1, there was a significant difference in the proportion of false alarms to uncued repeats between the attention conditions: participants false alarmed more in the perceptual vs. semantic attention condition ($t(43) = 2.48$, $p = 0.02$, Cohen's d = 0.18). This suggests that in this study, participants faced difficulty either engaging in perceptual attentional states, disengaging from semantic attentional states, or both. Surprisingly, this pattern of false alarms was the opposite of the pattern seen in Study 1, where there was a trend of greater false alarms in the semantic vs. perceptual attention condition.

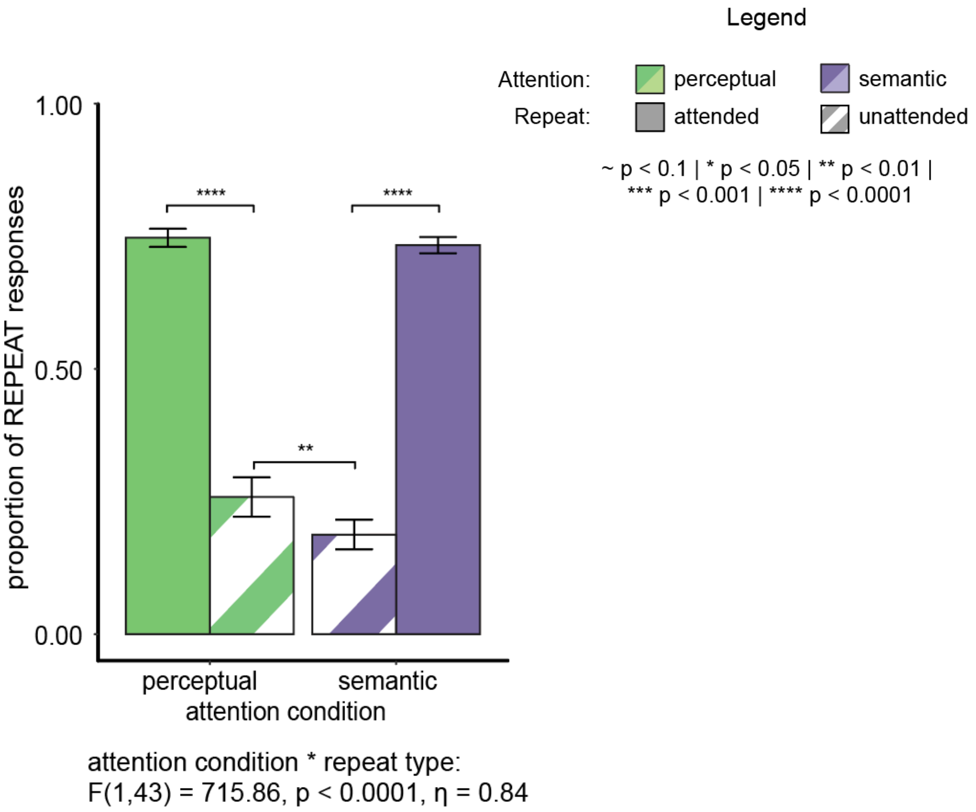


Figure 9. Study 2-Repeat Detection: The proportion of repeat responses to cued and uncued repeats from the perceptual vs. semantic attention condition. Participants responded "repeat" more to cued vs. uncued repeats, with significantly greater false alarms in the perceptual vs. semantic attention condition.

8.2 Retrieval Phase Results

The first analysis was to confirm whether participants could remember the studied illustrations (from both attention conditions) with the addition of new critical filler illustrations. Responses to lures were also examined to determine whether the lures added to the retrieval task were more likely to be endorsed as "old" in comparison to the new, unrelated illustrations. A repeated measures ANOVA revealed a significant main effect of old responses to different image types (F(1,43) = 232.21, $p < 0.0001$, $\eta = 0.67$). Similar to Study 1, participants responded "old" more to old illustrations vs. semantic lures (t(43) = 14.47, $p < 0.0001$, Cohen's d = 2.84), perceptual lures (t(43) = 15.80, $p < 0.0001$, Cohen's d = 3.11), and new illustrations (t(43) = 16.01, $p < 0.0001$, Cohen's d = 3.02). Participants also responded old more to semantic lures vs. new (t(43) = 7.24, $p < 0.0001$, Cohen's d = 0.39) and perceptual lures vs. new (t(43) = 2.24, p = 0.03, Cohen's d = 0.09), demonstrating that despite the changes to the lure stimuli, participants continued to false alarm more to lures than new illustrations. However, contrary to Study 1, participants false alarmed more to semantic lures than perceptual lures ($t(43) = 5.62$, $p < 0.0001$, Cohen's $d = 0.29$), suggesting that semantically similar experiences were endorsed as "old" more overall regardless of the attentional state at encoding.

8.2.1 Filler Memory Performance

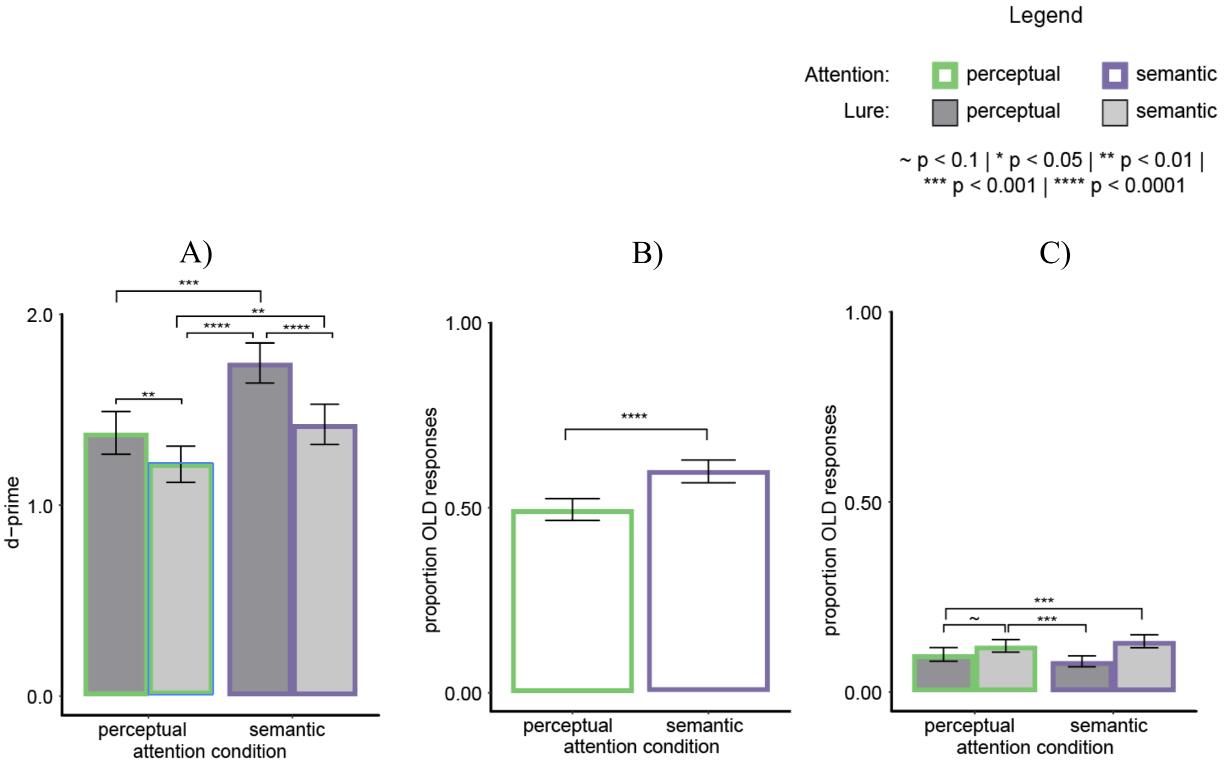
The mnemonic analyses in Study 2 paralleled the retrieval analyses conducted in Study 1. General recognition memory for fillers was examined to determine whether filler memory benefited from semantic vs. perceptual attention as in Study 1. Similar to Study 1, participants showed better memory (d') for fillers (hits) vs. new illustrations (false alarms) encoded during semantic vs. perceptual attentional states ($t(43) = 5.27$, $p < 0.0001$, Cohen's $d = 0.53$). Therefore, attending to semantic features at encoding still led to better recognition of illustrations depicting independent stories and artist styles.

8.2.2 Discriminating Old Fillers from Related Experiences

To examine the memory representation that underlies better memory for fillers from the semantic vs. perceptual attention condition, the following analyses examined the precision and integration of filler memories with highly similar illustrations. The precision and integration metric used was discrimination (d') of fillers (hits) from semantic or perceptual lures (false alarms). High d' scores indicated the ability to discriminate studied fillers from lures (precision), while low d' scores indicated low discrimination of studied illustrations from lures, related to the integration of the encoded memory with related experiences. A repeated measures ANOVA with attention condition and lure type as factors showed significant main effects for attention condition ($F(1,43) = 16.95$, $p = 0.00017$, $\eta = 0.04$) and lure type ($F(1,43) = 32.48$, $p < 0.0001$, $\eta = 0.03$), but no significant interaction ($F(1,43) = 2.69$, $p = 0.11$; Figure 10A). There was greater mnemonic precision of fillers from the semantic vs. perceptual attention condition overall. Fillers showed precision from perceptual vs. semantic lures overall as well. Therefore, semantic vs. perceptual attention benefited filler memories through higher discrimination from similar illustrations, especially from lures that shared perceptual vs. semantic features ($t(43) = 5.01$, $p < 0.0001$, Cohen's $d = 0.49$).

The proportion of hits to fillers as a function of attention condition was examined to determine whether the mnemonic precision seen among fillers was primarily composed of memory for fillers (hits) instead of discrimination from related illustrations. Coinciding with the pattern of filler memory discrimination seen, there were significantly more hits to fillers from the semantic vs. perceptual attention condition (t(43) = 6.23, $p < 0.0001$, Cohen's d = 0.55; Figure 10B). Therefore, general memory for fillers (hits) contributed to the greater mnemonic discrimination of fillers from the semantic vs. perceptual attention condition.

To assess whether false alarms to lures from a specific attention condition contributed to the pattern of filler memory precision demonstrated, a repeated measures ANOVA was performed for false alarms as a function of attention condition and lure type. There was a significant main effect for lure type (F(1,43) = 29.55, $p < 0.0001$, $\eta = 0.03$), but no main effect for attention condition (F(1,43) = 0.17, p = 0.68) or interaction (F(1, 43) = 2.68, p = 0.11; Figure 10C). There were greater false alarms to semantic vs. perceptual lures (semantic attention condition: t(43) = 4.40, $p < 0.0001$, Cohen's d = 0.27; perceptual attention condition: t(43) = 2.01, p = 0.05, Cohen's d = 0.17), suggesting that participants false alarmed to lures that shared sematic features with fillers irrespective of whether participants were attending to semantic features at encoding.



attention condition: F(1,43) = 16.95, p = 0.00017, η = 0.04

lure type F(1,43) = 32.48, p < 0.0001, η = 0.03

lure type (F(1,43) = 29.55, p < 0.0001, η = 0.03

Figure 10. Study 2-Discriminating Old Fillers from Related Experiences: A) D' for fillers vs. their respective semantic and perceptual lures, as a function of the attention condition. There was greater mnemonic precision of studied fillers from semantic vs. perceptual attention condition, with enhanced discrimination from perceptual vs. semantic lures. B) Hits to fillers as a function of attention condition. There were greater hits to fillers from the semantic vs. perceptual attention condition. C) False alarms to lures for fillers as a function of attention condition and lure type. There were greater false alarms to semantic vs. perceptual lures, regardless of the attentional state at encoding.

8.2.3 Discriminating Old Repeats from Related Experiences on the Repeated Dimension

Analogous to the analyses performed in Study 1, a repeated measures ANOVA was used to examine discrimination of illustrations that shared overlap at encoding (i.e., repeats) from lures that share the repeated feature. Discrimination (d') of the first illustration a part of each studied repeat (hits) from lures on the repeated dimension (false alarms; i.e., semantic repeats vs. semantic lures and perceptual repeats vs. perceptual lures) was evaluated. Unlike Study 1, there was no significant interaction (F(1,43) = 0.10, p = 0.76) or main effect of either attention condition (F(1,43) = 1.62, p = 0.21) or lure type (F(1,43) = 1.41, p = 0.24; Figure 11A). Surprisingly, the pattern of greater discrimination of attended perceptual repeats vs. all other conditions was not replicated in Study 2.

To examine the components contributing to the pattern of memory performance shown, hits to repeats as a function of attention condition and repeat type was examined. A repeated measures ANOVA was performed with attention condition and repeat type as factors. There was a significant main effect for repeat type (F(1,43) = 5.26, p = 0.03, η = 0.02) but no main effect for attention condition (F(1,43) = 0.00043, p = 0.98) or interaction (F(1,43) = 0.24, p = 0.63; Figure 11B). There was a significantly greater proportion of hits to attended vs. unattended repeats from the semantic attention condition (t(43) = 2.13, p = 0.04, Cohen's d = 0.35). This finding opposes the pattern of results demonstrated in Study 1, which showed greater hits to attended vs. unattended repeats from the perceptual attention condition.

To assess whether participants demonstrated false alarm patterns to lures as a function of the attention condition and lure type, a repeated measures ANOVA was performed with attention condition and lure type as factors. No main effects or interactions were significant (Figure 11C). However, similar to Study 1, there was a significant difference in false alarms to semantic lures associated with the semantic vs. perceptual attention condition (t(43) = 2.20, p = 0.03, Cohen's d = 0.25). This suggests that attending to semantic features at encoding may have led to the integration of the attended feature with prior knowledge.

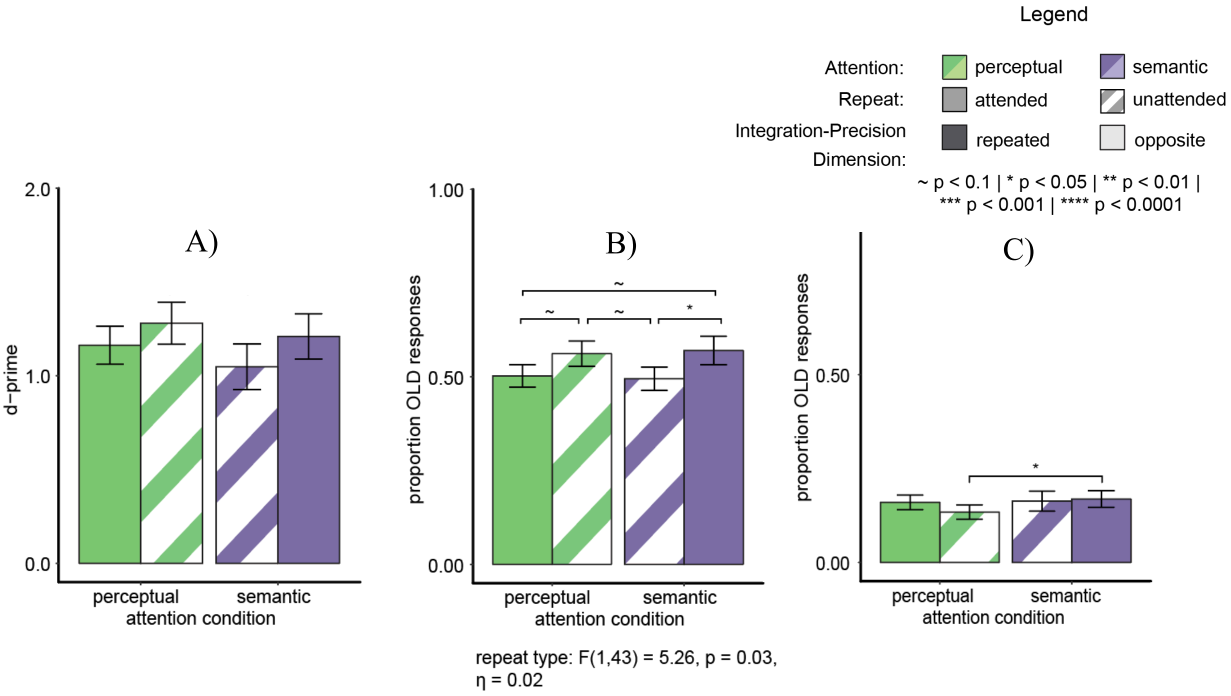
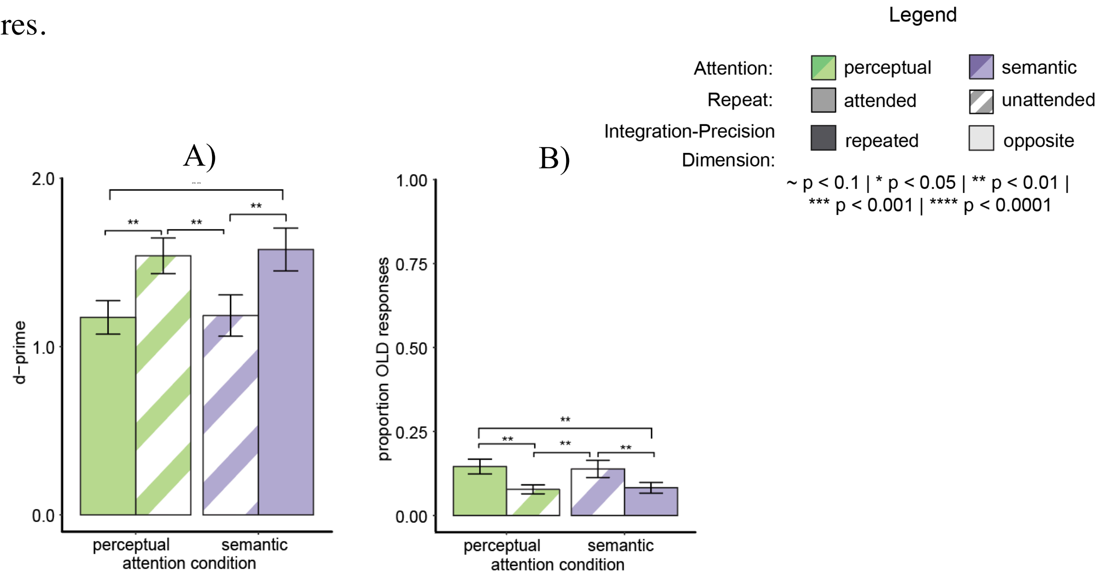


Figure 11. Study 2-Discriminating Old Repeats from Related Experiences on the Repeated Dimension: A) D' for repeats vs. lures on the repeated dimension, as a function of the attention condition. The pattern of discrimination from Study 1 was not replicated: there was no significant interaction or main effects found. B) Hits as a function of repeat type and attention condition. There were greater hits to attended vs. unattended repeats from the semantic attention condition. C) False alarms to lures on the repeated dimension. Reflecting the same pattern of false alarms seen in Study 1, there were more false alarms to lures from the semantic vs. perceptual attention condition.

8.2.4 Discriminating Old Repeats from Related Experiences on the Opposite Dimension.

The following analyses examined whether attentional states at encoding facilitated overall mnemonic precision or integration—along both semantic and perceptual dimensions. Importantly, these analyses examined whether semantic vs. perceptual attention impacts memory representation specifically for the attended feature or overall for both the attended and unattended features (i.e., along the semantic *and* perceptual dimensions). To test overall memory precision and integration as a function of attentional states, discrimination (d') of the first illustration within each repeat (hits) from lures on the opposite dimension (false alarms; i.e., perceptual repeats vs. semantic lures, or semantic repeats vs. perceptual lures) was evaluated. A repeated measures ANOVA with attention condition and repeat type as factors revealed a significant main effect of repeat type (F(1,43) = 13.18, p = 0.0007, $\eta = 0.06$), but no main effect for attention condition (F(1,43) = 0.087, p = 0.77) or interaction (F(1,43) = 0.044, p = 0.83; Figure 12A). There was overall greater precision from perceptual lures vs. semantic lures (semantic attention condition: t(43) = 3.19, p = 0.0027, Cohen's d = 0.48; perceptual attention condition: t(43) = 3.03, p = 0.0041, Cohen's d = 0.54), irrespective of the attentional state engaged at encoding. These findings suggest that participants are better at discriminating studied illustrations from perceptually similar illustrations vs. semantically similar illustrations and that this process was not enhanced by attending to either perceptual or semantic features at encoding.

Since the proportion of hits to repeats was constant across both repeat discrimination analyses (i.e., the same as Figure 11B), false alarm rates to lures were assessed to explore whether participants' tendency to mistake highly similar illustrations as "old" varied as a function of attention condition and lure type. A repeated measures ANOVA showed a significant main effect for lure type (F(1,43) = 15.53, p = 0.00029, η = 0.05), but no main effect for attention condition (F(1,43) = 0.0092, p = 0.92) or interaction (F(1,43) = 0.24, p = 0.62; Figure 12B). Participants false alarmed more to semantic lures than perceptual lures overall (semantic attention condition: t(43) = 2.98, p = 0.0048, Cohen's d = 0.42; perceptual attention condition: (t(43) = 3.27, p = 0.0021, Cohen's d = 0.58). This pattern suggests that illustration memories demonstrated stronger connections with semantically similar experiences (over perceptually similar experiences) regardless of the attentional manipulation at encoding. Therefore, other factors not manipulated in the encoding and retrieval tasks, such as the salience of prior familiarity with the presented fairytale stories, may have contributed to the higher false alarm rate to semantic vs. perceptual lures.



repeat type: F(1,43) = 13.18,
p = 0.0007, η = 0.06

lure type: (F(1,43) = 15.53,
p = 0.00029, η = 0.05),

Figure 12. Study 2-Discriminating Old Repeats from Related Experiences on the Opposite Dimension: A) D’ for repeats vs. lures on the opposite dimension (e.g., semantic repeats vs. perceptual lures), as a function of the attention condition. There was greater precision from perceptual vs. semantic lures overall, unrelated to the attention manipulation at encoding. B) False alarms to lures on the opposite dimension as a function of attention condition and repeat type. There were more false alarms to semantic vs. perceptual lures overall, irrespective of the attentional state at encoding.

9 Discussion

Study 2 emphasized the impact of experiences that share semantic vs. perceptual features on memory precision and integration. This study showed that memories for detailed experiences (illustrations) demonstrated mnemonic precision from perceptually similar experiences and integration with semantically similar experiences overall, with the impact of attentional states at encoding near absent. Contrary to what was predicted, the precision and integration of memories with similar experiences was not modulated by semantic vs. perceptual attentional states at encoding. There was no overall mnemonic benefit seen for attended information because neither semantic or perceptual attentional states at encoding led to overall precision from highly similar experiences. Here, memory precision and integration with similar experiences was dependent on the type of information the similar experience shared, not the attentional encoding state: semantically related experiences were incorrectly mistaken as “old” more so than perceptually related experiences, which participants successfully discriminated as new.

Surprisingly, the pattern of memory precision from experiences that shared the repeated feature seen in Study 1 was not replicated in Study 2. Specifically, perceptual attention at encoding was not associated with memory precision along the perceptual dimension. What might account for discrepancies in the results of Study 1 and Study 2? There were numerous design changes made in Study 2 that may have impacted participants’ subsequent memory behaviours. First, by presenting two semantic and two perceptual lures for each target image (i.e., repeats and critical fillers) at retrieval, the ratio of old to new illustrations (including lures) was reduced from Study 1 (1:1) to Study 2 (1:3). The presentation of more lures in Study 2 may have biased participants’ response criterion to responding “new” vs. “old” more overall, in comparison to Study 1. This shift in response criterion would have negatively impacted the behavioural metric of illustration memory (hits) and reduced the proportion of false alarms to lures. A comparison of the proportion of old responses to the retrieval image types from Study 1 vs. Study 2 revealed significant main effects for study type ($F(1,3) = 28.70$, $p < 0.0001$, $\eta = 0.18$) and image type ($F(1,3) = 463.96$, $p < 0.0001$, $\eta = 0.65$; Figure 13), suggesting that participants in Study 1 vs.

Study 2 showed different response criterion when discriminating between old and new illustrations. There were greater hits to old illustrations in Study 1 vs. Study 2 (t(43) = 3.66, $p = 0.00069$, Cohen's d = 0.75). Furthermore, participants false alarmed more to semantic lures (t(43) = 4.87, $p = 0.00002$, Cohen's d = 1.05) and perceptual lures (t(43) = 5.71, $p < 0.00001$, Cohen's d = 1.32) from Study 1 vs. Study 2. Therefore, it appears that participants in Study 2 were more conservative in responding "old" to illustrations in comparison to participants in Study 1. Lower hits and false alarms to lures in Study 2 may explain why both studies do not show similar patterns of mnemonic precision.

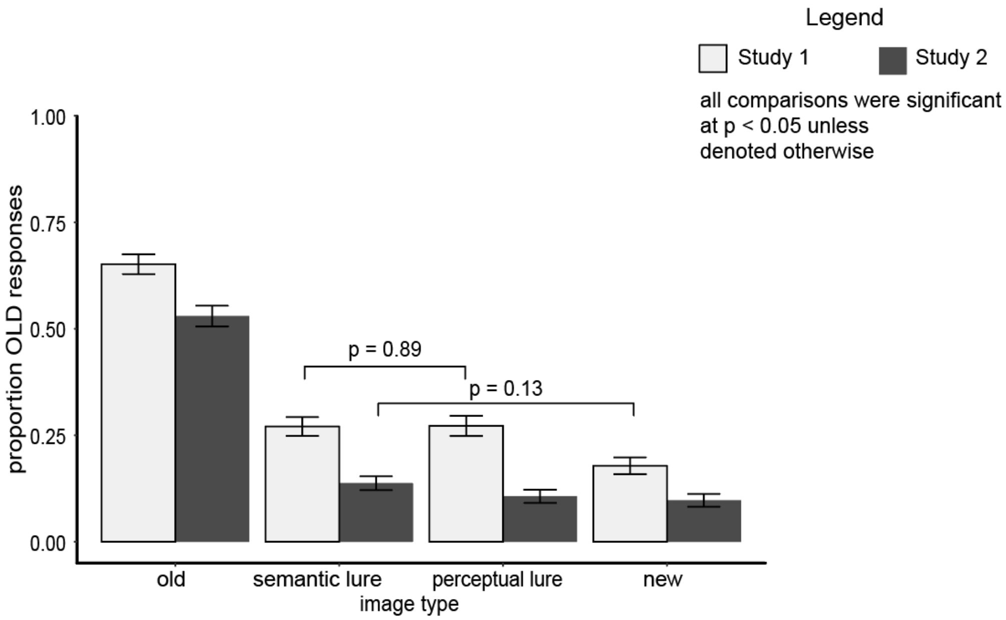


Figure 13. Proportion of Old Responses to Retrieval Image Types: Participants responded "old" more the targets and lures in Study 1vs. Study 2. Note: All comparisons are significant at $p < 0.05$ unless denoted otherwise.

In addition to stimulus changes between the retrieval phases in Study 1 and Study 2, differences in the encoding phase stimuli may have also contributed to the failure to replicate the mnemonic discrimination results from Study 1. In Study 1, nearly half (47%) of the perceptual repeats presented (different images of) stories that were also depicted as semantic repeats. Therefore, better discrimination and memory for perceptual repeats from the perceptual attention condition may be due to multiple presentations of specific semantic features, or, the combination of repeated perceptual *and* semantic features. Illustrations depicting both semantic and perceptual features encoded through multiple exposures would be remembered more so than illustrations that depicted either semantic or perceptual repeated features alone. Since only perceptual repeats displayed features incorporated within semantic repeats (and not the reverse), the enhanced memory for perceptual repeats within the perceptual attention condition may be due to a memory benefit for illustrations that contain both types of repeated features. It is unclear whether attention solely to perceptual features or the repetition of shared semantic and/or perceptual features aided in the pattern of memory precision demonstrated in Study 1.

Lastly, individual differences in prior story knowledge may have impacted the mnemonic precision of illustrations from similar experiences. In the encoding task, integration of the encoded experience with semantic knowledge requires (1) the ability to recognize the shared semantic theme and (2) prior semantic knowledge to be integrated with. Therefore, participants ability to discriminate from similar illustrations may have been influenced by their prior knowledge of fairytales. In the instance a participant did not know the fairytale a particular illustration depicted, they may have relied on perceptual similarities or general non-specific semantic knowledge among the illustrations to detect semantic repeats (e.g., similar characters). Depending on the complexity of the perceptual similarities and non-specific semantic features participants attended to, the semantic attention condition may have served as a lower level processing condition. Therefore, subsequent memory benefits for cued repeats from the perceptual attention condition may be the result of high processing demands, depending on the individual's prior knowledge.

To examine whether formal art knowledge would impact encoding task performance and subsequent memory behaviours, in Study 2, participants were asked to indicate if they had received formal art training in the past (e.g., art classes). Unfortunately, very few participants in the final sample indicated receiving prior art training (N = 12). Due to the small sample of individuals with prior art training, it is unclear whether art knowledge impacted task or memory performance.

In contrast to memory representation for illustrations that shared overlap at encoding, semantic attention led to better memory for independent filler illustrations than did perceptual attention in both Study 1 and Study 2. With the addition of illustrations highly similar to fillers on both semantic or perceptual dimensions, the precise-integrated nature of these incidentally attended illustrations was examined in this study. When participants were forced to make detailed discriminations between studied fillers and illustrations that shared filler features, semantic attention at encoding aided in mnemonic precision from similar illustrations. Contrary to predictions, semantic attention facilitated the precise memory representation of independent experiences. This pattern of memory behaviours was informative because although better recognition of fillers encoded during semantic attentional states is consistent with LOP theory, the theory does not address whether the type of memory formed at encoding impacts this remembering. Here, it’s shown that attending to semantic vs. perceptual features at encoding was associated with mnemonic precision mechanisms that benefited subsequent memory for the independent experience.

Since the pattern of memory discrimination from Study 1 was not replicated in Study 2, any interpretation about the results of both studies must be made with caution. Furthermore, given the design changes between Study 1 and Study 2, it is difficult to be certain the source of these behavioural differences. However, both studies consistently showed better memory for independent experiences encoded during semantic vs. perceptual attentional states, and greater false alarms to semantic lures when attending to semantic vs. perceptual features. This semantic attentional benefit is facilitated by variation in the precise-integrated nature of memory representation, with semantic attention facilitating precise representation of independent experiences. Additional replications of Study 2 are needed to confirm whether the patterns of mnemonic precision and integration demonstrated among illustration memories from this task are applicable across related paradigms or sensitive to situational constraints or individual differences.

Chapter 4
General Discussion

Prior work has shown that selective attention to either semantic or perceptual features at encoding yields better memory, but it is unclear what mechanisms contribute to this memory enhancement and why different situations show that attending to either type of feature leads to better memory. This investigation proposed that attention to semantic vs. perceptual features at encoding may form different types of memory representation: semantic attention potentially forming memories that become integrated across experiences to emphasize shared themes, while perceptual attention may form memories that remain distinct from related experiences, retaining the precise details of the experience. Therefore, whether attending to semantic or perceptual information at encoding leads to better memory may depend on the level of event-specific detail needed at retrieval. For situations that require remembering the exact details of the experience, attending to perceptual features may yield better memory than attending to semantic features, which may be optimal for remembering abstract themes.

Broadly, this investigation showed that the precision-integration of the resulting memory varies as a function of (1) semantic vs. perceptual attentional states, (2) the presence of overlapping features at encoding, and (3) the type of features the highly similar experience shares with the encoded experience. However, the specific pattern of memory behaviours differed between Study 1 and Study 2. Study 1 showed that perceptual attentional states led to mnemonic precision from similar experiences that shared the attended feature. In contrast, attending to semantic features led to the integration of memories that shared the attended feature, and consequently, false memories that shared semantic content. Memories of independent experiences instead benefited from semantic vs. perceptual attention states. Study 2 demonstrated that the type of information the encoded representation and related experiences contain may impact whether the memory demonstrates precision or integration with related experiences. Memories that shared overlap at encoding demonstrated precision from perceptually similar experiences and integration with semantically similar experiences, irrespective of the attentional state at encoding. In contrast, memories for independent experiences showed better mnemonic discrimination from related experiences when encoded during semantic vs. perceptual attentional states.

There is limited behavioural work on how attentional states impact the precise-integrated nature of memory representation to reference. However, early work on visual short- and long-term memory has shown that perceptual representations of unitary items (i.e., objects) are encoded rapidly into working memory with a great amount of precise detail (Brady, Konkle, Alvarez, & Oliva, 2008). Furthermore, complementary fMRI work has shown that perceptual attention attenuates stimulus-specific long-term memory representations within the brain (Chee & Chow Tan, 2007). Contrary to this, studies on memories for abstract semantic structures show wide-spread activation of gist representations within the brain (Addis & McAndrews, 2006; Chadwick et al., 2016; Coutanche & Thompson-Schill, 2015). Past fMRI work on the integrative nature of memory highlight how semantic aspects of an experience can become integrated into existing memory representations over time (Staresina & Davachi, 2006). With respect to past research on behavioural measures of mnemonic precision and integration processes, studies that examine behavioural measures of pattern separation—the processing of creating distinct representations from similar memories (Yassa & Stark, 2011)—show that representations of the same type of experience can vary in the level of detail they retain (Stark, Yassa, Lacy, & Stark, 2014). However, these findings were examined in the context of episodic memory decline among old adults (Stark et al., 2014) and episodic memory performance with clinical populations (Ally, Hussey, Ko, & Molitor, 2013; Planche et al., 2017), not with respect to how semantic and perceptual attentional states impact memory. The present investigation builds on this work by showing that semantic vs. perceptual attentional states at encoding can bias the representation of the experience, impacting that level of detail the memory retains.

10 Limitations

There are many open-ended questions this investigation did not address that are informative for understanding how attention impacts memory representation. Importantly, this investigation considered precise representation as beneficial for retaining the details of the encoded experience. It could be the case that integrated representations aid in detailed remembering as well. The analyses conducted considered high mnemonic discrimination (d') as the index for precise representation and thus, did not assess whether integrated memories are both connected with related experiences and able to maintain the unique details of the encoded experience. To investigate the association between precise-integrated memory representation and subsequent memory behaviours, an fMRI study that will relate hippocampal representation to detailed recollection will be conducted (see future directions section).

Lastly, this investigation did not examine whether reinstatement of the encoding context is needed to retrieve the encoded experience. The feature attended to at retrieval may have impacted the type of memories retrieved. For example, when participants were discriminating between old and new illustrations at retrieval, they may have attended to either semantic or perceptual features of the illustration (i.e., the story the illustration portrayed or. the artist style) to remember studied illustrations. In this investigation, we did not manipulate the retrieval strategies participants used and therefore, cannot determine whether attention to semantic vs. perceptual features at retrieval impacted the illustrations remembered. A follow-up study will be conducted to examine how manipulating attention to semantic vs. perceptual features at retrieval impacts subsequent memory behaviours (see future directions section).

11 Implications

The ability to attend to different levels of information at encoding may hider or optimize specific learning and reasoning abilities. Attending to semantic features when exposed to new information aids in identifying similarities in the shared relational structure among different contexts, allowing new information to be learned using prior knowledge of related experiences (Fisher, Matlen, & Godwin, 2011). Conversely, attending to perceptual information leads to perceived incongruence between different situational contexts, hindering analogical learning and the transfer of learning (Ralph & Patterson, 2008; Richland, Morrison, & Holyoak, 2006). Thus, the feature attended to at encoding may impact whether memories can be used flexibly to support new learning, dictating the experiences we build upon.

12 Future Directions

12.1 Implications of Transfer Appropriate Processing on Precise and Integrated Memory Retrieval

The interaction of attention and memory has been related to theories that emphasize context-dependent encoding and retrieval. According to transfer-appropriate processing theory, successful retrieval is dependent on the degree of overlap between the cognitive processes engaged in at encoding and retrieval (Morris, Bransford, & Franks, 1977). Therefore, the processes and strategies used during retrieval may dictate the memory behaviours presented. Empirical studies have shown that manipulating retrieval cues leads to better memory for different types of information (Lockhart, 2002; Roediger, Gallo, & Geraci, 2002; Schendan & Kutas, 2007). For example, when implicit and explicit memory tests for perceptual information were employed after participants were instructed to encode information by attending to either semantic or perceptual information, better memory was shown for information encoded during perceptual vs. semantic attention (Challis et al., 1996). In relation to the present investigation, participants could have engaged either semantic or perceptual feature focused retrieval strategies that may have restricted the types of memories they could retrieve. Given prior work that suggests adults demonstrate an attentional bias to semantic information (Brainerd & Reyna, 2004; Richland, Morrison, & Holyoak, 2006; Sood, Zhang, & Sood, 2002; Vendetti, Matlen, Richland, & Bunge, 2015), participants may have focused on the semantic features of the illustrations presented at retrieval, potentially biasing the integration of semantic attended illustration memories. To explore whether complementary encoding and retrieval tasks will show different patterns of mnemonic precision and integration among illustration memories, a follow-up study will be conducted with attention to semantic vs. perceptual features manipulated at retrieval.

12.2 Precise and Integrated Memory Representation Endurance

The fuzzy-trace theory proposes that fuzzy and verbatim traces decay at different rates, with verbatim traces showing greater degradation over time in comparison to fuzzy traces (Brainerd & Reyna, 2004). Prior studies have shown that verbatim traces are subject to proactive, retroactive, and concurrent interference that cause trace degradation. In contrast, fuzzy traces are not as susceptible to interference and are reinstated more frequently than verbatim traces (Reyna et al., 2002). Studies have shown that fuzzy trace reinstatement occurs often, with individuals frequently reinstating past memories when encoding situations that share semantic themes with the target experience (Marche & Brainerd, 2012). Verbatim traces, on the other hand, contain specific surface level features that do not overlap as easily as fuzzy traces do. These findings suggest that detailed recollection may be transient, while memory for abstract themes endures over time. To examine selective attention to semantic vs. perceptual features impacts the endurance of precise vs. integrated memories over time, a paradigm similar to the one used in this investigation will be conducted with a 24-hour delay between retrieval periods. Attention to either semantic or perceptual features at encoding may enhance the preservation of precise vs. integrated memory representations. Furthermore, it may be that although attending to semantic features leads to better memory for independent experiences, this memory benefit may be short-term. Conversely, attending to perceptual features at encoding may help maintain precise representation long-term.

12.3 Neural Evidence of Precise-Integrated Hippocampal Memory Representation

Behavioural measures alone cannot address the overarching research questions set forth in the introduction: whether selective attention to semantic vs. perceptual features biases the encoding of different hippocampal memory representations. Although past research has shown that attentional states modulate hippocampal activation that can predict successful remembering (Aly & Turk-Browne, 2016; Muzzio, Levita, et al., 2009), it is unclear why the hippocampus shows attentional modulation in response to different attentional states and how this relates to memory behaviour. How do attentional states at encoding constrain hippocampal processing patterns and consequent memory behaviours?

I hypothesize that attending to different types of information at encoding may bias the engagement of different extra-hippocampal networks, and consequently the subsequent hippocampal representation formed at encoding. Previous (fMRI) work has shown that the anterior and posterior regions of the hippocampus are a part of different functional brain networks; anterior hippocampal regions showing stronger connectivity with anterior extra-hippocampal regions like the perirhinal cortex vs. posterior hippocampus showing greater connectivity with posterior extra-hippocampal regions like the parahippocampal cortex (Libby, Ekstrom, Ragland, & Ranganath, 2012). Attending to different types of features at encoding may recruit different extra-hippocampal networks—either the anterior network with projections to anterior hippocampus, or the posterior network with projections to posterior hippocampus. With respect to how this may impact memory behaviours, the extra-hippocampal network recruited at encoding may impact the type of representation formed. As previously described, anterior and posterior hippocampus are thought to represent mnemonic information at different levels of detail, with anterior hippocampus forming more integrated representations and posterior hippocampus forming more precise representations. Attending to semantic information may engage anterior extra-hippocampal networks connected to anterior hippocampus, forming integrated memories, while attention to perceptual information may recruit posterior extra-hippocampal networks with projections to posterior hippocampus, forming precise memories. Therefore, the attentional state at encoding may impact the region of the hippocampus that participants in encoding the experience, and thus, whether the memory formed either (1) emphasizes common features across related experiences or (2) maintains idiosyncratic details to differentiate between similar experiences (Preston & Eichenbaum, 2013).

While the present investigation suggests that illustration memories show behavioural precision and integration with related experiences, it is unclear whether this phenomenon is due to semantic vs. perceptual attentional states constraining the information encoded by anterior and posterior hippocampus, and consequently, the nature of the hippocampal representation formed. To examine whether semantic vs. perceptual attention impacts the extra-hippocampal networks recruited at encoding, I will examine neural evidence of these attentional states and how their distinct (or lack of distinct) neural recruitment impacts subsequent remembering. Neuroimaging data from a modified version of the encoding and retrieval phases from Study 2 will be collected using fMRI to examine activation patterns during semantic vs. perceptual attention in the encoding phase and at retrieval. This investigation will (1) identify distinct semantic and perceptual attentional states within the brain using a whole-brain decoding approach, (2) relate the engagement of these attentional states at retrieval on a trial-by-trial basis to memory, and (3) assess how recruitment of these attentional states at encoding and retrieval impact memory behaviours. Pilot fMRI data (N = 4) collected during the encoding 1-back task suggests that semantic and perceptual attentional states do indeed recruit different brain regions: semantic attentional states recruited parietal cortex (including angular gyrus), and lateral and anterior temporal regions, while perceptual attentional states recruited visual regions of the brain like the occipital pole, lateral occipital cortex, and lateral prefrontal cortex. I aim to collect a full sample of individuals to address whether attention biases the hippocampal representation formed at encoding. This investigation will provide a mechanism through which selective attention impacts memory for complex visual information and offer a novel interpretation of the interaction between attention and memory.

13 Summary

Study 1 showed that perceptual attentional states led to mnemonic precision from experiences that shared the attended feature while attending to semantic information lead to the integration of memories that shared semantic features. In contrast, memories for independent experiences benefited from semantic vs. perceptual attentional states. Study 2 demonstrated that the level of information the encoded representation and related experiences contained influenced precision or integration with related experiences. Memories that shared overlap at encoding demonstrated precision from perceptually similar experiences and integration with semantically similar experiences, irrespective of the attentional state at encoding. Independent experiences showed better mnemonic discrimination from related experiences when encoded during semantic vs. perceptual attentional states. Collectively, Study 1 and 2 suggest that precise memory for independent experiences is aided by semantic vs. perceptual attentional states at encoding. Furthermore, semantic attentional states may aid in the integration of experiences that share the attended, semantic feature. However, given the discrepancies between both studies, further work is needed to examine the specific impact semantic vs. perceptual attentional states have on memory representation.

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