Inference and False Memory Within Multielement Events

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I, Siti Nurnadhirah Binte Mohd Ikhsan, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Abstract

Recollection of multi-element events reflects a process of pattern completion in which one element retrieves the others. However, recollection is reconstructive and unseen associations can be inferred. To study this, I used multi-element events composed of overlapping pairs of items (locations, people, objects/animals) presented sequentially, interleaved with pairs from other events. For events with all associations presented (AB, BC, AC), retrievals of seen ('direct') pairs from the same event were statistically interdependent, indicating pattern completion. However, for events with only some associations presented (AB, BC, CD; AC, BD, AD not seen), direct pairs were retrieved independently but inferred 'indirect' pairs (AC, BD, AD) were interdependent, demonstrating their common reliance on direct pair BC. These results were unaffected by the order of testing direct and indirect pairs or by repeated presentation, are consistent with an auto-associative network model, and establish a role for pattern completion in inference.

Although inferred associations can aid reconstructive retrieval, they might also cause false memories. To investigate further, I presented events comprising images of a person and an object superimposed onto a location, some events sharing an element with one other (e.g. Madonna-laptop-gym, Ronaldo-vase-gym). Inference-related false memories did arise (e.g. of seeing Madonna with the vase) but only showed weak (non-significant) dependency on direct associations (e.g. Madonna-laptop) unlike explicitly-tested indirect associations (e.g. Madonna-Ronaldo). Instead, false memories (e.g. Madonna-vase) were afforded by specific combinations of direct associations: those strongly linking the cue with the lure (e.g.

Madonna-gym, gym-vase) but not those with their correct associates (i.e. Madonna-laptop).

These experiments indicate that pattern completion supports reconstructive episodic memory and explicit inference for missing associations, while false memories can be created by false inference but have a more complex relationship with pattern completion. I discuss the implications for veridical memories, illusory memories, metacognitive awareness and explicit inference.

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Impact Statement

Despite decades of research using various methods ranging from the behavioural and genetic to the pharmacological and computational, there is much yet to be uncovered about episodic memory. It is not just remembering events as they are – episodic memory also infers across similar experiences to construct a more complete picture of what had happened and better inform future decisions. The brain's ability to implement such intricate, multifarious processes, which may, ironically, also make it fall victim to memory errors, poses the obvious question of how it does this. Through this thesis, I have moved closer to answering the question, and the presented insights have huge potential in impacting research and beyond.

Results demonstrated in this thesis will improve my understanding of memory and the brain and have implications on diverse disciplines. By investigating the mechanisms underlying the recollection of episodic memories and inferences across them, I am aware now that memory mediates multiple processes using the same associative neural network in healthy adults. Considering that ageing individuals and patients with memory disorders such as Alzheimer's have problematic episodic retrieval, further research can confirm whether they also fail to adequately deduce meaningful conclusions from related events. If that is the case, an association can be made between their neuropathology and resulting cognitive deficits. The findings on the effects of repetitive learning indicate that while repetition is a popular, effective learning strategy for students, other mnemonics such as separating veridical recollection and inference are better suited for strengthening the links between related associations. Other memory techniques such as using mental imagery might be more effective for that function, subject to further study. My research also has significance in the field of criminal justice. Acknowledging how easy it is to misconstrue unobserved inferred associations as genuine memories (e.g. seeing a man with a scooter and later the scooter outside the library, then mistakenly remembering seeing the man at the library) as found in this thesis, judicial and law enforcement officers should be cognisant of the vulnerability of eyewitnesses to such errors, given how costly they are in the courtroom. Eyewitnesses should be encouraged to delicately distinguish between true memories and mix-ups, and the possibility of honest, subliminal memory failures should always be recognised.

In addition, future lines of research suggested by this thesis may help identify what else needs to be done to further deepen my comprehension of episodic memory. Thoughtful discussions and collaborations may consequently be forged across labs as had been done in Experiment 5 of this thesis (see Chapter 8), where I worked with a memory group in Stanford on false memories. Studies in this thesis are shared with the global research community through journal publications and presentations to labs within and outside the institute.

This research not only refines my knowledge of memory in the brain, but also has the capacity to advance wellbeing, enhance classroom learning and safeguard the integrity of eyewitness memory and judiciary decisions. It also fosters greater exploration and academic cooperation in the area.

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1 Introduction

1.1 Background

The recollection of episodic memory is believed to assimilate together current knowledge and inferences across its components, recreating a systematic depiction of an event (Bartlett, 1932; James, 1890; Tolman, 1932; Eichenbaum, 2001; Tulving, 1985; Schacter et al., 1998; Schacter and Addis, 2007a, 2007b). Generally, an episodic memory is formed when distinct elements from a complex experience are merged into a comprehensive representation (Tulving, 1985; Norman and O'Reilly, 2003; Davachi, 2006; Eichenbaum et al., 2007). This, however, might not extend to every feature in an episode such as the relationship between several constituent items, making it essential to infer unattended information based on what has been perceived.

It is therefore imperative to examine the process of forming such novel inferences when recollecting episodic memories, even when some associations had not been observed. I aimed to probe if the retrieval of knowledge inferred across overlapping experiences fits with an auto-associative concept of memory function and identify in what ways it could impact or be influenced by or impact other processes. Consistent with the nature of recollection in episodic memory, the memory binding theory holds that the retrieval of events is holistic (Tulving, 1985). Early on, computational accounts of memory have posited that pattern completion in the hippocampus mediates such integrative retrieval, whereby encountering a partial cue reinstates all related aspects of an event (Marr, 1971; McClelland, 1995; Gardner-Medwin, 1976; Wills et al., 2005; Nakazawa et al., 2002).

To comprehend the importance of the associative structure of an episode in its recollection, it is helpful to consider the pattern of associative retrieval in multimodal events. Several studies have demonstrated a statistical relationship among distinct pairwise associations during their retrieval, suggesting that representations in episodic memory exhibit a congruity that is mediated by pattern completion (Horner and Burgess, 2013, 2014; Horner et al., 2015). Participants in these studies observed multielement events consisting of a location, person, object and animal, as simultaneously presented elements or as a series of overlapping paired associates. A cued recognition test followed, and results pointed to a retrieval dependency among the associations, such that the retrieval success of one association was statistically connected to the retrieval success of other associations from the same event. However, statistical dependency disappeared when an open chain of overlapping associations was learned with only some but not all of the associations explicitly disclosed (Horner and Burgess, 2014; Horner et al., 2015). These associations were instead remembered independently of each other despite their overlap, implying that they were not perceived as a single episodic event. What was still unknown was if it was possible to infer the untrained overlapping associations once asked about them, and if so, whether the inferences were retrieved through pattern completion even if seen associations were not recollected via the same mechanism.

A common method in evaluating associative inference across encoded events is to instruct participants to deduce missing associations (e.g. AC; Preston et al., 2004; Shohamy and Wagner, 2008; Zeithamova et al., 2016; Carpenter and Schacter, 2017), done by linking together learned associations from overlapping episodes (e.g.

AB, BC). The hippocampus has been heavily implicated in associative inference, building on its crucial role in associative memory (Davachi, 2006; Eichenbaum, 2004). For instance, increased activity in the brain region during an encoding period is predictive of subsequent inference accuracy (Shohamy and Wagner, 2008; Zeithamova and Preston, 2010; Schlichting et al., 2014) and the same neural activity has likewise been reported amid successful retrieval of inferential knowledge (Heckers et al., 2004; Preston et al., 2004). Hippocampal engagement in associative inference thus raises the likelihood that inference is facilitated through hippocampal pattern completion (Zeithamova et al., 2012a, 2012b; Kuhl et al., 2010).

Retrieval for encoded and inferred information might be determined not just by the type of memory retrieved but also by the order of their retrievals and by recently active retrieval processes. Studies reported that testing inferred stimuli prior to the encoded memories that supported the relevant inference had increased the quantity of mistakes made on the second test as opposed to testing the encoded memories first (Carpenter and Schacter, 2017, 2018), implying that altering the order of their retrievals had notable consequences. Moreover, it is possible for associations that are recollected by pattern completion to also be recalled independently (Horner and Burgess, 2013) and the selected mode of retrieval could be biased by the processes that are used by preceding retrievals (Loftus and Loftus, 1974) which might or might not have engaged pattern completion. When test trials on studied and inferred knowledge are alternated, the inability to anticipate what the upcoming test trial will be about might also decide which strategy is adopted for retrieval. Confining retrievals of different types of memory to distinct sessions would more accurately assess the retrieval operations for each type. The interaction between encoded and inferred memory processes during retrieval could therefore be investigated by manipulating the order of retrieval of inferences relative to retrieval of encoded information (inferences retrieved before encoded stimuli and vice versa). The extent to which the two forms of retrieval are separated could also be varied by arranging for inferences to be retrieved in between recollecting learned information in one experiment whilst segregating both retrievals in another.

Repetitive learning of overlapping events may also regulate associative inference, as affirmed by studies noting the favourable influence of encoding repetition on inference performance (Zeithamova et al., 2016; Zeithamova et al., 2012a, 2012b; Shohamy and Wagner, 2008), and may possibly drive greater integration of overlapping stimuli for more coherent retrieval. One such study, by Zeithamova et al. (2016), repeated the presentation of overlapping and non-overlapping object pairs (e.g. AB, BC) three times and observed neural changes throughout the task. Non-overlapping pairs that were repeated displayed repetition suppression effects in medial temporal lobe (MTL) areas but on the contrary, activity in the region was enhanced in response to repeated overlapping associates. Moreover, the increase in hippocampal activity corresponded with associative inference performance, implying that a stronger memory of an overlapping set of associations, boosted by repetition, leads to more accurate inference. It would thus be of interest to ascertain if learning associations multiple times would strengthen inferred associations enough for them to be assimilated more compactly with studied associations and induce stronger pattern completion upon retrieval.

A potential consequence of reconstructive retrieval processes is that inferred information might be confused for genuinely perceived information. The rich literature on erroneous recollection of events ranging from eyewitness research (Brainerd and Reyna, 2005; Wells and Loftus, 2003; for review, see Loftus, 2005) and fictitious memories of childhood abuse (Hyman et al., 1995; Spanos, 1996; Hyman and Loftus, 2001; Wells and Loftus, 2003) to the susceptibility of memory in humans (Hyman et al., 1995; Roediger and McDermott, 1995; Lindsay et al., 2004; Dennis et al., 2015) and animals (McTighe et al., 2010; Ramirez et al., 2013) proposed one interesting cause of untrue memories – successful inferences made across authentic, overlapping events. Retrieval-related integrative encoding and reconstructive processes that allow accurate inferential decisions (Schacter and Addis, 2007a, 2007b) could also ironically result in flawed recognition of inferences as actual observations (Devitt et al., 2016; Carpenter and Schacter, 2017, 2018; de Araujo Sanchez and Zeithamova, 2020). In one such study, scenes containing a person (A) and an object (B) were viewed, followed by scenes with the same person or object (e.g. same object (B) but different person (C); Carpenter and Schacter, 2017). Participants were asked to remember both trained (AB, BC) and indirect associations (AC) and were afterwards tested on them in a two-alternative forced choice. To see if retrieval-related inferential processes also resulted in source memory errors, participants were additionally examined on contextual details from both AB and BC scenes. Participants who did well in the associative inference task later tended to mix up contextual information across AB and BC episodes. This discrepancy was not seen in another group of participants who were examined on contextual details first, before being asked about indirect associates. It is hence possible that the reconstructive mechanisms at the heart of episodic retrieval could also produce corrupt source memory for encoded elements, and this is an important area I sought to explore.

Both inferences and false memories derived from overlapping events appear to be under the control of inferential mechanisms, but to understand more clearly how they are retrieved, their retrieval conditions could be manipulated. One way in which terms for retrieval could be modified is by repeatedly testing inferred knowledge and false memories combining elements from overlapping events. Repeated retrieval has been shown to impair memory via a process of reconsolidation, where the activation of an encoded memory destabilises it again (Lee et al., 2017; Alberini and LeDoux, 2013; Walker et al., 2003). Participants have erroneously mixed up elements from similar but separate groups when, during retrieval, they were reminded of the non-target set (Hupbach et al., 2007, 2009; Bryant et al., 2020), and repeatedly being questioned on a witnessed crime waters down the accuracy of the memory for it (Wixted et al., 2021; Chan et al., 2011 but see Bornstein et al., 1998). Moreover, testing an inference-based memory or false memory again might reveal whether participants were guessing, especially if first and second responses differed. It would thus be interesting to see whether the retrievals of true and false memories that are both mediated by inferential reasoning are differentially impacted.

Confidence has long been thought of as an influential predictor of memory integrity (Semmler et al., 2012; Penrod and Cutler, 1995; Krug, 2007), and indeed, a wealth of literature has shown an association between the two (Brewer and Wells, 2006; Deffenbacher, 1980; DeSoto and Roediger, 2014; Roediger and DeSoto, 2014; Brewer and Sampaio, 2006; Rimmele et al., 2012; Nguyen et al., 2018). Other studies, however, including those on eyewitness testimony, highlight the disparity between confidence and recollection accuracy (Fischhoff et al., 1977; Busey et al., 2000; Penrod and Cutler, 1995; Tomes and Katz, 2000). There is even evidence that illusory memories could be retrieved with high confidence (Bransford and Franks, 1971; Loftus, 1979; Roediger and McDermott, 1995). Confidence reports are representative of metamemory (Brewer and Wells, 2006; Metcalfe, 2000; Johnson, 2006), which deals with an individual's awareness, monitoring and knowledge of their memory (Flavell and Wellman, 1975; Nelson, 1990; Cavanaugh and Perlmutter, 1982), and are said to be governed by conscious recollection (Tulving, 1985). Examining confidence when retrieving memory for encoded, false and inferred information would establish if they are processed differently by metamemory operations. Confidence-accuracy correlations (where accuracy relating to false memories is denoted by their rejection) would also be useful to understand how precise metamemory is at calibrating confidence with memory accuracy.

1.2 Objectives of experiments

I was keen to find out, with pattern completion in the picture, whether recollecting events would include retrieving unperceived associations inferred from observed information, and how the processes involved could be influenced. I also aimed to investigate whether these inferences would also result in errors in recollection. The adaptable quality of episodic memory that enables the affiliation of encoded information with knowledge from more general sources (Bartlett, 1932; James, 1890; Tolman, 1932; Eichenbaum, 2001; Eichenbaum et al., 1999) makes it intriguing to study the retrieval mechanisms for both directly encoded and indirectly implied associations as well as the relation between them. While retrieving learned information is believed to engage pattern completion, retrieval of inferred material within episodic memory remains unexplored. I thus intended to understand the nature of retrieval for memory-based inferences and analyse it from a viewpoint of pattern completion, which was behaviourally measured by quantifying statistical relatedness among within-event retrievals. Factors that might affect integrated episodic retrieval such as repetition and varied testing procedures were also evaluated. It was additionally important to examine how these reconstructive processes could also distort the recollected memory (Carpenter and Schacter, 2017, 2018; de Araujo Sanchez and Zeithamova, 2020). Although illusory memories have been thoroughly researched on, a vital question that is still unaddressed is how they are retrieved in the context of episodic memory, especially when its reconstructive feature is said to cause such errors. My thesis delves into this, and because pattern completion is thought to mediate coherent episodic memory recollection, retrieval of inferences as well as that of false memories resulting from such inferences would be considered in terms of pattern completion.

For Experiments 1-4 (see Chapters 2, 3, 5, 7 respectively), holistic event retrieval was studied by presenting multielement events as a series of overlapping paired associates across which inferences could be made, before a cued forced choice recognition test. Experiment 1 (see Chapter 2) interleaved testing for directly observed (‘direct’) and inferred (‘indirect’) associations where indirect associations from an event were probed ahead of the direct associations from the same event, while Experiment 2 (see Chapter 3) isolated the test trials for the two types of associations into separate sessions starting with the one on direct associations. I additionally compared Experiments 1 and 2 (see Chapter 4) to discern differences in retrieval pattern of encoded and inferred associations caused by the changes made to the testing protocol in the experiments. In Experiment 3 (see Chapter 5), overlapping associations were repeated throughout the encoding phase to ascertain how boosting memory performance could affect pattern of retrieval. I then simulated the data in Experiment 3 using a neurocomputational model of associative memory (see Chapter 6). Repetition was again analysed in Experiment 4 at the same intensity (see Chapter 7) but this time each overlapping association was repeated within a shorter time frame. Indirect associations were not tested since the objective of the experiment was to analyse how a condensed form of repetition used in Experiment 3 could affect general retrieval of encoded associations. Participants also made confidence judgements during their response to examine metacognitive awareness and determine how confidence related to performance. To explore false memories that are facilitated by inference, Experiment 5 (see Chapter 8) showed participants pictures of events comprising a person and an object at a location, with a portion of the events sharing some content with others such that inferences could be forged across overlapping events and elements could be wrongly mixed up. Observed, inferred and false associations were tested in a yes/no recognition task during which confidence was also inquired to study variations in cognitive awareness amongst the three types of associations. Experiment 5 was also contrasted with Experiment 2 (see Chapter 9) to understand how coherent retrieval of events could differ when associations from the same event were displayed visually in a single image that might overlap with another or as a chain of overlapping word associations. Lastly, I summarised all my findings and addressed several points of discussion (see Chapter 10) before drawing the main conclusions from this thesis (see Chapter 11).

To assess the level of pattern completion in retrieval of events, I tested participants' memory for direct associations in all my experiments and ascertained the statistical relatedness ('dependency') of the retrievals from the same multimodal event (Horner and Burgess, 2014; Horner et al., 2015), whether the associations were presented in series (as in Experiments 1-4 and simulation) or simultaneously in an image (as in Experiment 5). In Experiments 1-4 and the simulation, half of the events displayed all possible associations between elements in an event (AB, BC, AC; closed-loop structure) while the remaining half appeared as a chain of only some of the possible pairs (AB, BC, CD while AC, BD and AD were not shown; open-loop structure). The extra fourth element in open-loop events (D) ensured that the number of associations in open-loop events was the same as that in closed-loop events and it was not expected to affect memory or retrieval pattern. A previous experiment (Horner and Burgess, 2014) found that dependency results were unchanged even when the number of elements in both loop structures was made the same (which also meant that open-loop events had fewer pairs, i.e. AB, AC versus AB, AC, BC in closed-loop events).

In addition to examining all attended associations as done in previous studies (Horner and Burgess, 2013, 2014; Horner et al., 2015), I also probed for unobserved indirect associations in Experiments 1-3 and 5. Experiment 4 did not cover analyses on indirect associations as it only set out to see if the effects of repetition on observed associations, identified in Experiment 3, would remain if repetition was imposed differently.

My work on the retrieval pattern of overlapping associations, i.e. Experiments 1-4 and the computational model, were supported by my supervisor Neil Burgess with overall guidance and lab colleague James Bisby with guidance on the analyses. My colleagues Daniel Bush and David Steins were crucially involved as well, with Daniel running the simulations through the hippocampal model and David helping to manage the testing of participants in Experiments 2 and 3. My research on false memories was supported by Neil and Anthony Wagner at Stanford University who also partly funded it and provided co-supervisorial advice on my methods and findings. Experiments 1-3 and the simulation, which all investigated how inferences across overlapping associations were retrieved, were also published in the Quarterly Journal of Experimental Psychology in October 2020 (Binte Mohd Ikhsan et al., 2020).

2 Experiment 1: Recollecting and Inferring Across Overlapping Associations With Interleaved Retrievals of Encoded and Inferred Associations

To understand how inferential judgements are retrieved, I began by conducting an experiment where participants encoded multimodal overlapping associations (e.g. AB, BC, CD) which made up an ‘event’ (e.g. A-B-C-D) and were afterwards tested on them as well as on the inferences forged across the overlapping associations, if any (e.g. AC). The statistical relatedness amongst the retrievals, which refers to how the retrieval success of an association related to that of other associations within the same event, was computed to indicate to what extent the event was retrieved holistically. Such dependency, if significant, demonstrates pattern completion amid retrieval. I intended to ascertain if inferences depended on one another and/or on encoded information for retrieval.

2.1 Method

2.1.1 Participants

Twenty-five healthy, English-speaking volunteers from the University College London student subject pool gave informed written consent to participate in the study. All of them were analysed for memory performance but one was excluded from dependency analysis due to accuracy scores surpassing 95% for direct pairs in all conditions. Participants performing extremely well in the memory test had to be removed from dependency analysis as the dependency model used in this experiment is less efficient with processing almost perfect accuracy rates (see

Chapter 2 – Method). I therefore only used data from 24 of the participants in analysing dependency and performance correlation (17 female, mean age = 26, age range 22–36). An approximate sample size required for Experiment 1 was obtained (estimated *N* range = 9–24; power = 0.80, α = .05) after conducting a power analysis according to effect sizes in earlier studies (Horner and Burgess, 2014; ηP^2 range = .11–.48; *N* = 15). An estimate sample size of 24 was acquired based on an effect size of $\eta P^2 = .11$, justifying my proposed sample size of 25. The experiment was approved by the UCL Research Ethics Committee.

2.1.2 Materials

For each participant, 60 novel events were generated through the random assignment of a location, famous person, common object and animal, each element from a collection of 60 items per category. Half of the events were made as closed-loop A-B-C events (object-location-person or animal-location-person; see **Fig. 1a**) while the further half as open-loop A-B-C-D events (object-location-person-animal; see **Fig. 1b**), producing 30 closed- and 30 open-loop events. Since events in the closed-loop condition only entailed three elements each, 50% of the events were designated as object-location-person events and the other 50% animal-location-person events. Open loops, on the other hand, used all four elements per event.

2.1.3 Procedure

Events were shown as three distinct overlapping pairwise associates during the encoding phase, spanning three blocks where each association was assigned to a block (60 pairs per block; see **Fig. 1c**). Every encoding trial consisted of a pairwise association presented as text for 3s and was randomly ordered within each block. Participants were told to ‘imagine the two elements interacting in a meaningful way

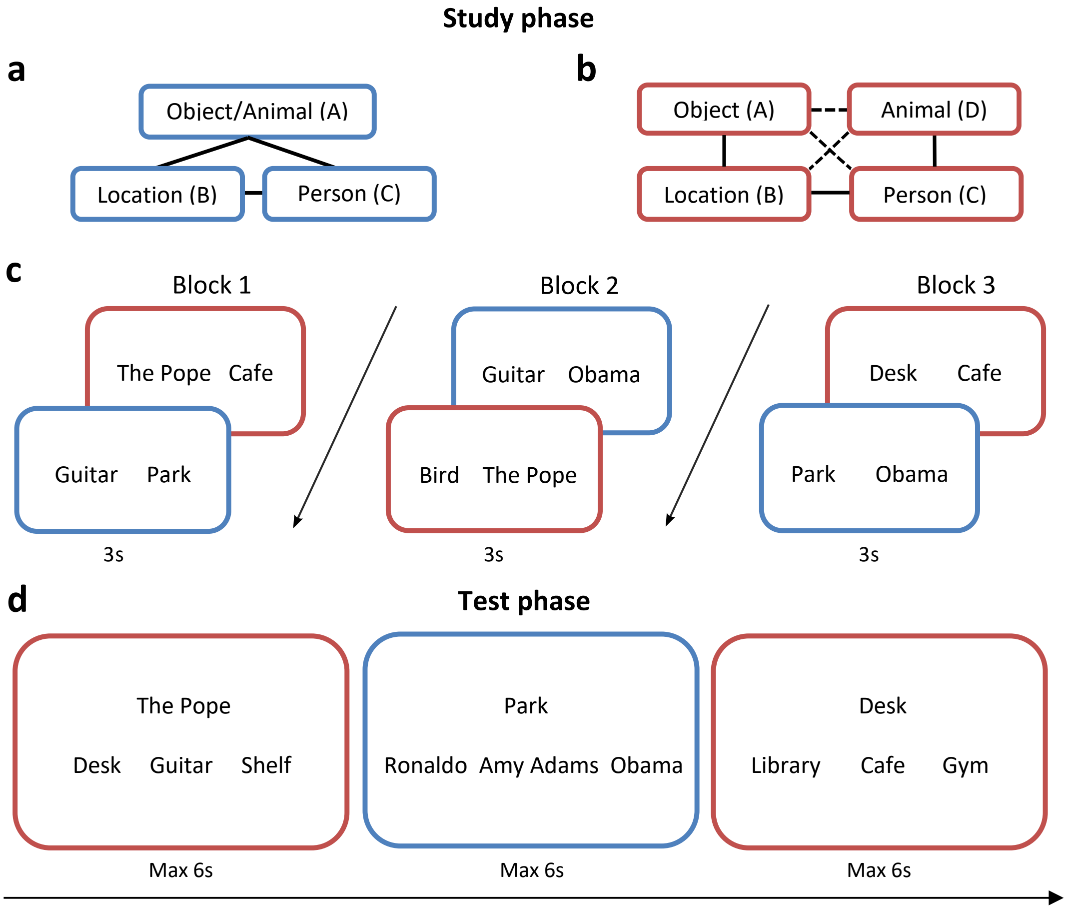

Figure 1. Design for Experiment 1. (**a**) Associative structure of a closed-loop A-B-C event. Half of the closed loops were object-location-person triads and the rest were animal-location-person triads. (**b**) Associative structure of an open-loop A-B-C-D event. Solid lines indicate trained, direct pairs while broken lines indicate indirect pairs inferred from trained pairs. (**c**) Study phase. Blue lines represent associations from closed-loop events while red lines represent associations from open-loop events. Line colour is for illustration purposes only; type of event structure was not indicated in the study. (**d**) Test phase. Trials testing memory for indirect associations were presented before trials for direct associations from the same event, in a pseudorandomised order.

as vividly as possible'. While no further instructions were offered and no response was warranted at this stage, most subjects in pilot studies where the same encoding demands were enforced performed satisfactorily, implying that they paid sufficient attention to the task for successful retrieval later. A 0.5s fixation cross appeared before a trial while a 0.5s blank screen occurred at its end. Participants viewed all overlapping associations present in the closed-loop structure (AB, BC, AC; see **Fig. 1a**) but only some of them in the open-loop structure (AB, BC, CD but not AC, BD, AD; see **Fig. 1b**).

The retrieval phase tested all direct associations (i.e. the pairs that they viewed at encoding) in each direction (e.g. cue with the location to retrieve the object, and cue with the object to retrieve the location) from all closed- and open-loop events, as well as all indirect associations (i.e. pairs inferred from those observed during encoding) in each direction from all open-loop events (see **Fig. 1d**). Each event, closed- or open-loop, generated three direct associations (AB, BC, AC for closed loops, see **Fig. 1a**; AB, BC, CD for open loops, see **Fig. 1b**) and each open-loop event produced three indirect associations (AC, BD, AD). Since each association of any type was tested in both directions, there were six associative memory trials per event (360 test trials altogether from 60 events) and six indirect association trials for each open-loop event (180 test trials altogether from 30 open-loop events). Trials on direct and indirect associations were lumped together in a pseudorandom order where trials on indirect associations from a closed-loop event were presented ahead of the trials on the respective direct associations from the same event so that the prior retrieval of direct associations did not aid the later retrieval of indirect associations.

Indirect associations had not been seen at encoding but could be inferred from directly observed pairs by virtue of the event structure (see **Fig. 1b**). Subjects viewed open-loop events A-B-C-D as a chain of three associative trials (e.g. AB, BC, CD) but were also able to deduce three other associations that were never shown (i.e. AC, BD, AD). I informed participants that the cue in a single trial was connected to one of the three presented options either directly or indirectly, and only one of the forced choice alternatives was the right match. As a result, inferences had to be actively made although they might not certainly be warranted for in real life – an issue reviewed later (see Chapter 10 – Inference in experiments versus in real life).

In each test trial, a text cue – a location, person, object or animal – was displayed at the top centre of the screen while three options were presented under the cue (see **Fig. 1d**). Previous studies had shown six options (Horner and Burgess, 2013, 2014; Horner et al., 2015) but because pilot experiments achieved low performance on indirect associations when the same number of alternatives was used while testing more events (60 instead of 36) as done in this experiment, I reduced the number of options to three. From these options, participants were asked to choose the correct associate paired either directly or indirectly with the cue, responding via button press within 6s. The test options in a trial were of the same type of element (e.g. people) and had all been seen during the learning phase. Every test trial was preceded by a 0.5s fixation cross and finished with 0.5s blank screen.

2.1.4 Associative Accuracy Analysis

I computed associative accuracy scores for events in closed- (A-B-C; object/animal-location-person respectively; see **Fig. 1a**) and open-loop conditions (A-B-C-D; object-location-person-animal respectively; see **Fig. 1b**). To assess direct associations, performance was averaged across all six direct pairs tested from each event (AB, BC and AC for closed-loop events and AB, BC and CD for open-loop events, each pair tested in both directions) before it was compared between conditions using paired samples t-tests. Meanwhile, each type of indirect association (AC, BD and AD) was separately examined for associative accuracy, which was averaged across both testing directions. A one-way ANOVA was conducted to compare the performance of the different indirect pair types.

2.1.5 Dependency Analysis

Dependency for direct associations within events (see **Figs. 1a**, **1b** for an illustration of event structure) was assessed in line with prior studies (Horner and Burgess, 2013, 2014; Horner et al., 2015) by means of contingency tables for every participant for retrieving two elements from an event when cued by the other element from that event (A_BA_C analyses where A is the common cue and B and C are the targets) and for retrieving one element when cued by the other two elements (B_AC_A analyses where A is the common target; see **Table 1**). It was thus possible to gauge how the retrieval of one association depended on the retrieval of another association belonging to the same event. Four contingency tables for each of the tested conditions (closed- and open-loop events) were generated per participant – 1) cueing with the location – location A_BA_C analysis; 2) retrieving the location – location B_AC_A analysis; 3) cueing with the person – person A_BA_C analysis; and 4) retrieving the person – person B_AC_A analysis. When I reviewed dependency of direct associations on other direct associations within the same event, only pairs with person or location as the common cue or target were considered because objects and animals were present in only some but not all events. I did not act similarly for dependency analyses involving indirect associations since only open-loop events were examined and all of them shared the same object-location-person-animal structure. Instead,

Table 1. Contingency table for the Independent model in dependency.

Retrieval of Element C	Retrieval of Element B	
	Correct (P_{AB})	Incorrect (1 – P_{AB})
Independent Model		
Correct (P_{AC})	$\sum_{i=1}^{N} P_{\mathrm{AB}} P_{\mathrm{AC}}$	$\sum_{i=1}^{N} P_{\mathrm{AC}}(1 - P_{AB})$
Incorrect (1 – P_{AC})	$\sum_{i=1}^{N} P_{\mathrm{AB}}(1 - P_{\mathrm{AC}})$	$\sum_{i=1}^{N}(1 - P_{\mathrm{AB}})(1 - P_{\mathrm{AC}})$

The frequency (over events) of the four combinations of correct or incorrect retrieval of elements B and C when cued by A is presented. In the Independent model, the probability of correctly retrieving B when cued by A (across all events) is P_{AB}.

direct associations with object or animal as the common cue or target were also evaluated, and four more contingency tables were constructed per participant – 5) cueing with the object – object A_BA_C analysis; 6) retrieving the object – object B_AC_A analysis; 7) cueing with the animal – animal A_BA_C analysis; and 8) retrieving the animal – animal B_AC_A analysis.

For each participant, data from each contingency table was compared with data estimated by the Independent model of retrieval (see **Table 1**). The Independent model measures the anticipated amount of dependency if all retrievals within an event were independent and consequently adjusts for any effects of overall performance. I removed from dependency analyses participants who scored more than 95% accuracy for direct associations across all conditions as the Independent model would be impaired in its computation following a nearly perfect performance.

Dependency for each condition was, on the whole, determined by the proportion of events where both associations were accurately or inaccurately retrieved, and from my data it ranged from 0.5 (full independence) to 1 (full dependence).

Dependency from data (Ddata) had to be contrasted with the Independent model's estimate (Di) to derive valid conclusions since dependency conforms with performance, so the difference between Ddata and Di (Ddata minus Di) was used as the measure of dependency for a condition. If Ddata was significantly greater than Di, a condition could be said to demonstrate dependency.

The Independent model provides the predicted amount of dependency supposing that the recollection of the associations in question was independent of each other, based on that participant's performance on the pairs. It is therefore possible for the data to indicate less dependency than the value estimated by the Independent model (i.e. Ddata < Di), an occurrence potentially caused by interference or competition between associations from the same event (e.g. correctly retrieving AB impedes the retrieval of AC).

The retrieval dependency for the unobserved indirect pairs from open-loop events was also investigated, in which case all direct associations were implicated including the ones with object or animal as the common cue or target. A comparison was made between this dependency and the dependency across direct associations from open-loop events.

In addition, the dependency of indirect pairs on linking direct pairs and the dependency of indirect pairs on non-linking direct pairs were also measured. Linking direct pairs are direct pairs on pathways that established the indirect pair (e.g.

linking direct pairs for indirect pair AC are AB and BC). Conversely, non-linking direct pairs are direct pairs that did not form the route expected for the inference to be made (e.g. non-linking direct pair for indirect pair AC is CD).

If dependency of indirect pairs on linking direct pairs was significant, it would mean that retrieving the inferential association hinged on how well the direct linking associations were remembered. This would be consistent with an account of pattern completion of inference, which posits that the ability to infer could be mediated by the spreading of activity from one constituent element in the inferred association to another via the encoded direct pairs, for instance from A to C via AB and BC. I also compared how dependent indirect pairs were on direct linking pairs for retrieval, with how they were on non-linking direct pairs. When AD was analysed, all trained pairs – AB, BC and CD – are its linking direct pairs.

I then subjected Ddata minus Di values to Shapiro-Wilk tests to assess the normality of data distribution and log-transformed them (see **Equation 1**) in consideration of the non-Gaussian distributions of dependency across direct pairs for closed events (W(24)=.82, p=.001) and that for open events (W(24)=.73, p<.001), dependency of indirect pairs on direct linking pairs (W(24)=.78, p<.001), and dependency of AD on all direct linking pairs (W(24)=.78, p<.001). ANOVAs and paired samples t-tests were afterwards performed to make comparisons and one-sample t-tests administered to determine dependency.

$$(Ddata - Di)_i = log[(Ddata - Di)_i + 1]$$

Equation 1. Log transformation of dependency values. Dependency is indicated by Ddata (dependency from the data) minus Di (dependency estimated by the independent model).

Accuracy scores of participants for indirect pairs were additionally correlated with the product of their accuracy scores for direct linking associations, across all events. I wanted to verify if retrieval-related processes within events, i.e. activity spreading through direct linking pairs when inferring indirect associations, were also supported by corresponding observations in performance of the relevant associations across events. For across-event analyses, performance correlations were undertaken because dependency can only be used for categorical 0/1 variables, which in this case is success or failure of retrievals, while correlations can analyse continuous variables, such as the 0, 1, 2 overall accuracy scores of associations (owing to the bidirectional testing of each association) or their products. This correlation was also compared with the performance correlation between indirect pairs and the respective non-linking direct associations. As an example, accuracy scores for indirect pair AC were correlated with the product of accuracy scores for direct pairs AB and BC on the same trial. A Fisher's Z-transformation was then implemented on the Pearson correlation coefficient or *r* values for each participant, and later a one-sample t-test to identify any relationship, across participants, between performance on indirect associations and performance on the respective linking and non-linking associations. Since Fisher's Z transformation of 1 or -1 are undefined, perfect correlations, i.e. r=1 or -1 were changed to 0.999 or -0.999 respectively to minimise exclusion of data. Sample size N could also vary because participants who were accurate in all of the relevant associations in a condition or inaccurate in all of them would yield an undefined correlation coefficient and so were not covered in this analysis.

2.2 Results

2.2.1 Associative Accuracy

For associative accuracy on direct associations across closed- and open-loop events, a paired samples t-test reported higher performance on closed loops than on open loops (t(24)=3.74, p=.001, *d*=0.75; see **Fig. 2a**). Analysis on indirect associations concerned open-loop events only since there were no indirect pairs in closed-loop events. When comparing average accuracy for direct with indirect associations, I found that participants scored better on direct associations (t(24)=7.67, p<.001, *d*=1.53) although a one-sample t-test on accuracy for indirect associations revealed a mean performance that was greater than chance (t(24)=3.89, p<.001, *d*=0.78; chance = 0.33). Accuracy was thus highest for direct associations in closed-loop events followed by those in open-loop events and then indirect associations.

Performance on indirect associations was then studied in detail, specifically on the different indirect pair types (AC, BD, AD; see **Fig. 2b**). A one-way ANOVA showed an effect of pair type (F(2,48)=6.10, p=.004, ηP^2=.20), caused by poorer performance for AD than AC (t(24)=3.58, p=.001, *d*=0.72) and BD (t(24)=2.33, p=.03, *d*=0.47). Memory for AC was no different from memory for BD (t(24)=0.69, p=.49). That accuracy for both AC and BD was similar while AD accuracy was significantly worse than their average is reasonable, given that the AC and BD pairs were inferred across two direct associations (AB and BC for AC; BC and CD for BD) while inferring AD involved three (AB, BC and CD).

2.2.2 Dependency Across Direct Associations

Dependency was first measured for direct associations in closed- and open-loop events (see **Fig. 3a**). A one-way ANOVA revealed that retrieval dependency was

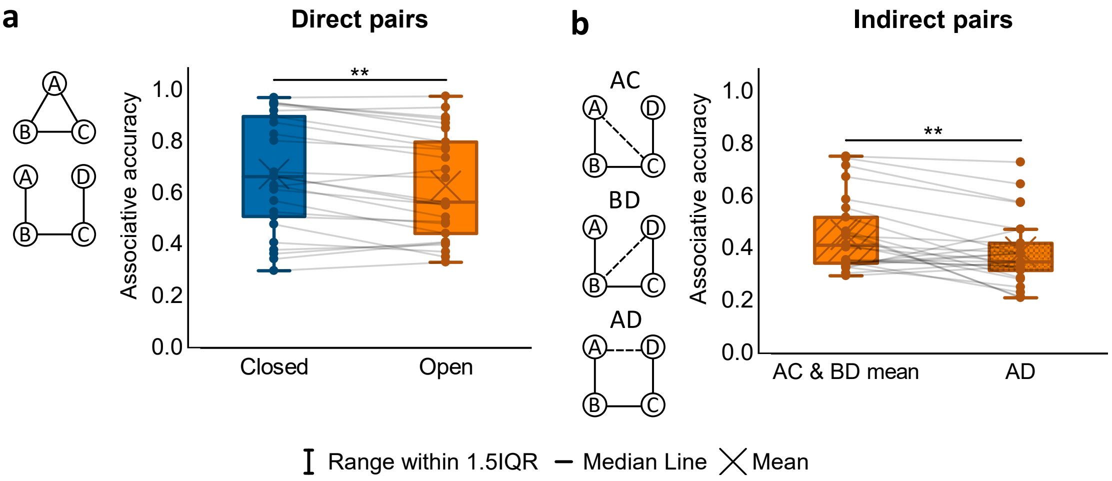

Figure 2. Associative accuracy results for Experiment 1. (**a**) Proportion correct retrievals for direct pairs in closed and open loops. (**b**) Proportion correct retrievals overall in indirect pairs AC, BD and AD, averaging across AC and BD since they showed no significant difference. $^{**}p < .01$. *N*=25 for **a**-**b**.

not significantly different between the two conditions (F(1,23)=2.79, p=.11). However, one-sample t-tests described significant dependency in closed-loop events (t(23)=3.08, p=.01, d=0.63) but not in open-loop events (t(23)=0.77, p=.45).

2.2.3 Dependency Across Indirect Associations

Dependency across all indirect associations from open loops (AC, BD, AD) was next assessed by means of a one-sample t-test on dependency (see **Fig. 3b**) which found that retrievals of indirect associations were interdependent (t(23)=4.12, p<.001, *d*=0.84). A paired samples t-test was further carried out comparing dependency across direct pairs in open-loop events with dependency across indirect pairs, showing no significant difference (t(23)=-1.59, p=.13).

2.2.4 Dependency of Indirect Associations on Direct Linking Associations

The relatedness across direct and indirect pairs was then measured by probing how dependent indirect associations were for retrieval on the direct associations that informed the inference (see **Fig. 3c**). I would expect, for instance,

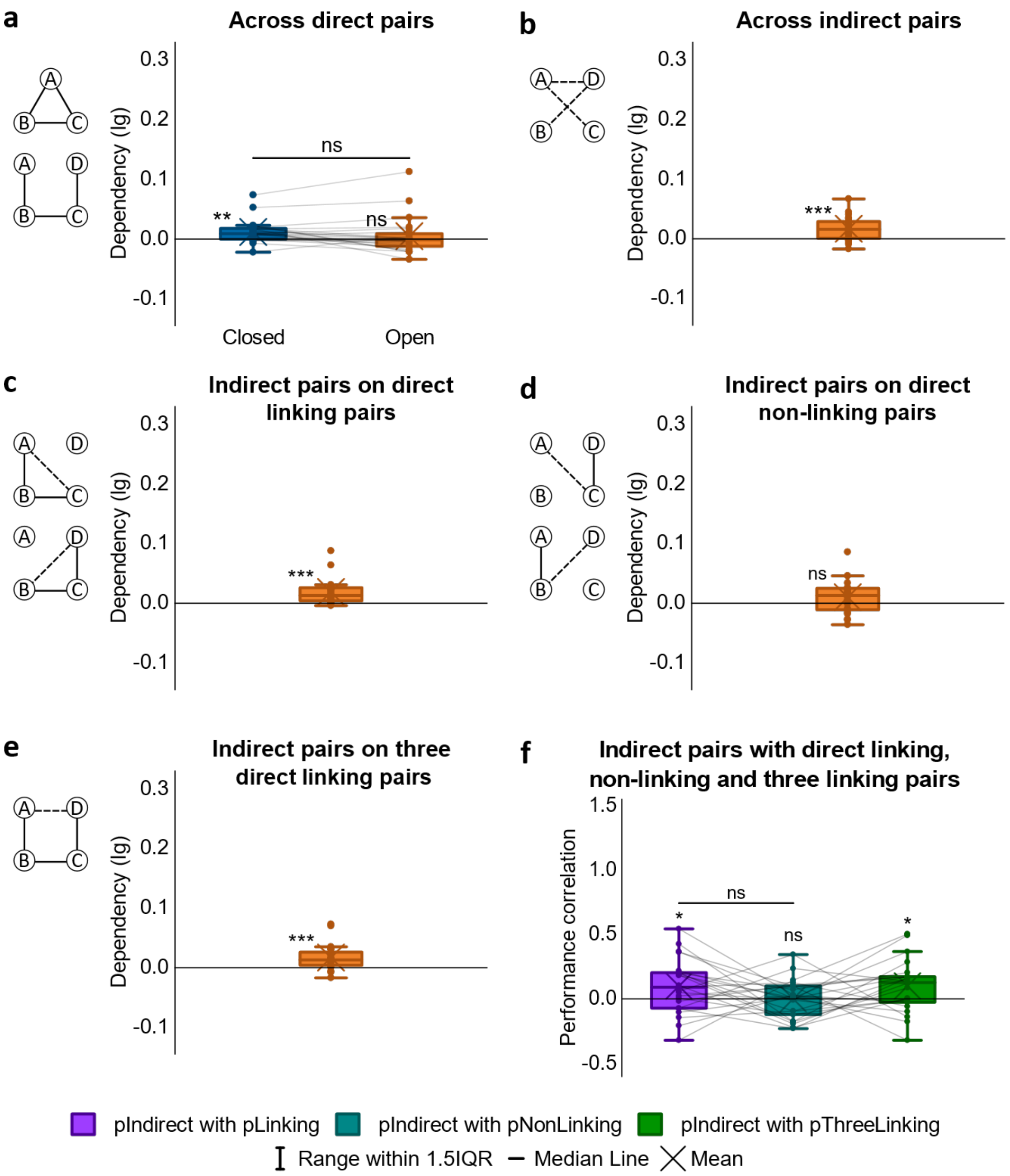

Figure 3. Dependency results for Experiment 1. (**a**) Dependency of direct pairs on other direct pairs from the same event for closed and open loops, log-transformed. (**b**) Dependency of indirect pairs on other indirect pairs from the same event for open loops, log-transformed. (**c**) Dependency of indirect pairs on related direct pairs from the same event for open loops, log-transformed. (**d**) Dependency of indirect pairs on unrelated direct pairs from the same event for open loops, log-transformed. (**e**) Dependency of indirect pair AD on all three related direct pairs from the same event for open loops, log-transformed. (**f**) Performance correlation between indirect pairs and related direct (for AC and BD), unrelated direct (for AC and BD) and all three related direct pairs (for AD; * within a column

reflects a significant difference from zero). ***p < .001; **p < .01; *p < .05; ns not significant. *N*=24 for **a**-**f**.

that the accurate retrieval of indirect pair AC would rely on that of direct pairs AB and BC, and the accurate retrieval of the indirect association BD on that of direct associations BC and CD (see **Fig. 1b** for an illustration of event structure). Analysis using a one-sample t-test demonstrated dependency (t(23)=4.32, p<.001, *d*=0.88), implying that inferring indirect associations was pertinent to the retrieval success of relevant overlapping direct associations.

I later examined how retrieving indirect associations (AC, BD) related to retrieving both the relevant linking direct associations (AB and BC for indirect pair AC, BC and CD for indirect pair BD). For each participant, the accuracy scores across events for the indirect associations were subjected to a Pearson correlation with the product of performance scores for the two linking direct associations (see **Fig. 3f**). The *r* values were then Fisher's Z-transformed before their average across participants were put to a one-sample t-test. The transformed correlation coefficients were found to be significantly greater than zero (mean *r*=.10; t(22)=2.30, p=.03, *d*=0.48), which suggests that across events, the retrieval of inferential associations was related to the retrieval of their linking associations.

2.2.5 Dependency of Indirect Associations on Direct Non-Linking Associations

Subsequently, dependency of indirect pairs was calculated in terms of retrieval on direct non-linking associations, which were pairs that were perhaps not necessary for inferring the indirect pair in question (see **Fig. 3d**). In other words, it referred to the retrieval dependency of the indirect AC pair on direct association CD as well as the retrieval dependency of the indirect BD pair on direct association AB (see **Fig. 1b** for an illustration of event structure). A one-sample t-test on the dependency showed that it was not significant (t(23)=1.85, p=.08) and hence indirect pairs did not rely on direct non-linking pairs.

I also looked at any difference between the dependency of inferred pairs on direct non-linking pairs and their dependency on direct linking pairs by carrying out a paired samples t-test. Indirect associations were noted to be more dependent on direct linking pairs than on direct non-linking pairs (t(23)=-2.08, p=.05, *d*=-0.42).

The performance correlation across open loops between inferred associations (AC, BD) and their direct non-linking pairs (CD, AB respectively) for every participant was also calculated (see **Fig. 3f**). After Pearson correlation coefficients were Fisher's Z-transformed, the mean across participants was put to a one-sample t-test, revealing that the *r* values did not deviate significantly from zero (mean *r*=-.0004; t(22)=0.02, p=.98). Performance in inferred associations was hence unrelated to that in non-linking associations across events.

2.2.6 Dependency of Indirect Association AD on All Linking Direct Associations

The indirect association AD was then assessed for its retrieval dependency on all direct associations from the same event (see **Fig. 3e**), seeing that they formed the chain of associative pairs that constituted the inference, i.e. AB-BC-CD (see **Fig. 1b** for an illustration of event structure). Analysis using a one-sample t-test showed significant dependency (t(23)=3.88, p<.001, *d*=0.79).

A paired samples t-test then contrasted dependency of AD on all linking direct associations with dependency of indirect associations (AC, BD) on respective linking direct associations (AB and BC for indirect association AC, BC and CD for indirect association BD). No difference was revealed (t(23)=-0.55, p=.59) despite higher performance for AC and BD averaged together than for AD (see **Fig. 2b**), suggesting that all types of indirect pairs were equally dependent on their direct linking pairs.

Finally, a Pearson correlation was performed for each participant between accuracy scores for AD and the product of accuracy scores for AB, BC and CD (see **Fig. 3f**) to determine the relationship between the retrieval success of AD across events and the retrieval success of the entire sequence of overlapping pairs AB, BC and CD. A one-sample t-test on Fisher's Z-transformed correlation coefficients reported that they were significantly greater than zero (mean *r*=.10; t(21)=2.34, p=.03, *d*=0.50). This provided evidence that across events, retrieval accuracy for AD correlated with performance of the full series of direct pairs AB, BC and CD.

2.3 Summary

Experiment 1 detailed statistical dependency in the retrieval success of direct pairwise associations belonging to closed-loop events, while it was absent in open-loop structures – a result consistent with earlier research (Horner and Burgess, 2014; Horner et al., 2015). Inferred associations from the same open-loop event (e.g. AC, BD, AD) were dependent on each other for retrieval and also on linking direct associations (e.g. AB, BC for indirect pair AC), but not on unrelated direct associations (e.g. CD for indirect pair AC). This particular finding suggested that the dependency amongst the indirect associations was due to them being contingent on a common direct linking association for retrieval, i.e. BC, with inferred pair AC depending on AB and BC, inferred pair BD on BC and CD, and inferred pair AD on AB, BC and CD. Accuracy in inferred associations was also found to be related to the product of performance on the linking direct associations across events.

My data overall lent support to an auto-associative network that serves as an interconnected system of all associations, encoded or inferential, where recollection is comprehensive and resembles pattern completion. The dependency in retrieval accuracy across inferred associations within an open-loop event and the lack of it across encoded associations from the same event condition might be explained by the independent recollection of direct associations, each relying on its own presentation, when inferred associations hinged upon pattern completion within an episode.

3 Experiment 2: Recollecting and Inferring Across Overlapping Associations With Separate Retrievals of Encoded and Inferred Associations

The paradigm used in Experiment 1 (see Chapter 2) mirrored that of previous studies on inference, where trials testing directly seen and indirectly inferred associations were intermixed (Preston et al., 2004; Shohamy and Wagner, 2008; Zeithamova and Preston, 2010; Schlichting et al., 2014; Banino et al., 2016). However, alternating both sets of trials might cause the retrieval of an association to be guided by the process taking place just recently. For instance, following the retrieval of an inference that builds on the retrieval success of other inferred associations in an event, a direct association from a closed-loop event might be more inclined to mobilise the same dependency-related pathways for recall instead of retrieving its stored memory trace, making its retrieval more dependent. Experiment 1 also presented test trials on inferred pairs prior to trials on direct associations from the same episode so that the latter could not assist in the recollection of the former. Still, my interest lies in the differences in performance between indirect associations (‘inference’) and direct associations (‘memory’), so in Experiment 2 I further reinforced the discrepancies between them and made it easier to study one apart from the other. Participants undertook test trials on direct associations first in a single session and later test trials on indirect associations in an ensuing session.

3.1 Method

3.1.1 Participants

Thirty-four healthy, English-speaking adults from a university subject pool were invited to participate. All of them were included in analyses on memory performance but one was ruled out of analyses on dependency and performance correlation, leaving data from 33 participants (24 female, mean age = 24, age range 18–33). The omission of the participant was due to a greater than 95% accuracy for direct pairs in all conditions. I conducted a power analysis based on effect sizes detailed in Experiment 1 (ηP^2 range = .15–.41, *N* range = 24–25; see Chapter 2 – Results) to find the rough sample size needed for Experiment 2 (estimated *N* range = 8–47; power = 0.80, α = .05). The median estimated sample size within the approximated range is 28, hence my sample size of 34 would more than suffice for this experiment.

3.1.2 Materials

The same stimuli were used as those in Experiment 1 (see Chapter 2 – Results, **Figs. 1a**, **1b**).

3.1.3 Procedure

The procedure was as that in Experiment 1 (see Chapter 2 – Method, **Figs. 1b**, **1d**) but with a few differences. Testing took place over two consecutive sessions, the first containing trials on direct pairs (see **Fig. 1a**) and the other encompassing trials on indirect pairs (see **Fig. 1b**). It was only before commencing the second test session that I informed participants that they would be tested on associations that had not been presented at encoding but could be deduced from the observed pairs, based on the structure of the event. This permitted them to form inferences in a way that might not occur in the real world (see Chapter 10 – Inference in experiments versus in real lifeInference in experiments versus in real life). As in Experiment 1, participants were asked in each trial for both test sessions to indicate out of three forced choice alternatives the correct paired associate for a presented cue. Trials in each session were randomly ordered.

3.1.4 Associative Accuracy Analysis

Associative accuracy was analysed as it was in Experiment 1 (see Chapter 2 – Method).

3.1.5 Dependency Analysis

Dependency analysis was the same as it was in Experiment 1 (see Chapter 2 – Method). Following Shapiro-Wilk tests of normality which noted that dependency across direct pairs over both types of loops (W(24)=.62, p<.001) and dependency across indirect pairs (W(33)=.92, p=.01) deviated from a Gaussian distribution, all Ddata minus Di data were log-transformed (see **Equation 1**).

3.2 Results

3.2.1 Associative Accuracy

I looked for differences in associative accuracy on direct associations between closed- and open-loop events, as in Experiment 1 (see Chapter 2 – Results). A paired samples t-test demonstrated that closed loops were better remembered than open loops (t(33)=4.79, p<.001, *d*=0.82; see **Fig. 4a**). Due to the absence of inferential pairs in closed-loop events, performance in indirect associations was compared with accuracy for direct pairs in open-loop events. Performance was higher for direct than indirect pairs (t(33)=4.27, p<.001, *d*=0.73) but a one-sample t-

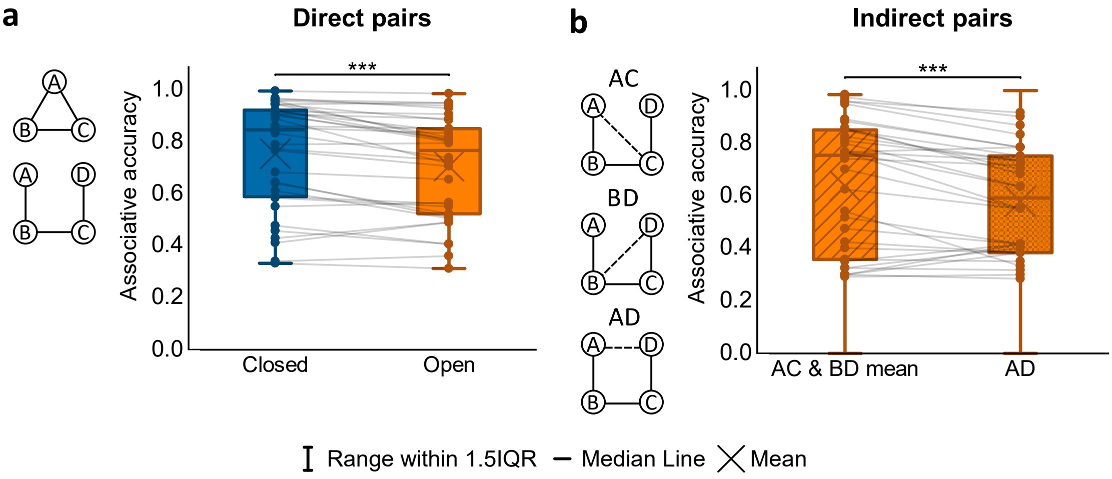

Figure 4. Associative accuracy results for Experiment 2. (**a**) Proportion of correct retrievals for direct pairs in closed and open loops. (**b**) Proportion correct retrievals overall in indirect pairs AC, BD and AD, averaging across AC and BD since they showed no significant difference. ***p < .001. *N*=34 for **a**-**b**.

test found that indirect associations had a greater than chance performance (t(33)=6.62, p<.001, *d*=1.14; chance = 0.33).

Further analysis on mean accuracy for indirect pairs was done on the various indirect pair types (AC, BD, AD) via a one-way ANOVA (see **Fig. 4b**), noting a main effect of pair type (F(2,66)=11.4, p<.001, ηP^2=.26). With the help of post-hoc paired samples t-tests, this was explained by participants performing worse on AD than on AC (t(33)=4.10, p<.001, *d*=0.70) and BD (t(33)=3.42, p=.002, *d*=0.59), though they remembered AC and BD equally (t(33)=1.49, p=.15).

3.2.2 Dependency Across Direct Associations

As in Experiment 1 (see Chapter 2 – Results), dependency in retrieval of direct associations from the same event on each other was examined among closed- and open-loop events (see **Fig. 5a**) through a one-way ANOVA. Both loop types differed significantly in terms of dependency (F(1.45,36.3)=16.8, p<.001, ηP^2=.40) with post-hoc paired samples t-tests displaying stronger dependency in closed than

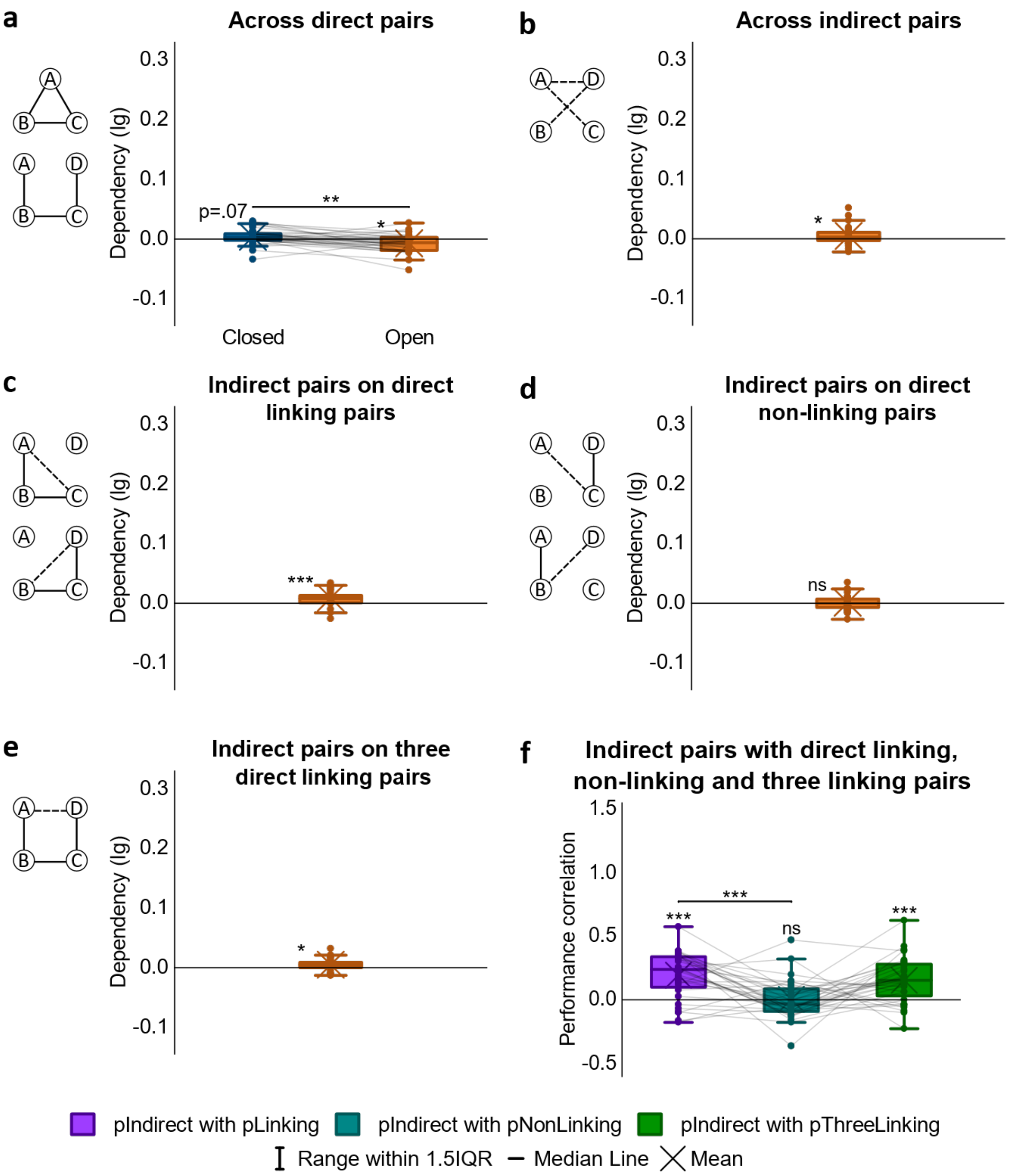

Figure 5. Dependency results for Experiment 2. (**a**) Dependency of direct pairs on other direct pairs from the same event for closed and open loops, log-transformed. (**b**) Dependency of indirect pairs on other indirect pairs from the same event for open loops, log-transformed. (**c**) Dependency of indirect pairs on related direct pairs from the same event for open loops, log-transformed. (**d**) Dependency of indirect pairs on all unrelated direct pairs from the same event for open loops, log-transformed. (**e**) Dependency of indirect pair AD on all three related direct pairs from the same event for open loops, log-transformed. (**f**) Performance correlation between indirect pairs and related direct (for AC and BD), unrelated direct (for AC and BD) and all three related direct pairs (for AD; * within a column

reflects a significant difference from zero). ***p < .001; **p < .01; *p < .05; ns not significant. *N*=33 for **a**-**f**.

open loops (t(32)=3.41, p=.002 *d*=0.59). One-sample t-tests were run to further study these results and reported a tendency for dependency in closed-loop events (t(32)=1.87, p=.07, *d*=0.33) while dependency level was lower than the Independent model's estimate in open-loop events (t(32)=-2.63, p=.01, *d*=-0.46). Therefore, successfully retrieving an association in an open-loop event might interfere with or hinder via retrieval-induced forgetting the retrieval of other within-event associations.

3.2.3 Dependency Across Indirect Associations

Retrieval dependency across indirect associations from open loops (AC, BD, AD) was then subjected to a one-sample t-test (see **Fig. 5b**), revealing a significant result (t(32)=2.10, p=.04, *d*=0.37). Following a paired samples t-test to compare within-event dependency between direct and indirect associations, I noted that dependency was greater among indirect pairs than it was among direct pairs in open-loop events (t(32)=-3.11, p=.004, *d*=-0.54).

3.2.4 Dependency of Indirect Associations on Direct Linking Associations

To examine the relationship between direct and indirect associations during retrieval, the dependency of retrieval success of indirect pairs on that of encoded pairs expected to support the inference was determined. Retrieving AC, for example, would likely rely on the recollection of AB and BC, and retrieving BD would reasonably be dependent on the recollection of BC and CD (see **Fig. 5c**). Using a one-sample t-test, significant dependency was found (t(32)=3.86, p<.001, *d*=0.67), which suggested that strength of inference was connected to the accurate retrieval of relevant direct associations.

A Pearson correlation was next performed between participants' accuracy scores for indirect associations and the product of accuracy scores for both direct linking pairs (see **Fig. 5f**) to establish whether retrieving indirect pairs was coupled with retrieving encoded linking pairs across events. The correlation coefficients underwent a Fisher's Z-transformation before a one-sample t-test, which confirmed that the transformed data were significantly more than zero (mean r=.19; t(31)=6.12, p<.001, d=1.08). These findings implied that across events, retrieval success of inferential associations cohered with retrieval success of their linking direct associations.

3.2.5 Dependency of Indirect Associations on Direct Non-Linking Associations

For the dependency of retrieving indirect associations on retrieving seen non-linking pairs, namely retrieval of indirect pair AC on retrieval of CD and retrieval of BD on retrieval of AB (see **Fig. 5d**), a one-sample t-test was run. Such dependency was identified to not be significant (t(32)=0.60, p=.55).

Next, the difference in dependency of indirect pairs on the successful retrieval of direct linking associations and on that of direct non-linking associations was studied. A paired samples t-test reported that inferred associations were more robustly dependent on direct linking pairs for retrieval than on direct non-linking pairs (t(32)=2.13, p=.04, d=0.37).

Looking for trends across events, I also examined the relation between performance on indirect associations (AC, BD) and the associative accuracy for the respective direct non-linking association for each participant (CD, AB respectively;

see **Fig. 5f**). Performance on indirect pairs across events for each participant was correlated with the accuracy scores of the corresponding non-linking pairs, and the *r* values were Fisher's Z-transformed. According to a one-sample t-test, the *r* values did not vary significantly from zero (mean *r*=.01; t(31)=0.21, p=.84), proposing that retrieving encoded non-linking associations was not related to the accurate retrieval of inferential associations.

3.2.6 Dependency of Indirect Association AD on All Direct Associations

Lastly, the indirect association AD was assessed on its retrieval dependency on all learned associations in the same event, which were also the pairs bolstering the inference (AB-BC-CD; see **Fig. 5e**). Dependency was found to be significant after a one-sample t-test was conducted (t(32)=2.59, p=.01, *d*=0.45).

Dependency of indirect pair AD on all linking direct pairs was then compared using a paired samples t-test with dependency of indirect pairs AC and BD on their respective linking direct pairs (i.e. AC on AB and BC, BD on BC and CD) analysed in the preceding section. There was no significant difference (t(32)=-1.48, p=.15) although performance averaging across AC and BD exceeded that for indirect association AD (see **Fig. 4b**). All indirect pair types hence relied equally on the direct pairs that supported them.

Next, I determined if the dependency result remained true across events, such that retrieving AD corresponded with the successful retrieval of the sequential chain of overlapping pairs AB-BC-CD over all events (see **Fig. 5f**). To analyse this, performance on AD was correlated across events with the product of accuracy scores for AB, BC and CD. Through a one-sample t-test, the Fisher's Z-transformed *r* values were noted to significantly exceed zero (mean *r*=.15; t(31)=4.92, p<.001, *d*=0.87), suggesting that retrieval of the inferred pair AD was connected to retrieval of all the overlapping direct associations in the AB-BC-CD chain across open-loop events.

3.3 Summary

Experiments 1 (see Chapter 2) and 2 both demonstrated steady dependency among indirectly deduced associations although the former delivered assorted testing of direct and indirect associations whereas the latter assessed direct associations first before indirect ones. The dependency across within-event inferred associations in both experiments was presumably due to the associations' common reliance on BC, which was a direct linking pair for all types of indirect associations (AC, BD, AD). Inferential ability was also found to not be contingent on correctly remembering unrelated direct associations. This result was observed in Experiment 1 too, as was the significant correlation across events between associative accuracy for indirect associations and the product of performances on direct linking associations. However, statistical dependency across inferred pairs in Experiment 2 exceeded that across direct pairs while the two types of dependency was not dissimilar in Experiment 1. In Experiment 2, retrievals of encoded pairs were also not statistically related to each other within any event, closed- or open-loop (though this dependency was stronger in closed loops than in open loops), contrary to Experiment 1 where significant dependency was implicated in closed loops only.

Essentially, results point to the existence of an auto-associative organisation of both perceived and inferred associations, within which the all-inclusive recollection of multimodal events takes place. Pattern completion spanning indirect pairs and their relevant direct linking pairs appeared to underlie inferential reasoning. Indirect associations also exhibited greater retrieval interdependency than direct associations from the same event, and this could suggest that the testing arrangements in Experiment 2 had increased the reliance of the indirect associations on one another. However, it might also be that those testing specifications had instead reduced dependency among direct pairs, which was noted to be negative, making it significantly lower than dependency among indirect pairs. By contrasting dependency outcomes from Experiment 2 with those from Experiment 1 where indirect pairs were inquired ahead of direct pairs and both pair types were tested in an alternating manner, the effects of testing style on holistic retrieval could be better understood (see Chapter 4), not just for this particular case but also for other points of comparison between the experiments.

4 Comparing Experiment 1 and Experiment 2

To explore any differences in the manner of retrieval between studied and inferred associations that could be attributed to variations in testing procedure, I compared dependency results in Experiment 1, where direct and indirect associations were tested in an interleaved fashion with indirect associations from an open loop tested first before direct associations from the same event (see Chapter 2), and Experiment 2, where test trials on direct associations were tested in one session and those on indirect associations in the session after (see Chapter 3). A cursory view of their results identified four main differences between them:

1) dependency across direct pairs was significant in closed-loop events in Experiment 1 (see **Fig. 3a**) but not in Experiment 2 (see **Fig. 5a**),

2) dependency across direct pairs in open-loop events was not significant in Experiment 1 (see **Fig. 3a**) but was significantly negative in Experiment 2 (see **Fig. 5a**),

3) dependency across direct pairs in closed-loop events was no different from that in open-loop events in Experiment 1 (see **Fig. 3a**) but it was higher in closed-loop events than open-loop events in Experiment 2 (see **Fig. 5a**), and

4) dependency across indirect pairs did not differ from that across direct pairs within open-loop events in Experiment 1 (see Chapter 2 – Results) but the former was greater than the latter in Experiment 2 (see Chapter 3 – Results).

It is, however, hard to interpret the effect of the testing protocol on retrieval of indirect and direct pairs based on these discrepancies; points 1 and 2 might be moot if the dependency variables in question were later proven to not be statistically different across the experiments, and points 3 and 4 concerned within-experiment rather than across-experiment comparisons. I therefore undertook further analyses to interpret how testing procedure affected holistic retrieval of events.

4.1 Method

4.1.1 Inter-experiment analysis

When sample size differs in two or more experiments, an independent t-test or an ANOVA is less effective for assessment across experiments since they assume equal variances in the examined samples (Boneau, 1960; Behrens, 1928; Fisher, 1935, 1941). As there were 25 participants in Experiment 1 and 34 participants in Experiment 2 in my accuracy data analyses as well as 24 and 33 respectively in my dependency data analyses (see Chapters 2, 3 – Method respectively), I carried out a Levene's test on the dependency of interest to first determine if the assumption of equal variances held true. If so, a one-way ANOVA was performed to see if the dependency significantly differed in Experiments 1 and 2; otherwise, a Welch's t-test test, which accommodates unequal variances (Welch, 1938, 1947; Satterthwaite, 1946; Fairfield Smith, 1936; Aspin, 1948), was implemented for the same purpose.

4.2 Results

4.2.1 Associative Accuracy

A Levene's test on the homogeneity of variances was first run to compare performance on direct pairs from closed-loop events in Experiments 1 (see **Fig. 2a**) and 2 (see **Fig. 4a**), showing a non-significant result which implied equal variances (F(1,57)=0.10, p=.75). A one-way ANOVA was thereupon undertaken to reveal no difference between Experiments 1 and 2 in terms of accuracy for encoded associations in closed loops (F(1,57)=1.96, p=.17). Similarly, for events organised as open loops, a Levene's test noted no difference in variance for accuracy on direct associations (F(1,57)=0.49, p=.49). Both experiments also did not exhibit differences in accuracy according to a one-way ANOVA (F(1,57)=2.12, p=.15).

Memory for indirectly perceived associations in open-loop events was then examined (**Figs. 2b**, **4b**). A Levene's test described significantly different variances in both experiments (F(1,57)=21.2, p<.001), requiring a Welch's test for comparison across the experiments. Participants in Experiment 2 were found to perform better in the inference task than those in Experiment 1 (t(51.9)=3.67, p<.001, *d*=0.92). When the indirect pairs were broken down into their respective association types (AC, BD, AD), I attained the same results. Using a Levene's test, variance in accuracy on indirect association AC was observed to be different in Experiments 1 and 2 (F(1,57)=26.8, p<.001), and a Welch's test consequently showed that subjects in the second experiment remembered AC better than subjects in the first experiment (t(49.4)=3.47, p<.001, *d*=0.87). The same was seen for indirect pair BD – a Levene's test indicated unequal variance in performance in the two experiments (F(1,57)=9.37, p=.003) and a Welch's test then saw higher accuracy in Experiment 2 versus Experiment 1 (t(56.2)=3.16, p=.003, *d*=0.81). Accuracy analyses on indirect association AD followed suit, with significantly different variances seen in both experiments based on a Levene's test (F(1,57)=14.1, p<.001) and subsequently greater performance in Experiment 2 than in Experiment 1 as shown by a Welch's test (t(54.0)=3.99, p<.001, *d*=1.00).

4.2.2 Dependency Across Direct Associations

I next compared the figures reported in Experiments 1 (see **Fig. 3a**) and 2 (see **Fig. 5a**) for retrieval dependency of direct associations on each other. In closed loops, a one-way ANOVA was run after a Levene's test indicated equal variances (F(1,55)=0.65, p=.42), reporting no significant difference in dependency (F(1,55)=3.05, p=.09). Variances were also comparable in both experiments for dependency in open-loop events (F(1,55)=3.03, p=.09), and a one-way ANOVA consequently showed that the difference in dependency almost reached significance (F(1,55)=3.81, p=.056, ηP^2=.07) where dependency was larger in the first experiment than in the second one.

4.2.3 Dependency Across Indirect Associations

I then contrasted dependency of indirect associations on one another in Experiment 1 (see **Fig. 3b**) with that in Experiment 2 (see **Fig. 5b**). Events of an open-loop configuration alone were analysed here since indirect associations were only present in open loops; all associations in closed loops were directly encoded. Variances in dependency were not significantly different based on a Levene's test (F(1,55)=3.17, p=.08) but according to a one-way ANOVA, dependency varied by experiment (F(1,55)=5.91, p=.02, ηP^2=.10) where it was higher in Experiment 1 than in Experiment 2.

4.2.4 Dependency of Indirect Associations on Direct Linking Associations

Following a non-significant Levene's test which pointed to equal variances in dependency of indirect pairs on linking direct pairs in Experiments 1 (see **Fig. 3c**) and 2 (see **Fig. 5c**; F(1,55)=0.80, p=.14), dependency in both experiments was subjected to a one-way ANOVA for comparison. A significant difference was reported (F(1,55)=4.62, p=.04, ηP^2=.08) with higher dependency found in Experiment 1 versus Experiment 2.

4.2.5 Dependency of Indirect Associations on Direct Non-Linking Associations

Because dependency of indirect pairs on non-linking direct pairs in Experiments 1 (see **Fig. 3d**) and 2 (see **Fig. 5d**) showed unequal variances, as noted by a Levene's test (F(1,55)=9.30, p=.004), a Welch's test was performed to ascertain any difference in dependency. No such disparity was found between both experiments (t(31.0)=1.47, p=.15).

4.2.6 Dependency of Indirect Association AD on All Direct Associations

I finally probed for any differences in the dependency of indirect pair AD on all direct associations in the event (AB, BC, CD) which also supported AD inference in Experiment 1 (see **Fig. 3e**) and Experiment 2 (see **Fig. 5e**). A Levene's test showed different variances in the experiments (F(1,55)=6.12, p=.02), prompting the comparison in dependency to be examined in a Welch's test. Dependency was noted to differ in the two experiments (t(31.4)=2.55, p=.02, *d*=0.72), with more robust dependency in Experiment 1 than in Experiment 2.

4.3 Summary

Across Experiments 1 and 2 (see Chapters 2, 3 respectively), dependency among direct associations did not significantly differ for either loop configuration. There was also no difference in how much indirect associations were dependent on non-linking direct associations for retrieval in both experiments. However, dependency of indirect associations on each other and on related direct associations (which includes dependency of indirect association AD on all direct associations) were all stronger in Experiment 1.

Thus, the reason why in Experiment 2 indirect pairs in an open-loop event were more dependent on each other for retrieval than direct pairs were on each other in the same event was because dependency across the direct pairs was negative to begin with, and so dependency across indirect pairs appeared stronger than that across direct pairs. The fact that both types of dependency were equivalent to each other in Experiment 1 did not mean that the test settings in Experiment 2 encouraged retrieval dependency amongst indirect associations – in actuality, greater interdependency existed in the first experiment. Other conflicting outcomes between Experiments 1 and 2 with regards to dependency across direct pairs did not translate to significant differences between the experiments. The extent to which direct associations in closed- or open-loop events depended on one another for recollection was the same in Experiments 1 and 2 although dependency in closed-loop events was significant only in Experiment 1, dependency in open-loop events was non-significant in Experiment 1 and negative in Experiment 2, and dependency did not differ between closed and open loops in Experiment 1 but did in Experiment 2.

Another noteworthy result is that performance on the inference test in Experiment 1 was lower than in Experiment 2 despite higher dependency among indirect associations in the first experiment. There are three possible implications from this observation – inferences are remembered more poorly when they are retrieved via pattern completion rather than independently, inferences that are remembered poorly are more likely retrieved via pattern completion than independently, and performance on inferences does not have a bearing on their retrieval dependency and vice versa. The first possibility is implausible because theoretically, the presence of dependency boosts instead of restricts memory for the associations since the correct retrieval of one association in an event that exhibits within-event dependency induces the correct retrievals of other associations in the event. That is why in all the experiments thus far, where closed-loop events were associated with dependency, events of this type were always linked to higher accuracy than open-loop events. My next experiments which proposed to study the influence of repetitive encoding on statistical dependency – Experiments 3 and 4 (see Chapters 5, 7 respectively) – would be able to clarify if improving memory, which was expected to happen when stimuli were learned repeatedly, enhances dependency. Alternatively, the weaker performance seen in Experiment 1 had less to do with dependency and more to do with testing arrangements that examined encoded and inferred associations alternatingly and which made for more challenging retrieval, as opposed to the separation of both types of tests in Experiment 2.

Overall, testing memory for direct and indirect associations in distinct sessions where direct associations are tested first, as in Experiment 2, is linked to reduced dependency of inferred associations on the direct associations which mediate their inference, and, since the various types of inferred associations (AC, BD, AD) rely on a common direct linking association (BC), on each other. Recollecting direct associations could trigger the retrieval of the inferences they support (e.g. recollecting direct pairs AB and BC could retrieve inferred pair AC), reinforcing the memory traces of the indirect associations such that they could be retrieved more independently when they are tested later on. As a result, indirect associations become less dependent on their respective direct linking associations for retrieval and therefore on each other.

5 Experiment 3: Effects of Spaced Repetition of Overlapping Associations on Recollection and Inference

That within-event dependency was more compelling amidst indirect associations than encoded associations illustrated the variation in processing between the two, as discovered in Experiment 2 (see Chapter 3), in spite of poorer performance in the former. It has been described that repeating the presentation of overlapping pairwise associations enhances memory for the inferences they support (Zeithamova et al., 2016). I therefore planned to evaluate if improving the ability to remember inferences, through repeated exposure of associations, would increase the non-significant retrieval interdependency of direct pairs in open loops. Other influences of repetition on retrieval of direct and indirect associations were also analysed.

Experiment 3 followed up on Experiment 2 but with some events displayed three times over the course of learning. Moreover, this experiment gave more time for encoding per trial – 6s instead of 3s – and involved more foil items per test trial – six instead of three – than Experiments 1 and 2 to more closely reproduce previous studies (Horner and Burgess, 2013, 2014; Horner et al., 2015). Three alternatives had been given in each test trial in Experiments 1 and 2 considering that participants in the pilot testing for those experiments did poorly on the associative memory and inference task when there were six alternatives, but I reverted to using six in this experiment since performance was expected to improve with repetition.

5.1 Method

5.1.1 Participants

Forty-three healthy, English-speaking participants recruited from the university student population gave full consent to the study. All participants were covered in memory performance analyses but only 42 were implicated in dependency and performance correlation analyses (28 female, ages 19–35, mean age = 24, three left-handed) after one was excluded for attaining more than 95% accuracy for direct pairs in all conditions. An estimate sample size for Experiment 3 (estimated *N* range = 9–99; power = 0.80, α = .05) was derived from a power analysis on effect sizes recorded in Experiment 2 (see Chapter 3 – Results; ηP^2 range = .12–.49, *N* range = 33–34). Eventually a sample size of 43 was adopted in this experiment since an effect size of .29 from Experiment 2 recommended a sample size of 35. Because Experiment 3 also studied repetition effects, enrolling 43 subjects would authorize further subgroup analyses.

5.1.2 Materials

The same stimuli used in Experiments 1 and 2 (see Chapter 2 – Method, **Figs. 1a**, **1b**) were adapted with a few changes. Thirty multimodal events were incorporated in each closed- and open-loop condition, 60% of which were repeated (18) and the remaining 40% were not (12). I elected to repeat a larger proportion of events to increase the repeated condition's level of difficulty given that an earlier pilot experiment in which the split was equal produced exceedingly high performances for the condition, causing the dependency model to be less robust. As a result, 12 closed-loop single presentation ('single closed' condition), 18 closed-loop repeated presentation ('repeated closed'), 12 open-loop single presentation ('single open’) and 18 open-loop repeated presentation events (‘repeated open’) were obtained.

5.1.3 Procedure

The protocol in Experiments 1 and 2 (see Chapter 2 – Method, **Figs. 1c**, **1d**) was repeated but several differences were introduced to accommodate repetitive encoding. Encoding trials were organised randomly over three sessions of three blocks, and every event from the repeated condition appeared three times overall versus once for singly presented events. All associations from a repeated event were shown within every session, one pair per block. A singly viewed event, meanwhile, was randomly allocated to one of the sessions, its pairwise associates slotted in separate blocks. Presentation order of associations within any event was random; for instance, order for a repeated closed-loop event was AB, AC, BC in session 1 whereas in session 2 it was AC, AB, BC. Furthermore, to reproduce the paradigm used in earlier studies on dependency (Horner and Burgess, 2014; Horner et al., 2015), each encoding trial lasted for 6s instead of 3s as was in Experiments 1 and 2, and test trials displayed six options instead of three.

5.1.4 Associative Accuracy Analysis

In addition to the same analyses as in Experiments 1 and 2 (Chapter 2 – Method), I also computed mean accuracy for single closed, single open, repeated closed and repeated open events and administered repeated measures ANOVAs to evaluate the significance of loop structure, encoding repetition and association type.

5.1.5 Dependency Analysis

I measured dependency as in Experiments 1 and 2 (see Chapter 2 – Method) but also looked for differences between single and repeated conditions. A log transformation (see **Equation 1**) was applied to all Ddata minus Di values after Shapiro-Wilk tests of normality revealed that dependency across direct pairs in repeated events (W(42)=.94, p=.03), closed events (W(42)=.94, p=.03), single closed events (W(42)=.93, p=.01) and repeated closed events (W(42)=.94, p=.04), as well as dependency across indirect pairs in single open events (W(42)=.93, p=.01), repeated open events (W(42)=.91, p=.003) and overall across repetition (W(42)=.90, p=.001), and dependency of indirect pairs on direct linking pairs in repeated open events (W(42)=.88, p<.001) had non-Gaussian distributions.

The performance correlation comparing accuracy scores across all open-loop events for indirect associations (AC, BD) with the product of accuracy scores of direct linking associations was also calculated for single and repeated conditions, both of which were later compared through a paired samples t-test. The same analysis was implemented when performance on indirect associations (AC, BD) was correlated with the product of accuracy scores for direct non-linking associations and when performance on indirect association AD was correlated with the product of accuracy scores for all direct associations.

5.2 Results

5.2.1 Associative Accuracy

Participants' associative memory of direct associations (see **Fig. 6a**), which were pairs that had been observed during learning, was noted across the two closed- and open-loop conditions that each consisted of singly presented and repeated

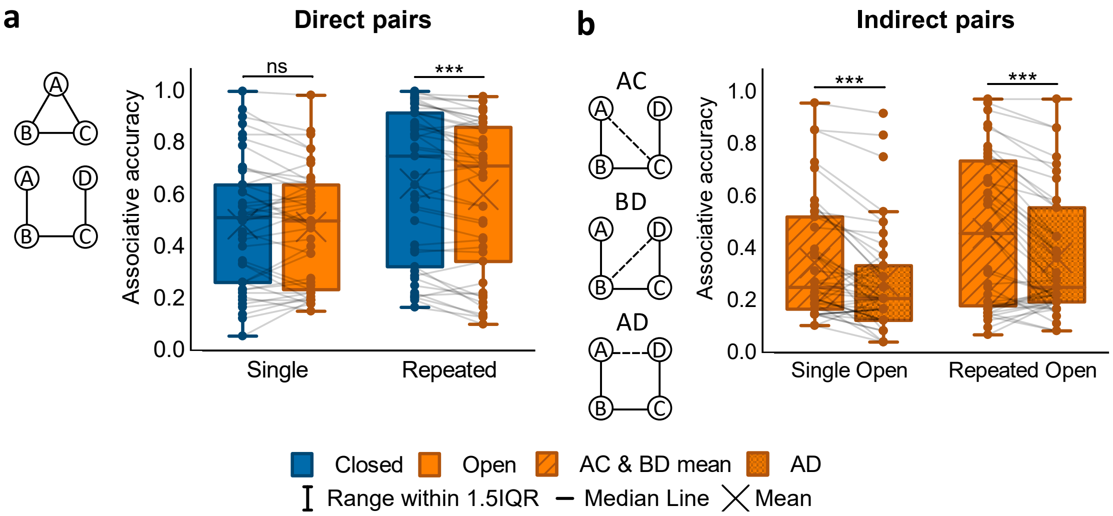

Figure 6. Associative accuracy results for Experiment 3. (**a**) Proportion correct retrievals in single and repeated events for direct pairs in closed and open loops. (**b**) Proportion correct retrievals in single open and repeated open loops for indirect pairs AC, BD and AD, averaging across AC and BD since they showed no significant difference. ***p < .001; ns not significant. *N*=43 for **a**-**b**.

events. Using a 2X2 ANOVA (loop type x repetition), I saw an interaction between loop structure and repetition that leaned towards significance (F(1,42)=4.05, p=.051, ηP^2=.09). There was a significant effect of loop type (F(1,42)=12.7, p<.001, ηP^2=.23) that owed to better accuracy for closed loops than open loops and a main effect of repetition (F(1,42)=63.3, p<.001, ηP^2= .60) that was interpreted by better performance for repeated loops as opposed to single loops.

Associative accuracy was also assessed for indirect associations. Because indirect pairs were solely derived from open-loop events, performance for direct associations appertaining open-loop events alone was contrasted with performance for indirect associations, as done in the previous two experiments. Data from a 2X2 ANOVA (association type x repetition) presented no significant interaction (F(1,42)=.81, p=.37, ηP^2=.02) but a main effect for association type (F(1,42)=74.2, p<.001, ηP^2=.64) as well as repetitive learning (F(1,42)=42.0, p<.001, ηP^2=.50) due to higher accuracy scores for direct associations and for repeated events respectively.

I then delved deeper into inferential associations and how performance on each type of indirect pair (AC, BD, AD) varied (see **Fig. 6b**). Ensuing a 3X2 ANOVA (pair type x repetition), a significant effect of pair type emerged (F(1.78,74.6)=14.7, p<.001, ηP^2=.26), which, according to paired samples t-tests, was due to better associative performance for AC (t(42)=5.15, p<.001, *d*=0.79) and BD pairs (t(42)=4.40, p<.001, *d*=0.67) versus AD, while accuracy for AC and BD did not differ (t(42)=-0.86, p=.40). I also reported a main effect of repetition (F(1,42)=24.8, p<.001, ηP^2=.37) where repeated exposure improved memory of associations. Indirect pair type, however, did not interact with repetition (F(2,84)=1.56, p=.22, ηP^2=.04).

5.2.2 Dependency Across Direct Associations

Dependency in retrieval of direct associations from an event on each other was compared across loop type and repetition (see **Figs. 7a**, **7b**) by means of a 2X2 repeated measures ANOVA (loop type x repetition). I found a main effect of loop type (F(1,41)=7.12, p=.01, ηP^2=.15) since closed-loop events possessed higher dependency than open-loop events, replicating what was found in Experiment 2 (see **Fig. 5a**). However, no significant results for repetition (F(1,41)=0.04, p=.85) nor for loop type x repetition interaction were obtained (F(1,41)=1.43, p=.24). Supplementary one-sample t-tests showed that significant dependency was present in closed-loop events (t(41)=4.25, p=<.001, *d*=0.66) but absent in open-loop ones (t(41)=0.31, p=.76), same as what was noted in Experiment 1 (see **Fig. 3a**).

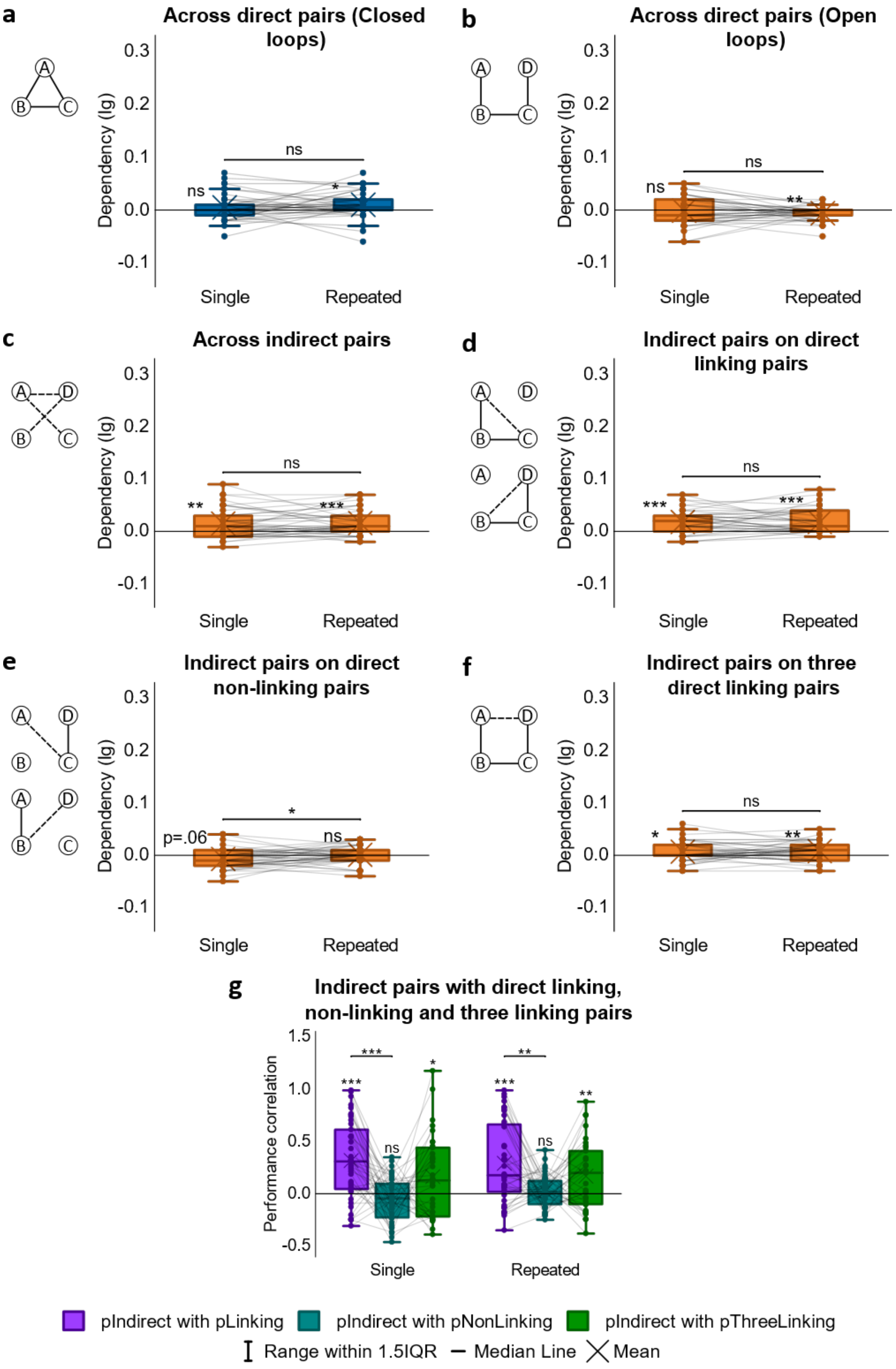

Figure 7. Dependency results for Experiment 3. (**a**) Dependency of direct pairs on other direct pairs from the same event for single closed and repeated closed loops, log-transformed. (**b**) Dependency of

direct pairs on other direct pairs from the same event for single open and repeated open loops, log-transformed. (**c**) Dependency of indirect pairs on other indirect pairs from the same event for single open and repeated open loops, log-transformed. (**d**) Dependency of indirect pairs on related direct pairs from the same event for single open and repeated open loops, log-transformed. (**e**) Dependency of indirect pair on unrelated direct pairs from the same event for single open and repeated open loops, log-transformed. (**f**) Dependency of indirect pair AD on all three related direct pairs from the same event for single open and repeated open loops, log-transformed. (**g**) Performance correlation between indirect pairs and related direct (for AC and BD), unrelated direct (for AC and BD) and all three related direct pairs (for AD), in single open and repeated open loops. ***p < .001; **p < .01; *p < .05; ns not significant. *N*=42 for **a**-**g**.

5.2.3 Dependency Across Indirect Associations

Afterwards, dependency was examined in terms of retrieval for indirect associations (AC, BD, AD) from the same open-loop event (see Fig. 7c). Upon a one-way ANOVA test, I observed that repetition had no main effect (F(1,41)=0.01, p=.94), indicating that dependency remained the same for single and repeated loops. Dependency across repetition was significant, as shown by a one-sample t-test (t(41)=5.15, p<.001, d=0.80).

I next probed for disparities in dependency between within-event direct pairs and within-event indirect pairs via a 2X2 ANOVA (direct versus indirect analysis x repetition). A main effect of dependency analysis was revealed (F(1,41)=20.3, p<.001, ηP^2=.33) brought about by higher dependency amongst inferred associations than it was amongst direct associations. However, no effect of repetition (F(1,41)=0.93, p=.34) nor an interaction (F(1,41)=0.39, p=.54) was present.

5.2.4 Dependency of Indirect Associations on Direct Linking Associations

Since inference of an indirect association is likely to have hinged upon the accurate retrieval of the two direct linking pairs that connect the elements in the indirect pair, the dependency of indirect pairs on the related direct pairs was measured (see **Fig. 7d**). That is to say, I sought to see if the probability of retrieving AC was larger when AB and BC were retrieved correctly, and similarly the probability of retrieving BD when BC and CD were retrieved correctly. A one-way ANOVA specified no main effect of repetition (F(1,41)=0.03, p=.86), and when dependency was inquired further using a one-sample t-test, it was significant in open-loop events regardless of number of presentation times (t(41)=6.68, p<.001, d=1.03). Overall, retrieving indirect associations likely relied on memory for the relevant direct associations that held up the inference.

To ascertain whether indirect associations and their respective linking direct associations related to each other in terms of performance across events, I ran a Pearson correlation for each participant between accuracy for the indirect pairs and the product of their accuracy scores for the direct linking pairs across open-loop events (see **Fig. 7g**). One-sample t-tests revealed that the Fisher's Z-transformed correlation coefficients were significantly higher than zero for both single (mean r=.27; t(41)=5.64, p<.001, d=0.87) and repeated open-loop events (mean r=.25; t(40)=4.85, p<.001, d=0.76). There was negligible difference in the mean transformed correlation coefficients between single and repeated events according to a paired samples t-test (t(40)=0.38, p=.70). Associative inference across events was therefore connected to the retrieval success of encoded linking associations in a manner unaffected by repetition.

5.2.5 Dependency of Indirect Associations on Direct Non-Linking Associations

To establish the retrieval dependency of indirect pairs on direct unrelated pairs that were not thought to be involved in associative inference (see **Fig. 7e**), i.e. the dependency of the indirect AC association on the direct CD association, and the dependency of the indirect BD association and the direct association AB, a one-way ANOVA was performed. Repetition exhibited an effect that was converging towards significance (F(1,41)=3.99, p=.052, ηP^2=.09), and one-sample t-tests later detailed dependency that almost attained significance in single loops (t(41)=-1.98, p=.055, *d*=-0.31) but was non-significant in repeated loops (t(41)=0.53, p=.60). I therefore saw no confirmation of any dependency between retrievals of indirect associations and retrievals of direct non-linking associations.

Next, the dependency of inferred associations during retrieval on non-linking direct associations was compared with that on linking direct associations. In a 2X2 ANOVA that looked at differences in dependency between the analyses on linking and non-linking pairs and between both rounds of encoding, I found a significant effect for dependency analysis (F(1,41)=27.2, p<.001, ηP^2=.40) driven by indirect pairs in both single and open-loop presentations being more dependent on direct linking pairs than on direct non-linking pairs. The effect of repetition was not significant (F(1,41)=2.19, p=.15) and no interaction between dependency analysis and repetition was seen (F(1,41)=2.14, p=.15).

The extent of relatedness between retrieving inferred associations and retrieving non-linking direct associations over all open-loop events was then studied. For every participant, I correlated accuracy on indirect pairs with the product of performance on the respective direct non-linking pair (see **Fig. 7g**). Based on one-sample t-tests, Fisher's Z-transformed Pearson correlation coefficients for single (mean *r*=-.06; t(41)=-1.74, p=.09) as well as repeated events (mean *r*=.02; t(41)=1.10, p=.28) were not found to vary from zero. When the transformed *r* values for single events were compared with those for repeated events in a paired samples t-test, they were revealed to increase with repetition (t(41)=-2.03, p=.05, *d*=-0.31). These data indicated that despite the advantageous effect of repetitive exposure on the correlation, performance on indirect pairs was not associated to performance on the corresponding non-linking pairs across all single and repeated open-loop events.

5.2.6 Dependency of Indirect Association AD on All Linking Direct Associations

The retrieval success of the indirect association AD was next analysed on its dependency on the retrieval of all within-event direct associations, which comprised the associative chain facilitating the inference (i.e. AB-BC-CD, see **Fig. 1b** for an illustration of the event structure; see **Fig. 7f**). A one-way ANOVA showed a lack of effect for repetition (F(1,41)=0.21, p=.65, ηP^2=.01), but across repetition conditions, a one-sample t-test noted that AD was dependent on all direct linking pairs for retrieval (t(41)=3.87, p<.001, *d*=0.60).

A comparison was later made between dependency of indirect association AD on all linking direct associations with dependency of indirect associations AC and BD on their respective direct linking associations (AB and BC for indirect association AC, BC and CD for indirect association BD) which I examined earlier. Through a 2X2 repeated measures ANOVA (AC and BD versus AD analysis x repetition), it was found that there was a significant effect of dependency analysis (F(1,41)=13.8, p=.001, ηP^2=.25) due to higher dependency of indirect pairs AC and BD on linking direct pairs than dependency of AD on all direct linking pairs. No effect of repetition, however, was observed (F(1,41)=0.03, p=.88) and neither was there an interaction between dependency analysis and repetition (F(1,41)=0.39, p=.54). This was consistent with stronger accuracy scores averaged across indirect pairs AC and BD than for indirect pair AD (see **Fig. 6b**).

Across all open-structure events, the association between inference of AD and recollection of all linking direct pairs was determined through a correlation between each participant's performance on AD and the product of their accuracy for AB, BC and CD over all open-loop events (see **Fig. 7g**). By means of one-sample t-tests, Fisher's Z-transformed *r* values were observed to be higher than zero for singly presented (mean *r*=.14; t(33)=2.41, p=.02, *d*=0.41) and repeated loops (mean *r*=.15; t(32)=3.01, p=.01, *d*=0.52), both not differing from each other, according to a paired samples t-test (t(30)=0.04, p=.97). Retrieving AD was hence connected to retrieving the full length of the AB-BC-CD associative chain across events, with repetitive learning bearing no impact on the relationship.

5.3 Summary

Dependency outcomes in Experiment 2 (see Chapter 3) and also Experiment 1 (see Chapter 2) persisted in the current experiment even though some events were now repeatedly presented and associative accuracy was boosted by encoding repetition. Encoded associations in closed-loop events exhibited within-event dependency as was the case in Experiment 1 and almost so in Experiment 2 (p=.07), but as the two earlier experiments found, dependency was not prominent in open-loop events. When it came to indirect associations from the same open-structure event, retrievals were dependent on each other and on retrieval of their particular direct linking associations, though not on retrieval of direct non-linking associations, as reported in Experiments 1 and 2. The capability to infer moreover correlated across events with the product of performance on the relevant direct linking associations but not direct non-linking associations. Dependency across inferred associations was higher than across direct associations – a result also seen in Experiment 2 but not in Experiment 1, which was potentially explained by participants being tested on direct associations ahead of indirect ones (contrary to Experiment 1 on both aspects). Similar to what developed in Experiment 2, the recollection of studied pairs before indirect pairs might have improved memory for direct linking associations that bolstered subsequent associative inference, which in turn promoted dependency amongst within-event inferred associations.

In addition, indirect pairs AC and BD were more dependent on their direct linking pairs (AC on direct pairs AB and BC, BD on direct pairs BC and CD) than indirect pair AD was on all direct linking pairs (AB, BC, CD), contradicting Experiments 1 and 2 where both types of dependency were not different from each other. It could be that participants in the current experiment retrieved inferences by a stepwise recall of the related overlapping direct pairs – for instance, retrieving indirect pair AC would involve recollecting AB first, which in turn would recollect BC. In this manner of retrieval, the greater the number of direct pairs an inference relies on for retrieval, the lower the probability is of retrieving the inference successfully. Hence, AD retrieval, implicating more direct linking pairs than AC and BD retrievals, became less statistically related to the retrievals of its direct linking pairs than AC and BD retrievals were to the retrievals of their own direct linking pairs. Meanwhile, participants in Experiments 1 and 2 recollected all linking direct pairs instantly when attempting to retrieve inferences. Thus, the number of direct pairs that needed to be recalled when retrieving an indirect pair did not affect the inference's dependency on its linking direct pairs as much. This discrepancy between Experiment 3 and Experiments 1 and 2 might be a consequence of poorer memory for direct associations within singly presented open-loop events in Experiment 3 compared to the two earlier experiments, such that amid retrieving indirect associations, the direct linking associations could not be all immediately recollected. Instead, the direct linking pairs themselves depended on each other, where retrieving one would then recall the other, and finally retrieve the inferences they supported together. To verify if performance on studied associations was indeed better in the open loops of Experiment 1 than in the single open loops of Experiment 3, I first administered a Levene's test which identified equal variances across the experiments ($F(1,66)=0.03$, $p=.88$). A one-way ANOVA was hence permitted for the comparison, confirming significantly greater accuracy in Experiment 1 ($F(1,66)=7.68$, $p=.01$, $\eta P^2=.10$). The same analysis was repeated to contrast performance on direct associations in the open-loop events of Experiment 2 with that in the single open loops of Experiment 3. Upon a non-significant result from a Levene's test which denotes equal variances ($F(1,75)=0.74$, $p=.39$), a one-way ANOVA revealed performance to also be better in Experiment 2 ($F(1,75)=22.2$, $p<.001$, $\eta P^2=.23$). Although this experiment adopted the same test procedure as Experiment 2 and even provided a longer study period per event (6s versus 3s in Experiment 2), performance on indirect associations in single events was weaker in Experiment 3 perhaps due to the need to encode many more trials in the experiment (360 versus 180 in Experiment 2).

One result in this experiment which was different in Experiment 2, despite both having the same retrieval protocol, was the significant dependency across direct pairs in single closed events which was not significant in singly presented closed-loop events in the earlier experiment (p=.07; see Chapter 3 – Results). I sought to find out how much the dependency differed in the two experiments by first carrying out a Levene's test, noting a significant result that demonstrated unequal variances across them (F(1,73)=6.60, p=.01). A Welch's test, which accommodated such heterogeneity, was then performed to compare the dependency between Experiment 2 and this experiment. No main effect of experiment was reported (t(73)=0.05, p=.83), so dependency across direct pairs within non-repeated closed loops in Experiment 2 and within single closed events in this experiment was not significantly different.

With regards to encoding repetition, only memory for both direct and indirect associations benefited from repetitive learning; within-event dependency and across-event performance correlation remained unaltered. This implied that repetition-mediated improvement in associative memory did not stimulate the unification of encoded associations into a more integrated representation. The idea of repetition-resistant pattern completion hints at the separation of memory acquisition and integration processes despite occupying the same locus.

The negligible effects of repeated exposure on dependency for inferences also shed some light on the possible causal role of performance in dependency. Upon comparing Experiments 1 and 2, both of which studied retrieval manner of encoded and inferred associations, it was revealed that inferred associations in the first experiment were recollected at a lower rate and were more interdependent during retrieval than inferred associations in the second experiment. This was a result that prompted speculation on whether memory performance suppresses dependency – it was unlikely to be the other way round as significant dependency denotes facilitated retrieval of associations within an event. Seeing that repetition strengthened performance which in turn did not vary dependency, strength of memory for inferences therefore might not influence the occurrence of dependency. In fact, accuracy scores for indirect associations were worse in Experiment 1 than in Experiment 2 potentially because of more demanding retrieval provisions – test trials for direct and indirect associations were intermixed in Experiment 1 but split into separate sessions in Experiment 2. Bearing in mind that performance was calculated across all events whereas dependency only concerned associations within each event, lower performance and higher dependency in Experiment 1 than in Experiment 2 could imply that a smaller portion of open-loop events produced successfully retrieved inferences in Experiment 1 versus Experiment 2, but within those events, dependency was greater than within open-loop events in Experiment 2, which had a larger portion of open-loop events that produced successfully retrieved inferences. Performance therefore did not affect retrieval dependency.

Data from my three experiments so far had consistently maintained an associative account of memory that told of a network storing both acquired associations and deduced associations arising from the former. The encoding of overlapping information, the resulting associative inference as well as the holistic reinstatement of a multielement episode are borne out of this associative organisation. Although pattern completion was not engaged during the retrieval of partially viewed events, it was heavily implicated during inferential activity as asserted by the statistical dependence of indirect associations on direct linking associations. Repetitive encoding of associations had an advantageous effect on memory but none on the relatedness among retrievals of direct and inferred associations.

6 A Model of Experiment 3: Simulating Hippocampal Pattern Completion During Inference in Episodic Memory

Similar observations on dependency have been consistently established across all experiments so far, recounting significant dependency amongst indirect associations in open-loop structures as well as between indirect associations and the respective direct linking associations in open loops. The negligible effect of encoding repetition on dependency also critically suggests that coherent retrieval of associations in an event makes use of different mechanisms from those employed for memory acquisition. My next step was to verify if a computational model of hippocampal memory function could justify these results by simulating a simple auto-associative neural network model of the hippocampus (adapted from Horner et al., 2015). The network was subjected to operations akin to the experimental procedure in Experiment 3 (see Chapter 5) and began by encoding an array of overlapping pairwise associations, some once and others thrice. Retrieval of an association then consisted of the extrinsic activation of a 'cue' neuron and the limited stimulation of six 'target' neurons, the latter reflecting the test options. To find out whether retrieval had taken place successfully (as marked by firing rates exceeding a defined threshold), the firing rates in each of the target neurons were surveyed, which were also liable to excitation by recurrent connectivity. Accuracy and dependency for every event and pair type were examined too in a similar fashion. Altogether, I sought to decide whether the empirical conclusions gathered from Experiment 3 primarily and also Experiments 1 and 2 (see Chapters 2, 3 respectively) could be resolved by hippocampal pattern completion.

6.1 Method

A network of N rate-coded neurons that were wholly recurrently connected besides self-connections (adapted from Horner et al., 2015) were simulated (see **Equation 2**). The firing rate r_i of the neurons was governed by a time constant τ_r=25ms, a combination of externally administered currents $I_{i,ext}$ and recurrent synaptic currents $I_{i,syn}$, and a sigmoidal transfer function (see **Equation 3**). I parameterised the transfer function with a threshold r_t=10 and a peak firing rate of r_{max}=10Hz, and originally fixed the firing rates r_i and synaptic connections w_{ij} within the network as zero.

$$\tau_r \frac{dr_i}{dt} = -r_i + f(I_{i,ext} + I_{i,syn})$$

Equation 2. Neural network simulation.

$$f(x) = \frac{r_{max}}{1 + \exp(r_t - x)}$$

Equation 3. Transfer function for neural network.

Every element in an event was depicted by a specific neuron. The order in which events were encoded and the culminating associative structures for the closed-loop and open-loop events in Experiment 3 (see Chapter 5) were reproduced in this simulation. At encoding, synaptic connections with a strength of w_{ij}=1.1 were assumed to have been forged between neurons projecting the pair of stimuli shown in each trial with a probability of p_{enc}. The random selection of p_{enc} values for each simulation from a Gaussian distribution with a mean of μ_{enc}=0.3 and a standard deviation of σ_{enc}=0.2 was to account for variance in accuracy across simulated participants. For stimuli pairs that were repeated, synaptic connections were revised only if they had a strength of w_{ij}=0 (i.e. synaptic connections developed in previous encoding blocks were not phased out, meaning ‘forgetting’ had not occurred), leading to a rise in the total proportion of potentiated synaptic connections across blocks.

At retrieval, the order in which each association from any type of loop was retrieved remained as it was in Experiment 3. I applied a constant current of I_{ext}=15 to the neuron designated as the cued element for a duration of t_{ret}=1s, and I_{ext}=6 to the neurons serving as the three test options. The recurrent synaptic current I_{syn}, which is the product of the synaptic weights and firing rates of connected neurons (see **Equation 4**), contributed additional activity.

$$I_{i,syn} = \sum_j w_{ij} r_j$$

Equation 4. Synaptic current in neural network, applied to the neuron representing the cued element.

Neurons that resembled the three forced choice target items and whose firing rate, upon completion of a test trial, superseded a retrieval limit of r_{ret}=8Hz, were probed to interpret performance on that trial from their firing rates. Supposing that more than one neuron topped this threshold, the simulated response would then be selected at random from the active neurons. Similarly, if all six neurons persisted below the retrieval threshold when a trial ended, I would randomly single out one as representative of the simulated response.

Performance (see Chapter 5 – Method) and dependency (see Chapter 5 – Method) were derived in the same way relative to the behavioural data in Experiment 3. On the whole, 43 simulations were completed (each an equivalent of a participant in Experiment 3; see Chapter 5 – Method) with 60 events each (30 closed-loop and 30 open-loop, with 60% i.e. 18 events of each loop type shown three times during learning and the remaining 40% i.e. 12 events shown once).

The distribution of Ddata minus Di data was then checked for normality via Shapiro-Wilk tests. Since dependency across direct pairs in repeated closed events (W(43)=.87, p<.001), single open events (W(43)=.95, p=.04), repeated open events (W(43)=.95, p=.04) and repeated events (W(43)=.91, p=.002), as well as dependency across indirect pairs in single open events (W(43)=.91, p=.003) and repeated open events (W(43)=.94, p=.03), dependency of indirect pairs on direct linking pairs in single open events (W(43)=.94, p=.02), dependency of indirect pairs on direct non-linking pairs in single open events (W(43)=.94, p=.02), and dependency of AD on all linking pairs in single open events (W(43)=.91, p=.002) exhibited non-Gaussian distributions, I imposed a log transformation (see **Equation 1**) on all dependency analyses before running statistical tests on them.

6.2 Results

6.2.1 Associative Accuracy

Performance in this experiment and in Experiment 3 (see Chapter 5 – Results) was compared to determine if the computational model produced the same accuracy rates as my empirical data. A 2X4 ANOVA contrasting the two experiments and the four accuracy conditions (single closed, single open, repeated closed, repeated open) noted a main effect of accuracy condition (F(1.96,82.1)=114.9, p<.001, ηP^2=.73) and an experiment x accuracy condition interaction (F(2.08,87.3)=9.28, p<.001, ηP^2=.18). However, no main effect of experiment was seen (F(1,42)=1.59, p=.21). Post-hoc paired samples t-tests reported that there was no difference between Experiment 3 and the neural network model in associative accuracy for single closed (t(42)=-0.92, p=.36), single open (t(42)=-0.02, p=.99) and repeated open loops (t(42)=-1.54, p=.13). Accuracy scores for repeated closed-loop events, however, were higher in the simulations than in the behavioural experiment (t(42)=2.13, p=.04, *d*=0.33). Experiment 3 and the model emulating it therefore performed as good as each other except for repeated closed-loop events.

Participants' performance in the different loop type and repetition conditions was first assessed for direct associations, which were pairs presented at study (see **Fig. 8a**). In a 2X2 ANOVA (loop type x repetition), there was a main effect of associative structure (F(1,42)=30.4, p<.001, ηP^2=.42) due to better associative memory for closed-loop events than open-loop events, and a main effect of repetition (F(1,42)=121.1, p<.001, ηP^2=.74) due to stronger memory for repeated pairs in contrast to unrepeated ones. I noticed, however, no significant interaction between loop type and repetition (F(1,42)=.93, p=.34).

Performance on direct associations was then compared with that on indirect associations in open-loop events only, given that inferences were only possible in partially seen open loops. A 2X2 ANOVA (association type x repetition) disclosed main effects of association type (F(1,42)=151.5, p<.001, ηP^2=.78), driven by greater accuracy for direct associations, and repetition (F(1,42)=102.0, p<.001, ηP^2=.71), caused by higher accuracy for repeatedly presented events, together with a significant interaction (F(1,42)=7.69, p=.01, ηP^2=.16) which was next studied via post-hoc paired-sample t-tests. It was reported that in open-loop events, participants scored better on direct pairs when they were shown more times (t(42)=9.83, p<.001, *d*=1.50), with the same result for inferred pairs (t(42)=9.42, p<.001, *d*=1.44). There

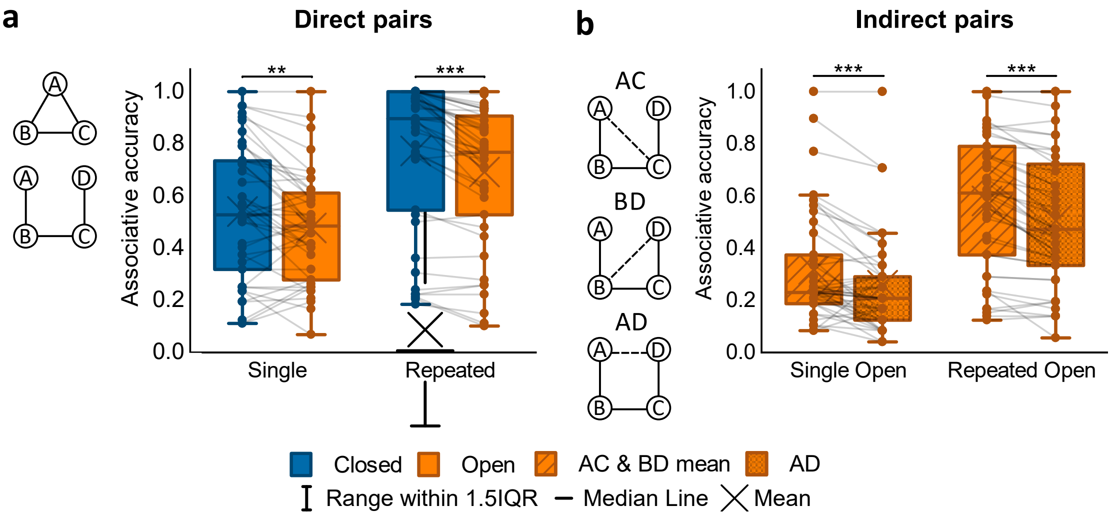

Figure 8. Simulated associative accuracy results. (**a**) Proportion correct retrievals in single and repeated events for direct pairs in closed and open loops. (**b**) Proportion correct retrievals in single open and repeated open loops for indirect pairs AC, BD and AD, averaging across AC and BD since they showed no significant difference. ***p < .001; **p < .01. *N*=43 for **a**-**b**.

was also more robust performance in direct pairs versus indirect pairs for single open-loop (t(42)=11.1, p<.001, *d*=1.69) and repeated open-loop events (t(42)=9.62, p<.001, *d*=1.47). The interaction was spurred by a larger disparity in memory performance between direct and inferred associations in repeated than in singly presented events, according to a paired samples t-test (t(42)=2.77, p=.01, *d*=0.42).

Associative accuracy for the various types of inferred associations within open-loop events (AC, BD, AD; see **Fig. 8b**) was later measured in a 3X2 ANOVA (pair type x repetition). It was noted that pair type had a main effect (F(2,84)=21.4, p<.001, ηP^2=.34) brought about by, as revealed by paired samples t-tests, higher associative accuracy for AC (t(42)=5.95, p<.001, *d*=0.91) and BD pairs (t(42)=5.62, p<.001, *d*=0.86) in comparison with AD while performance scores for AC and BD were comparable (t(42)=0.89, p=.38). There was also a significant effect of repetition

(F(1,42)=88.5, p<.001, ηP^2=.68) since performance was better on repeated than on single associations, though overall no interaction was observed (F(2,84)=0.80, p=.45).

6.2.2 Dependency Across Direct Associations

To study how dependent encoded associations were for retrieval on retrieving others from the same event, whether it was of a closed- or open-loop structure, or it was single or repeated (see **Figs. 9a**, **9b**), a 2X2 ANOVA (loop type x repetition) was performed. A main effect of loop type was observed (F(1,42)=41.5, p<.001, ηP^2=.50) which described greater dependency in closed loops than in open loops, along with no effect of repetition (F(1,42)=2.47, p=.12) though loop type x repetition interaction was significant (F(1,42)=4.85, p=.03, ηP^2=.10). Further analyses into the interaction using paired samples t-tests reported that the discrepancy between dependency in closed- and in open-loop events was more remarkable in single events than in repeated ones (t(42)=2.20, p=.03, *d*=0.34). Hence, upon repetition, the gap in dependency between closed- and open-loop events reduced. When examined on its own through one-sample t-tests, dependency in closed-loop events was significant (t(42)=8.00, p<.001, *d*=1.22) but not so in open-loop events (t(42)=0.72, p=.48).

6.2.3 Dependency Across Indirect Associations

My next step was to measure statistical dependency across retrievals of inferred associations (AC, BD, AD) from the same open loop (see Fig. 9c). In a one-way ANOVA, dependency in single and repeated open-loop events were noted to be significantly different (F(1,42)=19.0, p<.001, ηP2=.31) with stronger dependency when events were repeated. Dependency amongst within-event indirect pairs in

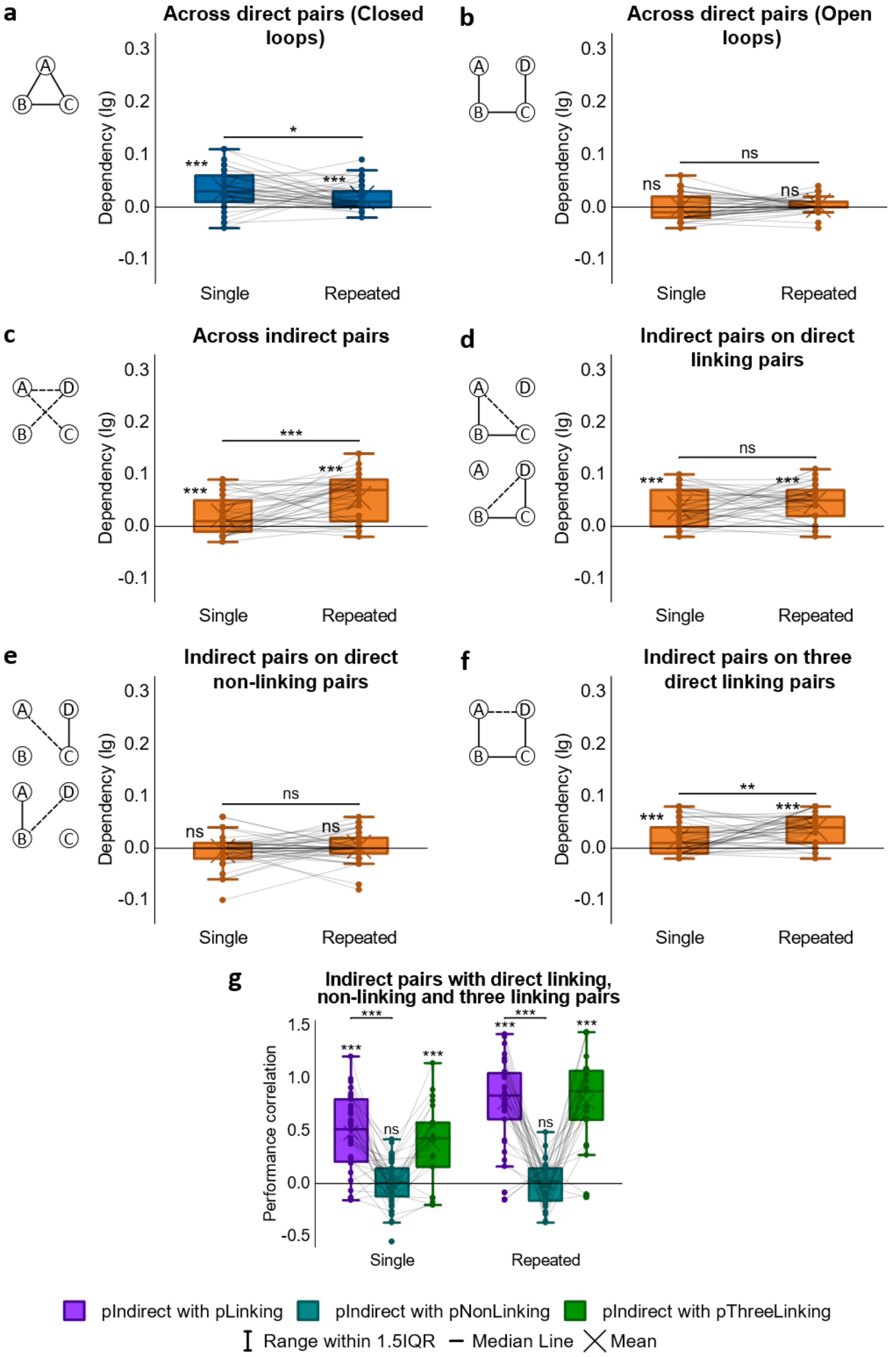

Figure 9. Simulated dependency results. (**a**) Dependency of direct pairs on other direct pairs from the same event for single closed and repeated closed loops, log-transformed. (**b**) Dependency of direct

pairs on other direct pairs from the same event for single open and repeated open loops, log-transformed. (**c**) Dependency of indirect pairs on other indirect pairs from the same event for single open and repeated open loops, log-transformed. (**d**) Dependency of indirect pairs on related direct pairs from the same event for single open and repeated open loops, log-transformed. (**e**) Dependency of indirect pair on unrelated direct pairs from the same event for single open and repeated open loops, log-transformed. (**f**) Dependency of indirect pair AD on all three related direct pairs from the same event for single open and repeated open loops, log-transformed. (**g**) Performance correlation between indirect pairs and related direct (for AC and BD), unrelated direct (for AC and BD) and all three related direct pairs (for AD), in single open and repeated open loops. ***p < .001; **p < .01; *p < .05; ns not significant. *N*=43 for **a**-**g**.

open loops was shown by a one-sample t-test to be significant (t(42)=8.37, p<.001, d=1.28).

This retrieval dependency across indirect associations was also considered in parallel with dependency across direct associations in open-loop structures. According to a 2X2 ANOVA comparing the two dependency analyses as well as the two presentations of the events, dependency analysis generated a significant effect (F(1,42)=63.8, p<.001, ηP^2=.60) which was a culmination of greater within-event dependency for indirect than direct associations. A main effect of repetition also appeared (F(1,42)=14.1, p=.001, ηP^2=.25) where repeated events exhibited stronger dependency than single events. Both dependency analysis and repetition also had an interaction (F(1,42)=16.1, p<.001, ηP^2=.28), which, as affirmed by a paired samples t-test, presented that in open-loop events, the extent to which dependency across indirect pairs was larger than that across direct pairs widened when events were repeated. These results, taken together, posited that indirect pairs were more dependent on each other in an open-loop event than direct pairs.

6.2.4 Dependency of Indirect Associations on Direct Linking Associations

Successful retrieval of indirect associations was thought to rely on retrieving the two linking direct associations that aided associative inference – in particular, between the retrieval of AC and that of AB and BC, and the retrieval of BD and that of BC and CD (see **Fig. 9d**). A one-way ANOVA indicated no main effect of repetition (F(1,42)=2.76, p=.10), and open-loop events regardless of repetition showed dependency during retrieval in a one-sample t-test (t(42)=8.37, p<.001, *d*=1.28). Hence, retrieval success of inferred associations depended on the successful retrieval of direct linking pairs required to form an inference.

I next addressed the relatedness in accuracy between indirect associations and their encoded linking associations across open-loop events. Accuracy scores for indirect pairs and the product of scores for the relevant linking associations were correlated for each participant (see **Fig. 9g**). After being subjected to one-sample t-tests, Fisher’s Z-transformed *r* values were found to be greater than zero for both single (mean *r*=.43; t(34)=8.15, p<.001, *d*=1.38) and repeated open-loop events (mean *r*=-.63; t(34)=11.0, p<.001, *d*=1.86). However, the transformed correlation coefficients were significantly higher when events were repeatedly encountered based on a paired samples t-test (t(29)=-5.17, p<.001, *d*=-0.94). An association was consequently determined between the retrieval of inferred associations and the retrieval of direct linking associations across events – a result also reported in Experiment 3 (see Chapter 5 – Results) – but prone to facilitation by repetition, unlike what Experiment 3 found.

6.2.5 Dependency of Indirect Associations on Direct Non-Linking Associations

Indirect associations were then examined on their dependency in retrieval success on within-event direct non-linking associations, which were pairwise associates not likely to promote inference (see **Fig. 9e**). In other words, the retrieval dependency of the indirect AC pair on correctly retrieving the direct pair CD was assessed, along with the dependency of the indirect BD pair on correctly retrieving the direct pair AB. No effect of repetition was seen in a one-way ANOVA (F(1,42)=1.90, p=.18) and a one-sample t-test revealed no dependency in the data (t(42)=.12, p=.91), suggesting that no dependency existed between indirect associations and direct non-linking associations.

After testing for dependency of successful retrievals of inferred associations on retrieving direct non-linking associations, I explored any difference between this dependency and dependency on direct linking associations. Per a 2X2 ANOVA (linking versus non-linking analysis x repetition), a main effect of dependency analysis was demonstrated (F(1,42)=88.5, p<.001, ηP^2=.68) which was down to stronger dependency that indirect pairs had on direct linking pairs than on direct non-linking associations. The effect of repetition approached significance (F(1,42)=3.97, p=.053, ηP^2=.09) where dependency improved when events were learned repeatedly, though no interaction with dependency analysis was detected (F(1,42)=0.25, p=.62). Thus, retrieving indirect pairs was statistically linked to the recollection of direct linking pairs from the same event, more so than on direct non-linking pairs.

The relationship between accurate retrievals of inferred associations and those of non-linking associations was then inspected across events. Following a

Pearson correlation between the two (see **Fig. 9g**) for every participant, *r* values that were Fisher's Z-transformed did not diverge from zero for both single (mean *r*=.001; t(41)=-0.0003, p>0.99) and repeated loops (mean *r*=.01; t(37)=0.16, p=.87) as reported by one-sample t-tests. A paired samples t-test contrasting the two repetition conditions also saw that there was no difference between their transformed *r* values (t(37)=-.13, p=.90). As a result, I did not distinguish any correlation that an inference had with performance on corresponding direct non-linking pairs across events, and repetition could not change the relationship.

6.2.6 Dependency of Indirect Association AD on All Linking Direct Associations

Next, dependency in retrieval success of the indirect association AD on all encoded associations in the chain of overlapping pairs that potentially comprised the inference (i.e. AB-BC-CD, see **Fig. 1b** for an illustration of event structure) was verified (see **Fig. 9f**). Repetition produced a main effect based on a one-way ANOVA (F(1,42)=7.83, p=.01, ηP^2=.16), accounted for by higher dependency in repeated than in singly encoded loops. A one-sample t-test also noted dependency in open events, repeated or not (t(42)=9.47, p<.001, *d*=1.44), indicating that retrieving the indirect association AD was reliant on the retrieval of all direct linking pairs, and such dependency built up with repetition.

To identify any difference between dependency of indirect association AD on all linking direct associations with dependency of indirect associations AC and BD on their corresponding direct linking associations (direct associations AB and BC for indirect association AC, direct associations BC and CD for indirect association BD), a 2X2 repeated measures ANOVA (AC and BD versus AD analysis x repetition) was conducted. A significant effect of dependency analysis was described (F(1,42)=28.2,

$p<.001$, $\eta P^2=.40$), whereby dependency of indirect pairs on linking direct pairs was greater than dependency of AD on all direct linking pairs, together with a significant effect of repetition ($F(1,42)=5.83$, $p=.02$, $\eta P^2=.12$) that favoured repeated events. Nevertheless, the interaction between type of dependency analysis and repetition was non-significant ($F(1,42)=1.36$, $p=.25$). These results were in accordance with better performance averaged across indirect pairs AC and BD than for indirect pair AD, and higher accuracy for repeated stimuli compared to singly presented stimuli (see **Fig. 6b**).

In further analyses on the connection between retrieval performance of AD and the accuracy of all direct linking associations across events, a Pearson correlation was conducted between accuracy scores for AD and the product of accuracy scores for AB, BC and CD across open-loop events (see **Fig. 9g**). Like in Experiment 3 (see **Fig. 7g**), one-sample t-tests were run on the resulting Fisher's Z-transformed correlation coefficients which were seen to significantly exceed zero for both single (mean $r=.43$; $t(21)=4.66$, $p<.001$, $d=0.99$) and repeatedly learned events (mean $r=.67$; $t(26)=9.11$, $p<.001$, $d=1.75$). However, as opposed to the same experiment, a paired samples t-test demonstrated that the Z-transformed r values were boosted by encoding repetition ($t(13)=-2.68$, $p=.02$, $d=-0.72$). These results established that retrieval success of AD was correlated with that of the whole sequential AB-BC-CD chain across events, and this relation could be enhanced by repetitive exposure.

6.3 Summary

As demonstrated, the empirical conclusions reported in my previous experiments (Experiments 1-3; see Chapters 2, 3, 5 respectively) were replicated by a canonical computational model of hippocampal memory function. Dependency was significant among retrievals of directly encoded associations from the same closed-loop event but not when they were from an open-loop event, supporting the findings in Experiments 1, 2 and 3. (Although dependency in closed loops was only nearly significant in Experiment 2, i.e. p=.07, it was not statistically different from that in Experiments 1, see Chapter 4 – Results, and 3, see Chapter 5 – Summary, where it was indeed significant.) Additionally, strong retrieval interdependency appeared between inferred pairs from an open-loop event, which was mediated by dependence on direct linking associations but not direct non-linking associations. This specific finding was corroborated by a significant correlation between inference accuracy and performance of respective encoded linking associations, where repetitive presentation constructively enhanced the relationship. Furthermore, indirect pairs from an open-loop event were seen to be more dependent on each other than within-event direct pairs were, consistent with Experiments 2 and 3 but not Experiment 1. Dependency of indirect pairs AC and BD on their relevant direct linking pairs was also greater than that of indirect pair AD on all direct pairs, echoing results from Experiment 3, but this difference was shown by the model to enlarge with repetition unlike in Experiment 3. I also indicated that repetition in encoding improved participants’ accuracy on direct and indirect associations – as in Experiment 3 – and similarly for dependency across indirect associations on each other, dependency of indirect pair AD on all direct associations, and the difference between them – contrary to Experiment 3.

In summary, the primary findings from my experiments can be justified by a pattern completion mechanism of recollection which was sustained by an auto-associative neural network as proposed by my model simulations. The neural network also reported advantageous effects of encoding repetition on some aspects of dependency, contradicting the non-significant effects shown in behavioural data, but that would be subject to further examination in future studies (see Chapter 10 – Repeated presentation weakens dependency if repetition is massed). Considering that the model succeeded in reproducing the crucial dependency trends noted in all my experiments so far, the experimental data thus complemented contemporary hippocampal models of memory function.

7 Experiment 4: Effects of Massed Repetition of Overlapping Associations on Recollection

As reported in my third experiment (see Chapter 5), repetitive learning of associations facilitated memory for observed and inferred associations but exerted a negligible effect on retrieval dependency for either type of associations. In the experiment, encoding repetition occurred in a distributed manner, meaning that for a specific repeated event, all associations were shown once every session, resulting in three repetitions after all three encoding sessions were conducted. It was possible, however, that some of the repetition effects had consequently worn off over the long interval between two presentations of an association, hence failing in altering dependency. I therefore intended to probe whether displaying each pairwise associate three times within one session (whereby associations in an event were allotted different sessions) would have a more compelling impact on dependency.

The current experiment took on the protocol in Experiment 3 but with a few changes. Besides varying repetition-related parameters in this experiment, only directly seen associations were tested and not associative inference since my focus was to identify the primary influence of repetition on memory and dependency. Participants were asked to rate their confidence as well when responding to test trials since metacognitive awareness, which is reflected through confidence decisions (Brewer and Wells, 2006; Metcalfe, 2000; Johnson, 2006), was also of interest. Additionally, Experiment 4 presented equal amounts of single and repeated events unlike Experiment 3 which had more repeated events than single events (see Chapter 5 – Method). Pilot testing in Experiment 3, where the proportion of repeated events was the same as that of single events, saw very high accuracy scores for the repeated condition, compelling the actual experiment to increase the percentage of repeated events to 60% so as to enhance their difficulty and thus deflate their accuracy rates. Experiment 4 faced no such issue when the ratio of non-repeated to repeated events was balanced and so this arrangement was maintained. To further emulate prior works that used a similar experimental design sans repetition (Horner and Burgess, 2014; Horner et al., 2015), the intertrial interval was lengthened from 0.5s to 1.5s.

7.1 Method

7.1.1 Participants

Thirty-four healthy, English-speaking volunteers from the university student population gave informed consent to participate. All participants were included in memory accuracy and confidence analyses but data from only 32 were evaluated in dependency analyses (17 female, mean age = 25, age range 18–40) after removing two participants who scored above 95% accuracy for direct pairs across all conditions. An approximate sample size needed for Experiment 4 (estimated *N* range = 8–47; power = 0.80, $\alpha = .05$) was obtained from a power analysis based on effect sizes reported in Experiment 3 (see Chapter 5 – Results; ηP^2 range = .15–.40, *N* range = 8–24). Seeing that the maximum sample size estimated was 24, my sample size of 32 would more than suffice.

7.1.2 Materials

The stimuli used were as the ones in Experiment 3 (see Chapter 5 – Method, **Figs. 1a**, **1b**) with several exceptions. Forty-eight multimodal events were generated for each closed- and open-loop condition, but half of them were repeated and the other half were not. Overall, 12 events were formed for every condition – closed-loop single presentation (single closed), closed-loop repeated presentation (repeated closed), open-loop single presentation (single open) and open-loop repeated presentation (repeated open).

7.1.3 Procedure

The study procedure was the same as that in Experiment 3 (see Chapter 5 – Method, **Figs. 1c**, **1d**) except that every repeated event would have a pairwise associate displayed once in all three blocks of one session, followed by another association in the three blocks of the next session, and then the same for the third association. Each single presentation event was randomly allocated to a session and each of the three associations from the event was assigned to one of the three blocks in that session. For instance, a repeated closed-loop event ABC might have AB presented in every block of session 1, BC in every block of session 2, and AC in every block of session 3, whereas a single closed-loop event ABC might be presented in session 3 and AB presented in block 1, BC in block 2, and AC in block 3 of the session. The presentation order for the associations within an event, single or repeated (e.g. AB first, then AC, then BC) was random.

There was also only one test phase, which comprised of trials on direct associations only (see **Fig. 1a**). I asked participants ensuing each test trial to also indicate their confidence in their response on a 1-4 scale, 1 being least confident and 4 being most confident. A trial started with a 0.5s fixation cross and then cue presentation and response for 6s, followed by a 0.5s blank and another 6s for confidence judgment before a 1.5s blank screen at the end.

7.1.4 Associative Accuracy Analysis

Associative accuracy was analysed the same way as in Experiment 3 (see Chapter 5 – Method).

7.1.5 Confidence Analysis

Participants' subjective confidence in the accuracy of their response, based on a 1-4 rating scale where 1 was lowest and 4 was highest, was first expressed as a proportion of the maximum rating attainable by dividing each score by four. The resulting judgements were within a 0-1 range. Confidence scores in single closed, repeated closed, single open and repeated open loop events were obtained, and scores specifically for accurate retrievals in the four conditions were then put to repeated measures ANOVAs and paired samples t-tests for comparison between conditions.

To discern the relationship between confidence and memory accuracy, I performed correlations using a within-subject approach, which is also known as resolution. The analysis focused on whether metamemory accuracy matched actual accuracy, that is, whether responses made by each participant with greater certainty were more likely to be correct than those made less convincingly. Within every participant and for each condition, Goodman-Kruskal correlation, also known as gamma correlation (Nelson, 1984), was run between confidence scores and performance. A gamma correlation was obtained from two-by-two contingency tables of accuracy (accurate versus inaccurate) and confidence (high versus low confidence). In this case, high confidence referred to scores above 0.5, and low confidence referred to scores equal to or below 0.5. Null values across a whole row or column would lead to an undefined gamma (γ), so to solve this issue, any row or column in a contingency table with solely zeroes was replaced with 0.001 in both its cells. Then, a Fisher's Z-transformation was enacted on the resulting γ values to improve their normality, which were then consigned to a one-sample t-test. γ coefficients that were 1 or -1, illustrating a perfect correlation, would be undefined upon a Fisher's Z-transformation, so to retain the data, the γ values were instead represented as 0.999 or -0.999 respectively. Repeated measures ANOVAs and paired samples t-tests were also administered to study any difference in confidence-accuracy correlation among loop type and repetition conditions.

I also carried out between-subject correlations on confidence and memory accuracy for each condition to determine whether participants who were more self-assured also performed better in the memory task than participants who were less so. Because analyses within and across participants are conceptually distinct – across-subject correlations compare confident with less confident individuals in terms of performance while within-subject correlations compare each individual's accurate responses with their inaccurate responses in terms of confidence – both might sometimes not align. For between-subject analyses, Pearson correlations between confidence values and performance across participants and in all trials were conducted and the correlation coefficient *r* values were put to one-sample t-tests to ascertain if confidence significantly fluctuated with memory accuracy for encoded associations.

7.1.6 Dependency Analysis

Dependency was evaluated as it was in Experiment 3 (see Chapter 5 – Method). Following Shapiro-Wilk tests of normality, data distributions of all Ddata minus Di analyses were described as Gaussian, but a log transformation was still needed to standardise dependency comparisons with other experiments so far in this thesis in which dependency was transformed (Experiments 1-3; see Chapters 2, 3, 5 – Method).

7.2 Results

7.2.1 Associative Accuracy

Memory for direct associations was considered with respect to loop type and number of times shown (see **Fig. 10a**). I ran a 2X2 ANOVA (closed versus open x single versus repeated) that disclosed a main effect of loop type (F(1,33)=26.9, p<.001, ηP^2=.45), induced by participants remembering closed loops better than open loops. The effect of repeated presentation was also significant (F(1,33)=41.3, p<.001, ηP^2=.56) where more frequent exposure improved performance. Nevertheless, there was no interaction between the two factors (F(1,33)=0.88, p=.36).

7.2.2 Confidence

As with associative accuracy, I derived mean confidence scores for single closed, single open, repeated closed and repeated open loop events. Proportions of responses based on their accuracy and confidence level were compiled (see **Table 2**), where a response was classified as one of high confidence (‘sure’) if its confidence rating was 0.5 or more and as one of low confidence (‘not sure’) if it was below 0.5. Since the confidence scores were expressed as a proportion out of the maximum rating possible, i.e. 4, responses that indicated 1 or 2 on the confidence scale were low confidence answers whilst a 3 or 4 on the scale demonstrated high confidence.

To see if confidence during correct retrievals varied with encoding frequency and associative structure of events (see **Fig. 10b**), a 2X2 ANOVA (loop type x

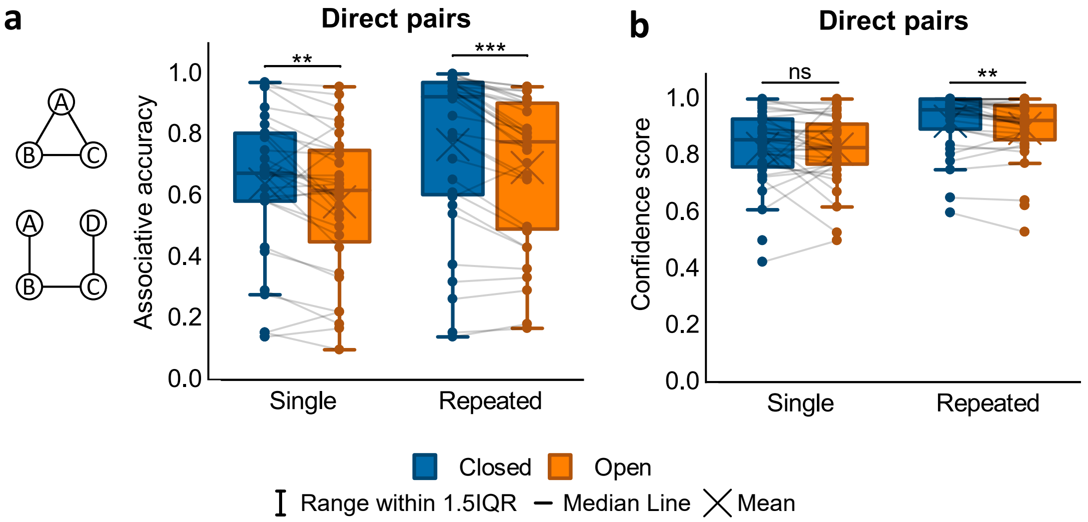

Figure 10. Associative accuracy results for Experiment 4. (**a**) Proportion correct retrievals in single and repeated events for direct pairs in closed and open loops. (**b**) Confidence scores for correct retrievals in single and repeated events for direct pairs in closed and open loops. ***p < .001; **p < .01; ns not significant. *N*=25 for **a**-**b**.

repetition) was performed. Confidence in closed- and open-loop events showed no difference (F(1,32)=2.44, p=.13) but repetition had a main effect (F(1,32)=60.0, p<.001, ηP^2=.65) which increased confidence. Loop configuration also had no interaction with repetition (F(1,32)=0.05, p=.82).

Confidence reports were then compared with memory performance using gamma correlations for within-subject methods (see **Table 3**). Within participants, responding to trials testing single closed-loop events yielded confidence that was proportional to actual performance (t(33)=6.35, p<.001, *d*=1.09), and I found a similar result for repeated closed-loop events (t(33)=7.93, p<.001, *d*=1.36). Subjective confidence also related to accuracy in the single open (t(33)=9.32, p<.001, *d*=1.18) and repeated open conditions (t(33)=12.0, p<.001, *d*=1.12). A 2X2 ANOVA (loop type x repetition) was then conducted to compare confidence's association with accuracy across conditions. While loop structure did not show an effect

Table 2. Confidence results for Experiment 4.

Test on direct associations

Repetition condition	**Loop type**	**Confidence**	**Accuracy & Confidence**			
		Sure	**Correct, sure**	**Correct, not sure**	**Incorrect, sure**	**Incorrect, not sure**
Single	Closed	.73 (.16)	.54 (.27)	.13 (.08)	.07 (.09)	.26 (.21)
	Open	.69 (.14)	.48 (.26)	.12 (.08)	.08 (.12)	.32 (.20)
Repeated	Closed	.85 (.16)	.73 (.32)	.05 (.06)	.06 (.09)	.16 (.22)
	Open	.80 (.16)	.65 (.28)	.06 (.05)	.06 (.09)	.23 (.21)

Mean proportion (and standard deviation) of confident responses (regardless of accuracy; ‘Sure’) and breakdown of responses based on accuracy (Correct, Incorrect) and confidence (Sure, Not Sure) for single closed, single open, repeated closed and repeated open events. Number of trials analysed might differ from number of presented trials for each pair type as some trials might be omitted due to invalid response (e.g. wrong keyboard press).

(F(1,33)=0.95, p=.34), repetition did (F(1,33)=7.37, p=.01, ηP^2=.18) by enhancing confidence ratings, though the interaction between loop structure and repetition was not significant (F(1,33)=0.40, p=.53).

Confidence analysis across subjects was also performed using Pearson correlations (see **Table 3**). A significant positive confidence-accuracy relation was found in single closed (*r*=.87, n=34, p<.001), single open (*r*=.76, n=34, p<.001), repeated closed (*r*=.94, n=34, p<.001) and repeated open loops (*r*=.91, n=34, p<.001), conforming with within-subject results.

Table 3. Correlations between confidence and accuracy for Experiment 4.

Test on direct associations			
Repetition condition	**Loop type**	**Within subjects (z-transformed γ)**	**Between subjects (*r*)**
Single	Closed	1.57^{***} (1.44)	$.87^{***}$
	Open	1.90^{***} (1.19)	$.76^{***}$
Repeated	Closed	2.23^{***} (1.64)	$.94^{***}$
	Open	2.31^{***} (1.12)	$.91^{***}$

Pearson correlations and mean gamma correlations (with standard deviation), performed for each type of test pair within the test phase as well as for Overlap and Unique events. * within a column reflects a significant difference from zero. ***p < .001. *N*=34.

7.2.3 Dependency Across Direct Associations

I afterwards assessed how retrievals of direct associations from the same closed-loop or open-loop event depended on each other, and how their dependency was affected by repeated presentation (see **Figs. 11a**, **11b**). While a 2X2 ANOVA (loop type x repetition) demonstrated a main effect of associative structure (F(1,31)=6.15, p=.02, ηP^{2}=.17) that accounted for greater dependency in closed-loop events than in open-loop ones, repetition had no effect (F(1,31)=1.47, p=.24) and loop type x repetition interaction was significant (F(1,31)=4.60, p=.04, ηP^{2}=.13). The interaction was then investigated using paired samples t-tests. For singly presented events, retrievals of associations in closed loops had significantly larger dependency than retrievals of associations in open loops (t(31)=3.20, p=.003, *d*=0.56) whereas for repeated events, retrieval dependency in closed loops did not differ from that in open loops (t(31)=0.33, p=.74). Moreover, based on one sample t-tests, closed loops

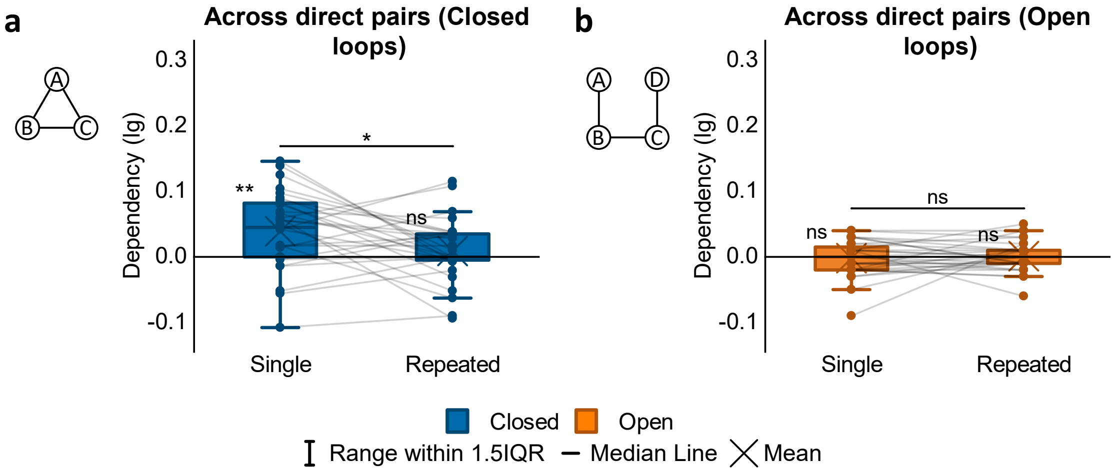

Figure 11. Dependency results for Experiment 4. (**a**) Dependency of direct pairs on other direct pairs from the same event for single closed and repeated closed loops, log-transformed. (**b**) Dependency of direct pairs on other direct pairs from the same event for single open and repeated open loops, log-transformed. **p < .01; *p < .05; ns not significant. *N*=32 for **a**-**b**.

possessed significant retrieval dependency (t(31)=4.20, p<.001, *d*=0.76) but not open loops (t(31)=1.34, p=.19). Therefore, when associations were learned once, dependency in closed-loop events was higher than that in open-loop events, but it reduced with repetition to the same non-significant level as in open-loop events. Meanwhile, dependency in open-loop events was unaffected by repetition.

7.3 Summary

The influence that repetitive encoding of events had on dependency, missing in Experiment 3 (see Chapter 5), was more perceptible when repetition of each association took place within a more condensed time frame rather than spaced throughout the retrieval phase. Data from this experiment as well as Experiment 3 revealed that associative accuracy became stronger when associations were repeatedly exposed. However, Experiment 3 described no influence of repetition on dependency whereas Experiment 4 did – specifically, statistical dependency across retrievals of direct associations waned to non-significant levels in closed-loop events. In terms of dependency between closed- and open-loop structures, all my experiments so far (Experiments 1-3; see Chapters 2, 3, 5 respectively) as well as my hippocampal model consistently projected dependency to achieve significance in closed loops but not in open loops (dependency in closed loops was almost significant in Experiment 2 at p=.07 but was not significantly different from that in Experiments 1, see Chapter 4 – Results, and 3, see Chapter 5 – Summary, both of which showed it to be significant). However, when associations were each repeated within a session during encoding, dependency in closed-loop events became absent as it was in open-loop events. Repeatedly observing pairwise associates within a closed-loop event had made their retrievals independent enough such that they no longer hinged upon one another. On the other hand, recollection of repeated associations within an open-loop event remained as independent as it was when they were viewed just once.

Confidence-wise, subjective judgements during correct retrievals were boosted by repetition in both closed-loop and open-loop events but were indifferent across loop type although memory was better for closed-loop events. Within participants, confidence was correlated with accuracy in all events irrespective of loop type and repetition, and this relationship was unaffected by loop type but enhanced with repetition. Confident subjects also remembered trained direct associations from any event better than less certain subjects. The dependable confidence-accuracy relationship seen within and across participants in all events supports previous literature on how sense of belief in a memory's validity coincides well with the memory's actual credibility (Brewer and Wells, 2006; Deffenbacher, 1980; DeSoto and Roediger, 2014; Roediger and DeSoto, 2014; Brewer and Sampaio, 2006; Rimmele et al., 2012; Nguyen et al., 2018).

In summary, information appeared to be recorded and recollected altogether in a singular associative network, as supported by Experiments 1, 2 and 3 as well as my neurocomputational model (see Chapter 6). Associative memory processes benefited from multiple encoding but integration of diverse associations into a sole representation suffered when associations were encountered several times within the same period of learning. Retrieval dependency among the associations, however, remained unperturbed when events which did not exhibit it in the first place (i.e. open loops) were encountered several times within the session. These repetition-related changes to dependency only materialised when each association was repeated compactly within a session and not when repetition spanned several sessions (as in Experiment 3). Conscious monitoring of encoded associations was equally applied to closed and open loops and permitted confidence levels in both loop types to match memory accuracy. Although metacognitive awareness is linked to pattern completion and pattern completion here implicated closed-loop events alone, participants appeared to be cognitively aware of associations equally from both closed- and open-loop events. Repeatedly learning associations also improved confidence's ability to calibrate with performance.

8 Experiment 5: Retrieval of False Memories Caused by Overlapping Multielement Events

Throughout my experiments so far (Experiments 1-4; see Chapters 2, 3, 5, 7 respectively) and as demonstrated by my computational model (see Chapter 6), pattern completion has been shown to operate the retrieval of associations in fully encoded episodic events as well as associative inference in fractionally attended events. Successful inference, nevertheless, may lead to the mistaken affirmation of inferred material as a real event; indeed, recombination processes determining accurate inferential decisions (Schacter and Addis, 2007a, 2007b) have been said to also ironically result in the flawed recognition of the same inferences as actual observations (Carpenter and Schacter, 2017, 2018). Although these false memories recruit inferential reasoning as inferences do, further differences in their retrieval mechanisms might exist, and one way they could be investigated is by repeatedly testing the two forms of memory. Additionally, since modality affects neural processing (Paivio and Csapo, 1971; Rajaram, 1996; Bright et al., 2004), learning word associates may yield different memory test results from viewing scenes (Jenkins et al., 1967; Bonin et al., 2014) which would be closer to real-life memory acquisition. The simultaneous encoding of all associations from the same event instead of their sequential presentation also better resembles learning in the real world and demonstrates within-event dependency (Horner and Burgess, 2014). Bearing these factors in mind, I explored in this experiment the possibility of erroneously accepting inferences as legitimate events as well as encoding events in their entirety as pictures instead of word stimuli. Inferences and false memories merged from overlapping events were also tested repeatedly to see how their retrieval varied with repetition in order to derive if they engaged the same retrieval processes. Confidence was also measured during test to study metamemory processes and cognitive awareness in encoded, inferred and illusory memories as well as how well metamemory accuracy calibrates with performance for these types of memory.

8.1 Method

8.1.1 Participants

Twenty-six healthy volunteers were enlisted from the Stanford student subject pool to take part in the experiment. Data from 25 of them were used for associative memory, performance correlation and dependency analyses (16 female, mean age = 23, age range 18-32) after data obtained from one of the participants was incomplete. I deduced a sample size for this study (estimated *N* range = 13–30; power = 0.80, α = .05) from a power analysis on effect sizes quoted in an earlier study where all associations in an event were displayed as words and simultaneously (Horner and Burgess, 2013; ηP^2 range = 0.20–0.28; *N* = 25). My current sample size of 25 exceeded the median approximated sample size of 21.5.

8.1.2 Materials

Forty-two elements in each location, famous person and everyday object category were allocated randomly to 48 ‘events’, each composed of a person and an object superimposed onto a location (see **Figs. 12a**, **12b**). Thirty-six of the events were overlapping (‘Overlap’; ABC; see **Fig. 12a**) where one event shared an element (place, person or object; C) with a second event (DEC; see **Fig. 12a**), yielding 18 pairs of overlapping events. The remaining twelve events did not overlap with any other

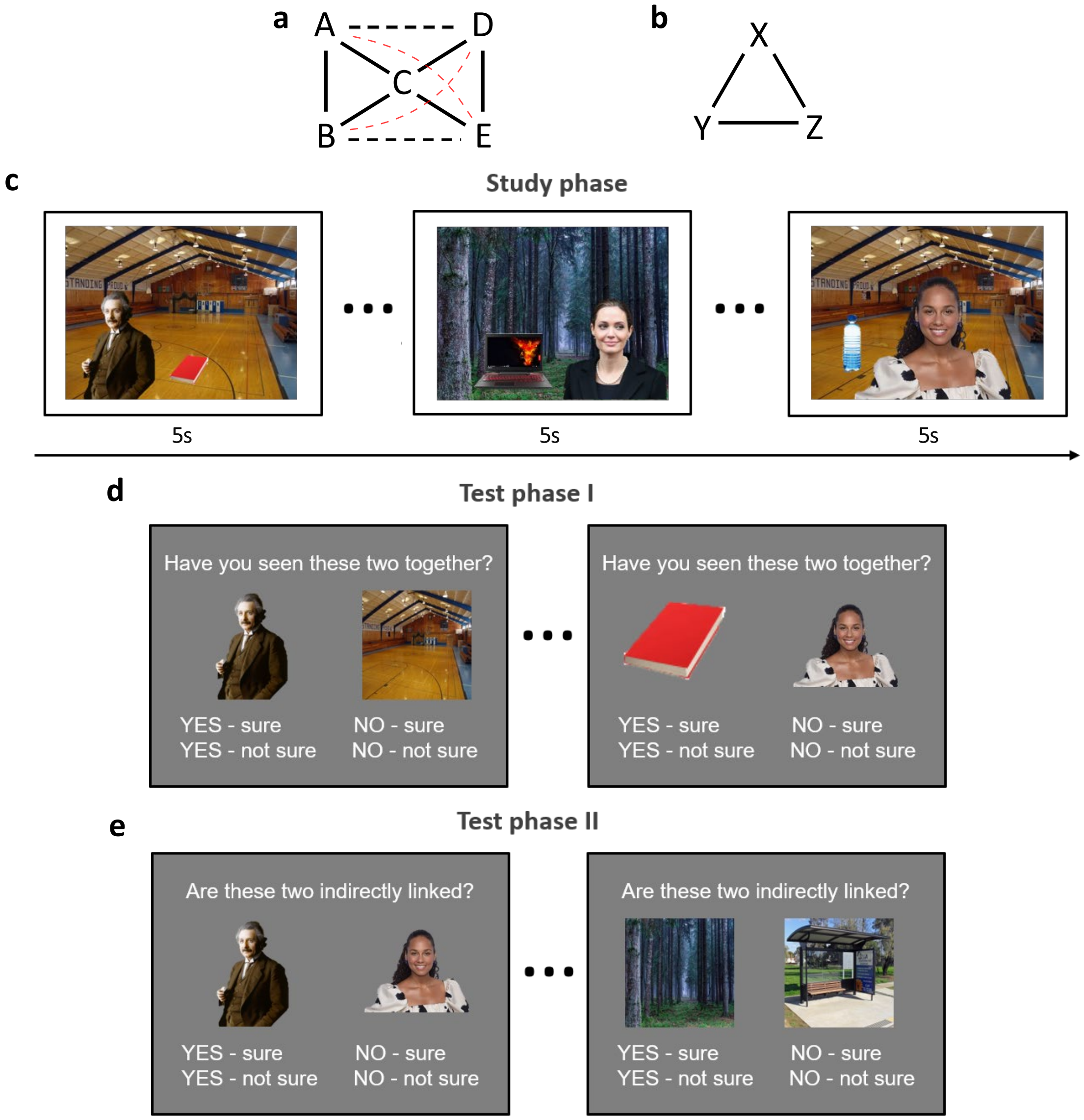

Figure 12. Design for Experiment 5. (**a**) Associative structure of a pair of overlapping events ABC and DEC, with C as the common element. Three quarters of events (36 out of 48) formed 18 pairs of overlapping events, split equally in terms of the shared element – Person Overlap, Location Overlap and Object Overlap. Black solid lines indicate trained direct pairs tested in test phase I (see (**d**)), red broken lines indicate pairs containing elements from overlapping events and potentially acting as false memories, tested in test phase I (see (**d**)), and black broken lines indicate indirect pairs connected via trained pairs tested in test phase II (see (**e**)). (**b**) Associative structure of the unique XYZ events. A quarter of events (12 out of 48) did not overlap with any other event. (**c**) Study phase, showing the first and third events as a pair of Location Overlap events. (**d**) Test phase I. The left trial shows a direct pair and the right trial shows a potential false memory from overlapping events. (**e**)

Test phase II. The left trial shows an indirectly associated pair of elements from overlapping events, the right trial shows a pair of elements from unrelated events.

event (‘Unique’; XYZ; see **Fig. 12b**). The structure of an overlapping pair of events is referred to as ABC-DEC, where C is the common element. I equally divided overlapping event pairs according to the type of element they had in common – ‘Location Overlap’, ‘Person Overlap’, ‘Object Overlap’ – with six event pairs in each overlap condition.

8.1.3 Procedure

Participants were instructed to ‘imagine the scene occurring in front of them as vividly as possible’ as they viewed a series of events for 5s each, separated from one another by a 0.5s blank and randomly ordered over three encoding blocks (see **Fig. 12c**). Immediately after, a self-paced recognition task was conducted where volunteers had to indicate if a pair of elements (of different types, e.g. person-place) presented on the screen had appeared together in the earlier phase and how confident they were in their response (see **Fig. 12d**). Elements in a pair belonged to either the same observed event (‘direct’ pairs, e.g. AB, XY; see **Figs. 12a**, **12b**), distinct unrelated events (foil ‘unrelated’ pairs, e.g. A_1B_2 where A_1 and B_2 were from different ABC events) or events that overlapped each other (‘false memory’ pairs, i.e. AE, BD; see **Fig. 12a**). For unrelated pairs, each element from an event was paired randomly with an element of a different type (e.g. person-place) from an unrelated event, with both events being of the same condition as with the case for direct and false memory pairs (e.g. for unrelated pairs in Person Overlap condition, both elements came from Person Overlap events). Every event generated three direct pairs and six unrelated pairs (each of the three elements paired with two other element types from nonrelated events), and each pair of overlapping events additionally gave rise to two false memory pairs (AE, BD). While direct and unrelated pairs were tested once, false memory pairs were tested twice to study any change in performance and dependency when they were retrieved one more time, allowing me to study the retrieval mechanisms for the false memories more clearly. In total, there were 144 direct pairs, 288 unrelated pairs and 72 potential false memory pairs (testing the overall 36 false memory pairs twice) in this test phase.

It was only subsequently that I told participants of a second test phase (see **Fig. 12e**) which examined memory for inferred 'indirect' associations (AD, BE; see **Fig. 12a**), composed of elements from events that overlapped each other, in an analogous procedure as the first test phase (see **Fig. 12c**). Unlike test phase I in which false memories were incorrect responses mistaking two elements of different types (e.g. person-place) from overlapping events as having been part of the same event, in test phase II participants were explicitly asked whether elements in a pair were from events that overlapped one another, and the pairs of elements used were of the same type (e.g. person-person) which could not have been in the same event as all events contained a single person, object and place. In this test phase, some trials featured indirect pairs while others showed unrelated pairs where the two elements came from randomly chosen unrelated events (both of which might be unique or might overlap with another event). As with unrelated pairs in test phase I, unrelated pairs in test phase II each consisted of events that were both from the same condition (e.g. unrelated pairs in Unique condition involved Unique events only). Two indirect pairs (AD, BE) and five unrelated pairs (each of the five elements paired with the same element type from nonrelated events) were produced by each pair of overlapping events while three unrelated pairs (each of the three elements paired with the same element type from nonrelated events) were generated by each unique event. To assess the effect of repetitive retrieval on accuracy and dependency for inferences so as to further define the nature of their retrieval, every indirect association was tested two times. This is contrary to unrelated associations which were tested once, resulting in 72 indirect pairs (testing 36 indirect associations twice) and 126 unrelated pairs in test phase II overall.

In both test phases, each trial began with a 0.5s fixation cross and terminated with a 0.5 blank. Presentation order for trials in both test sessions was random. While the first test allowed implicit interference between overlapping events to cause incorrect responses (false memories), consistent with the implicit nature of false memories, the second test explicitly asked participants to infer the indirect links between elements although the inferential process may not always be licensed in real-life situations (see Chapter 10 – Inference in experiments versus in real life).

8.1.4 Associative Accuracy Analysis

Participants' performance on direct, inferred and false associations was noted. While direct and false associations of elements from nonrelated events were queried once, inferred and false memory associations were tested two times to investigate their retrieval operations further and ascertain more differences between them. In general, performance analyses only included the first tests for associations that were tested twice, i.e. false memory and indirect associations, unless the second tests were of interest, as it would be more accurate to examine participants' first response to the associations in studying their memory. When associations that were tested once, i.e. direct pairs and unrelated pairs in test phases I and II were analysed, only test trials that were presented around the same time as the first tests for indirect or false memory associations within the respective test phase would be considered. However, when second tests for indirect or false memory associations were examined, only test trials that were presented around the same time as the second tests within the respective test phase would be considered. This is because the random arrangement of test trials had caused the first test trials of false memory and indirect pairs to likely be in the first half of a test phase and the second test trials in the second half, while test trials for the direct and unrelated pairs were spread out across the session. This disparity in interval between learning and retrieval should be eliminated as associations that were tested later than others could be forgotten more easily. A test trial is said to have been shown about the same time as false memory or indirect pairs were in a test phase if its trial order was between 1, which is the start of the test phase, and twice the mean trial position for the first tests of the false memory or indirect pairs. For example, if the average test trial position for first-tested false memory pairs is 130 out of 504 trials in test phase I, then a direct pair with a trial position between 1 and 260 would be deemed as having been seen at the same time as the first-shown false memory pairs were on average. Because order of test trials was different for every participant, participants differed in terms of mean trial position for false memory pairs and indirect pairs and thus had variable numbers of unrelated pairs selected for analysis.

I analysed data from test phase I for two types of memory – associative memory for direct associations, indicated by correct recognition of pairs of elements from the same event compared to false alarms (FAs) for pairs of elements from unrelated events (see **Figs. 12a**, **12b**), and 'false memory', indicated by incorrect recognition (FAs) of pairs of elements from overlapping events as pairs from the same event compared to FAs for pairs of elements from unrelated events (e.g. false memory pair AE compared to unrelated pair A_1B_1; see **Fig. 12a**). Data from test phase II was analysed for explicit memory for indirect associations, indicated by correct recognition of pairs of elements of the same type from overlapping events (e.g. AD; see **Fig. 12a**) compared to FAs for pairs of elements from unrelated events (e.g. A_1B_1; see **Fig. 12a**).

Participants' yes/no answers to the question of whether a pair of elements had been from the same event (asked in the first test phase) or were from events that overlapped one another (asked in the second) were merged across both confidence grades ('sure', 'not sure'; see **Figs. 12c**, **12d**) and classified into four groups – 'hits' which are the proportion of correct 'yes' responses, FAs which are the proportion of incorrect 'yes' responses, 'correct rejections (CRs)' which are the proportion of correct 'no' responses, and 'misses' which are the proportion of incorrect 'no' responses. In test phase I, correct recognition of a direct pair is a hit, incorrect dismissal of it is a miss, correct dismissal of a false memory or unrelated pair is a CR, and incorrect recognition of it is an FA. In test phase II, correct recognition of an indirect pair is a hit, incorrect dismissal of it is a miss, correct dismissal of an unrelated pair is a CR, and incorrect recognition of it is an FA.

Hits and FAs in each test phase were singled out to calculate d' (d-prime) or sensitivity index, which is the difference in standard deviation units between the means of Signal Present and Signal Absent distributions. d' assesses how well participants discern between old (i.e. presented) and new (i.e. non-presented) associations taking into account response bias (the inclination to answer ‘yes’ whatever the test pair was). d’ was computed for direct associations (as the difference between the z-transformed proportion of hits for pairs from the same event and the z-transformed proportion of FAs for pairs from unrelated events in test phase I; see **Equation 5**), false memory associations (difference between z-transformed proportion of FAs for pairs from overlapping events and z-transformed proportion of FAs for pairs from unrelated events in test phase I; see **Equation 6**) and indirect associations (difference between z-transformed proportion of hits for pairs from overlapping events and z-transformed proportion of FAs for pairs from unrelated events in test phase II; see **Equation 7**). The z-transformation is the inverse of the standard normal cumulative distribution, and since the inverse cumulative distribution of 1 or 0 could not be calculated, the proportions used in the d’ equations were adjusted to allow for Hit and FA rates that were 1 or 0 by adding 0.5 to the number of responses and 1 to the number of trials (see **Equations 5**, **6**, **7**).

$$d'_{direct} = z\left(\frac{nHits_{direct\ pair} + 0.5}{n\mathrm{Trials}_{direct\ pair} + 1}\right) - z\left(\frac{nFAs_{unrelated\ pair} + 0.5}{n\mathrm{Trials}_{unrelated\ pair} + 1}\right)$$

Equation 5. d’ for direct associations in Experiment 5, involving direct and unrelated pairs in test phase I.

$$d'_{false\ memory} = z\left(\frac{nFAs_{false\ memory\ pair} + 0.5}{n\mathrm{Trials}_{false\ memory\ pair} + 1}\right) - z\left(\frac{nFAs_{unrelated\ pair} + 0.5}{n\mathrm{Trials}_{unrelated\ pair} + 1}\right)$$

Equation 6. d’ for false memory associations in Experiment 5, involving false memory and unrelated pairs in test phase I.

$$d'_{indirect} = z\left(\frac{nHits_{indirect\ pair} + 0.5}{n\mathrm{Trials}_{indirect\ pair} + 1}\right) - z\left(\frac{nFAs_{unrelated\ pair} + 0.5}{n\mathrm{Trials}_{unrelated\ pair} + 1}\right)$$

Equation 7. d’ for indirect associations in Experiment 5, involving indirect and unrelated pairs in test phase II.

While d’ for direct associations and for indirect associations both measure recognition for studied information, d’ for false memory associations determines the opposite, that is, the tendency to form false memories caused by overlapping events. False memory here, according to its d’, is defined as the difference in distributions of FAs between overlapping and unrelated pairs, so a larger d’ for false memory pairs reflects a greater probability of committing FAs for pairs of elements from overlapping events compared to those from unrelated events.

The random organisation of encoding events during study raised a question of whether time lag, which is the number of study trials between two particular events, affected performance during test. This is relevant because, excluding direct pairs which involved no study lag since they contained elements from the same event, the mean study lag for pairs of events containing elements used in unrelated pairs in test phase I (mean=16.3, SD=0.84) was significantly shorter than that for pairs of events containing elements used to test for false memories (mean=17.6, SD=0.79), as per a paired samples t-test (t(24)=5.56, p<.001, *d*=1.11). Unrelated pairs used in this comparison were only those containing items from Overlap events since false memory pairs were as such, and only first tests of false memory pairs were analysed. The mean study lag for pairs of events containing elements used in unrelated pairs in test phase II (mean=16.3, SD=1.31) was also shown by a paired samples t-test to be significantly less than that for pairs of events containing elements used to test for indirect associations (whose mean and SD study lag were the same as with false memory pairs since both pair types combined elements from overlapping events; t(24)=4.71, p<.001, *d*=0.94). Again, unrelated pairs used in this comparison were only those containing items from Overlap events since indirect pairs were as such, and only first tests of indirect pairs were analysed.

To eliminate the discrepancy in test phase I, certain unrelated pairs were discarded to match the average study lag for unrelated pairs with the average study lag for false memory pairs across subjects, as there were originally more unrelated pairs than false memory pairs in test phase I. For each of the 50% of the participants (n=13) who had the highest number of unrelated pairs, unrelated pairs with the shortest lags were omitted from analysis one by one until the mean lag for the unrelated pairs exceeded the mean lag for false memory pairs. Meanwhile, for the other 50% of the participants (n=12) who had the lowest number of unrelated pairs, I continually excluded from analysis within each subject unrelated pairs with the shortest lags just before the mean lag for the unrelated pairs surpassed the mean lag for false memory pairs. A paired samples t-test between mean study lags across the subsampled unrelated pairs (mean=17.2, SD=0.99) and across false memory pairs was then conducted again, showing no significant difference (t(24)=1.65, p=.11). The same procedure was applied to unrelated pairs in test phase II, and participants' mean lags for the selected unrelated pairs were contrasted with the mean lags for indirect pairs using a paired samples t-test. The new mean study lag across unrelated pairs (mean=17.1, SD=1.27) was now no different from the mean lag across indirect pairs (t(24)=1.44, p=.16). These selected unrelated pairs were used in all subsequent analyses.

The three d' variables were found for memory for pairs of elements from Overlap and Unique events, and for the different types of overlap: Person Overlap, Location Overlap and Object Overlap. Comparisons in d' among overlap conditions and between Overlap and Unique conditions were made using repeated measures ANOVAs and paired samples t-tests. In judging whether d’ was significant, one-sample t-tests were undertaken to see if d’ deviated from zero.

8.1.5 Confidence Analysis

Subjective confidence ratings from the test phase were collected to analyse metamemory differences among encoded, inferred and illusory memories, and the association between confidence and memory accuracy was determined to discriminate metacognitive awareness among the three types of memories. As with performance analyses in this experiment, confidence analyses regarding false memory and indirect associations, which were tested twice, comprised solely of the associations’ first tests except when categorically assessing their second tests. Confidence scores for direct and unrelated pairs in test phases I and II only considered data from test trials that were shown around the same time as the first-tested false memory or indirect pairs within the corresponding test phase (test phase I and II respectively), but when second tests for the false memory or indirect pairs were specifically analysed, data from test trials that were shown around the same time as the second-tested false memory or indirect pairs within the corresponding test phase was used. In addition, confidence ratings for unrelated pairs in both test phases were for subsampled unrelated pairs where the average study lag across participants had been equalised with the average study lag for false memory pairs in test phase I or indirect pairs in test phase II, depending on which retrieval phase the unrelated pairs were in.

Confidence was assessed in each test session (see **Figs. 12d**, **12e**) whereby high certainty responses, i.e. ‘yes – sure’ and ‘no – sure’, were graded as 1 and low certainty responses, i.e. ‘yes – not sure’ and ‘no – not sure’, were graded as 0. I measured mean confidence scores representing memory for encoded, false and inferred associations within each participant by analysing confidence for hits for direct pairs, FAs for false memory pairs and FAs for unrelated pairs in test phase I, as well as hits for indirect pairs and FAs for unrelated pairs in test phase II. These types of responses were obtained for each of the Overlap and Unique conditions except FAs for false memory pairs which were only applicable in the Overlap condition. The average scores for the different overlap conditions (Person Overlap, Location Overlap, Object Overlap) and between Overlap and Unique events were later compared using repeated measures ANOVAs and paired samples t-tests.

I examined the confidence-accuracy relationship in this experiment by carrying out correlations between confidence and accuracy within and between participants, as it was in Experiment 4 (see Chapter 7 – Method). Because the aim of this analysis was to study how metamemory accuracy calibrated with actual accuracy, ‘accuracy’ here for false memory and unrelated pairs refers to their CRs unlike in the preceding confidence analyses where FAs were considered. Within- and across-subject correlations were conducted for hits for direct pairs, CRs for false memory pairs and CRs for unrelated pairs in test phase I as well as hits for indirect pairs and CRs for unrelated pairs in test phase II for the Overlap condition, and hits for direct pairs and CRs for unrelated pairs in test phase I as well as CRs for unrelated pairs in test phase II for the Unique condition. For within-subject correlations, the two-by-two contingency table required for the calculation of the gamma correlation grouped responses according to confidence level and accuracy, where a confidence score of 0 (‘not sure’) was regarded as ‘low confidence’ and 1 (‘sure’) as ‘high confidence’. Repeated measures ANOVAs and paired samples t-tests were also undertaken to compare correlations among pair types and conditions. Finally, Pearson correlations were run to correlate confidence with accuracy across participants.

8.1.6 Dependency Analysis

For each participant, dependency was analysed in a similar way as in Experiments 1-4 (see Chapters 2, 3, 5, 7 – Method respectively) albeit with several differences. Contingency tables were still used to compare performance of two associations at a time and obtain a dependency value averaged across their common outcomes, be it success or failure (see **Table 1**). However, as with accuracy analyses in this experiment, I focused on direct, false memory and indirect associations. Dependency was measured among direct associations within an event by comparing hits for each direct association with hits for other within-event direct associations (i.e. AB-AC, AB-BC, AC-BC in Overlap event; XY-YZ, XY-XZ, YZ-XZ in Unique event; see **Figs. 12a**, **12b**). To calculate how retrievals of falsely remembered associations from overlapping events depended on each other, instead of hits, FAs for each false memory association were compared with FAs for the other false memory association within the same pair of overlapping events (i.e. AE-BD; see **Fig. 12a**). Dependency across indirect associations from overlapping events also analysed hits for each indirect association with hits for the other indirect association within the same pair of overlapping events (i.e. AD-BE; see **Fig. 12a**).

Dependency of false memory associations in test phase I on linking direct pairs and the dependency of false memory associations on non-linking direct associations was also computed. Direct linking associations are encoded associations that connect elements in a pair of overlapping events directly and their retrieval could be responsible for the formation of the false memory. The linking direct pairs for false memory pair AE were AC and CE, and those for false memory pair BD were BC and CD (see **Fig. 12a**). By contrast, direct non-linking associations are studied associations from the same overlapping pair of events that do not connect elements in a false memory pair in a straightforward manner and their retrieval might hence not be important for retrieving the false memory. The non-linking direct associations for false memory pair AE were AB, BC, CD and DE while those for false memory pair BD were AB, AC, CE and DE (see **Fig. 12a**). Thus, I calculated how making an FA on a pair of elements from two overlapping events depended on 1) making a hit on the direct associations that linked the pair of elements across the overlapping events, and separately on 2) making a hit on the direct associations that did not link the pair of elements across the overlapping events. Through these analyses, I sought to see if incorrect recognition of false memory associations from overlapping events relied on remembering the direct associations that might comprise the false inference, or also on the direct associations that did not. In a similar fashion, the dependency of indirect associations in test phase II on linking direct associations and on non-linking direct pairs were derived. The linking direct pairs for indirect pair AD were AC and CD, and those for indirect pair BE were BC and CE. On the other hand, the direct non-linking pairs for indirect pair AD were AB, BC, CE and DE, whereas those for indirect pair BE were AB, AC, CD and DE. Such an analysis would determine whether correct recognition of inferences across overlapping events hinged upon retrieving the direct associations that might comprise the inferences, or also those that did not.

Additionally, dependency between false memory associations and indirect associations was measured by comparing FAs for each false memory association with hits for each indirect association in a pair of overlapping events (i.e. FA for AE with hit for AD, FA for AE with hit for BE, FA for BD with hit for AD, FA for BD with hit for BE; see **Fig. 12a**). The theory that inaccurately adjoining elements from different but overlapping events draws on successful inference across the events assumes that false memory pairs depend on the retrieval accuracy of inference-driven indirect associations (Devitt et al., 2016; Carpenter and Schacter, 2017, 2018). Hence, results from this analysis could shed more light on the validity of the hypothesis.

Dependency values were log-transformed (see **Equation 1**) ensuing Shapiro-Wilk tests that reported a non-normal distribution of dependency of false memory pairs on each other within the same pair of events in Person Overlap (W(25)=.68, p<.001), Location Overlap (W(25)=.90, p=.02), Object Overlap (W(25)=.82, p=.001) and overall Overlap conditions (W(25)=.90, p=.02) for the first tests and Person Overlap (W(25)=.81, p<.001), Location Overlap (W(25)=.87, p=.003) and Object Overlap conditions (W(25)=.79, p<.001) for the second tests, dependency of false memory pairs on direct non-linking pairs in Person Overlap (W(25)=.92, p=.05), Location Overlap (W(25)=.82, p=.001), Object Overlap (W(25)=.92, p=.04) and overall Overlap conditions (W(25)=.76, p<.001) for the first tests, dependency of indirect pairs on each other in Object Overlap condition (W(25)=.90, p=.02) for the first tests, dependency of indirect pairs on direct non-linking pairs in Location Overlap (W(25)=.91, p=.03) and overall Overlap conditions (W(25)=.91, p=.04) for the first tests and Person Overlap (W(25)=.89, p=.01) and overall Overlap conditions (W(25)=.91, p=.03) for the second tests, and dependency of false memory pairs on indirect pairs in Person Overlap (W(25)=.89, p=.01) and Location Overlap conditions (W(25)=.91, p=.03) for the first tests and Object Overlap condition (W(25)=.91, p=.03) for the second tests.

I also compared, using paired samples t-tests, dependency pertaining to false memory or indirect associations when the pairs were tested first with dependency when they were tested again to investigate if retrieval dependency would change with repeated testing.

Finally, to reinforce my analyses on the dependency of false memories on direct linking as well as direct non-linking associations, supplementary analyses were carried out to understand if false memories were induced by both the successful retrieval of all their direct linking associations (i.e. direct linking pairs AC and CE for false memory pair AE, direct linking pairs BC and CD for false memory pair BD; see **Fig. 12a** for an illustration of event structure) and the incorrect retrieval of all the direct associations that contradicted the false memories (i.e. direct pairs AB and DE both contradicting false memory pairs AE and BD; see **Fig. 12a** for an illustration of event structure). Comparisons were made on the proportion of pairs of overlapping events where at least one false memory pair was wrongly recognised, in pairs of overlapping events where all the relevant direct linking associations (AC and CE for false memory AE, BC and CD for false memory BD) were remembered (‘BDL Remembered’ or Both Direct Linking Remembered events), versus the proportion in all other overlapping event pairs (BDL Remembered’ events; i.e. the proportion of pairs of overlapping events where at least one false memory pair was wrongly recognised, in pairs of overlapping events where one or all the relevant direct linking associations were not remembered). The same analysis was repeated looking at such false memory incidences in pairs of overlapping events where both the correct alternatives to the false memory pairs, AB and DE, were remembered (‘ABDE Remembered’ events) compared to the proportion in all other events (ABDE Remembered’ events; i.e. the proportion of overlapping event pairs with wrong recognition of at least one false memory pair in event pairs where either one or both of AB and DE were not retrieved). If the BDL Remembered proportion significantly superseded the BDL Remembered’ proportion, and if there were more ABDE Remembered’ events than ABDE Remembered ones, then the erroneous endorsement of a memory that blended two overlapping events together could be said to be aided by the accurate recognition of linking direct associations as well as the failure to retrieve the correct alternatives to the false memory. I conducted one-tailed paired samples t-tests to test the predictions.

The dependency variables overall were tallied for every overlap condition as well as for non-overlapping events, where applicable. Comparisons between conditions were performed using repeated measures ANOVAs and paired samples t-tests.

8.2 Results

8.2.1 Associative Accuracy

Mean accuracy rates relating to direct pairs (indicated by hits), false memory pairs (indicated by CRs) and unrelated pairs (indicated by CRs) in test phase I, as well as indirect pairs (indicated by hits) and unrelated pairs (indicated by CRs) in test phase II were compiled for Overlap and Unique conditions (see **Table 4**). Average proportions of responses based on their accuracy (hit/CR) and confidence (sure/not sure) were also recorded. I also analysed participants’ correct recognition of directly

Table 4. Associative accuracy and confidence results for Experiment 5.

Test phase I on direct associations: *'Have you seen these two (items) together?'*

Type of event	Type of test pair	Accuracy	Confidence	Accuracy & Confidence			
		Hits/CRs	Sure	Hit/CR, sure	Hit/CR, not sure	Miss/FA, sure	Miss/FA, not sure
Overlap	Direct pairs	0.53 (0.20)	0.50 (0.19)	0.35 (0.34)	0.18 (0.21)	0.17 (0.25)	0.30 (0.20)
	False memory pairs	0.80 (0.13)	0.46 (0.23)	0.43 (0.37)	0.38 (0.29)	0.06 (0.14)	0.13 (0.20)
	Unrelated pairs	0.83 (0.11)	0.47 (0.21)	0.42 (0.39)	0.41 (0.32)	0.04 (0.10)	0.13 (0.20)
Unique	Direct pairs	0.79 (0.13)	0.50 (0.22)	0.44 (0.40)	0.34 (0.32)	0.07 (0.11)	0.14 (0.17)
	Unrelated pairs	0.86 (0.14)	0.48 (0.30)	0.47 (0.45)	0.42 (0.34)	0.04 (0.09)	0.07 (0.12)

Test phase II on indirect associations: *'Are these two (items) indirectly linked?'*

Type of event	Type of test pair	Accuracy	Confidence	Accuracy & Confidence			
		Hits/CRs	Sure	Hit/CR, sure	Hit/CR, not sure	Miss/FA, sure	Miss/FA, not sure
Overlap	Indirect pairs	0.46 (0.21)	0.39 (0.32)	0.20 (0.25)	0.25 (0.22)	0.17 (0.28)	0.37 (0.26)
	Unrelated pairs	0.77 (0.14)	0.33 (0.30)	0.31 (0.37)	0.47 (0.36)	0.05 (0.10)	0.18 (0.17)
Unique	Unrelated pairs	0.76 (0.24)	0.39 (0.37)	0.29 (0.31)	0.45 (0.32)	0.06 (0.10)	0.20 (0.26)

Mean proportion (and standard deviation) of hits for direct pairs, CRs for false memory pairs, CRs for unrelated pairs in test phase I, hits for indirect pairs and CRs for unrelated pairs in test phase II, mean proportion (and standard deviation) of confident responses (regardless of accuracy; ‘Sure’) and breakdown of responses based on accuracy (Hit/CR, Miss/FA) and confidence (Sure, Not Sure) for Overlap and Unique events. Blue cells indicate false memories binding elements from overlapping events while green cells indicate false memories binding elements from unrelated events. Number of trials analysed might differ from number of presented trials for each test pair type as trials might be omitted due to invalid response (e.g. wrong keyboard press).

observed pairs of elements from an event, erroneous recognition of pairs of (different types of) elements from overlapping events as having been presented together, and correct recognition of indirectly associated pairs of (the same types of) elements across pairs of overlapping events by interpreting direct pairs, false memory pairs and indirect pairs respectively, relative to unrelated pairs, and expressing them as d’ (see **Equations 5**, **6**, **7**).

d’ for direct associations, reflecting the difference between rates of hits for element pairs from the same event and rates of FAs for element pairs from unrelated events in test phase I (see **Equation 5**, **Fig. 13a**), was examined in the overlap conditions Person Overlap, Location Overlap and Object Overlap to see if they differed. A one-way repeated measures ANOVA reported no variation (F(2,48)=1.55, p=.22). Consequently, a one-way ANOVA was carried out to compare d’ for directly observed associations in Overlap events with that in Unique events (see **Fig. 13a**). Results showed a main effect of event condition (F(1,24)=27.7, p<.001, ηP^2=.54) where d’ was higher for Unique events than for Overlap ones, although one-sample t-tests on d’ in both Overlap (t(24)=6.84, p<.001, *d*=1.37) and Unique events (t(24)=11.1, p<.001, *d*=2.21) indicated that it was significant in both event types. This suggested that participants had good memory for all encoded associations but especially those from unique events.

d’ for false memory pairs, reflecting the difference in FA rates between false pairs from overlapping events and those from unrelated events in test phase I (see Equation 6, Fig. 13a), was afterwards compared among Person Overlap, Location Overlap and Object Overlap and among both tests for false memory pairs (first versus second tests) in a 3X2 repeated measures ANOVA. False memory associations

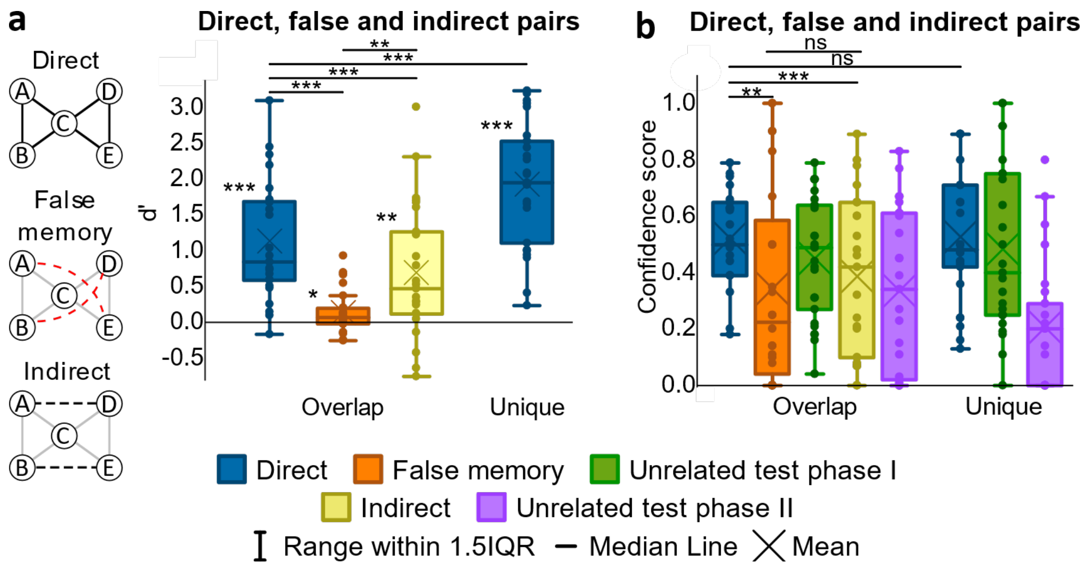

Figure 13. Associative accuracy and confidence results for Experiment 5. (**a**) d' for direct, false memory and indirect associations in Overlap and Unique events. (**b**) Confidence scores for hits on direct associations, FAs of false memory associations (first tests), FAs of unrelated pairs in test phase I, hits on indirect associations (first tests), and FAs of unrelated pairs in test phase II in Overlap events and for hits on direct associations, FAs of unrelated pairs in test phase I and FAs of unrelated pairs in test phase II in Unique events. ***p < .001; **p < .01; *p < .05; ns not significant. *N*=25 for **a**-**b**.

were probed twice to better identify the mechanisms mediating their retrieval. I found overlap type to not have a significant effect (F(2,48)=1.15, p=.33) and neither did test order (i.e. first or second; F(1,24)=2.15, p=.16). The interaction between both factors was also non-significant (F(2,48)=0.20, p=.82). In all other analyses where first and second tests were not specifically contrasted against each other, only first tests of twice-tested associations were used, so d' in Overlap events for the first tests of false memory pairs was put to a one-sample t-test. d' was revealed to be significant (t(24)=2.40, p=.03, d=0.48). There were thus more FAs for pairs of elements from overlapping events than from unrelated events, indicating that the overlap between the events in this study caused a significant inclination to form false memories of co-occurrence of elements from the two events.

I next assessed d’ for indirect pairs, reflecting the difference between rates of hits for indirectly linked pairs and rates of FAs for unrelated pairs in test phase II (see **Equation 7**, **Fig. 13a**). As with false memory associations, testing for inferred associations was performed twice to permit a more precise examination of their retrieval processes. According to a 3X2 ANOVA (overlap condition x first versus second tests), d’ depended on the type of shared element (F(1.71,40.9)=4.31, p=.03, ηP^2=.15). Post-hoc paired samples t-tests probed the effect of overlap type averaging across first and second tests of indirect pairs, revealing d’ in Person Overlap events to be greater than d’ in Location Overlap events (t(24)=2.13, p=.04, *d*=0.43) and d’ in Object Overlap events (t(24)=3.12, p=.01, *d*=0.62), but d’ in Location Overlap events to not differ from d’ in Object Overlap events (t(24)=1.20, p=.24).There was also a main effect of test order (first or second tests; F(1,24)=5.61, p=.03, ηP^2=.19) explained by higher d’ for the first tests but the interaction between overlap condition and test order was not significant (F(2,48)=0.99, p=.38). To ascertain if d’ was significant, one-sample t-tests were then conducted concerning only the first tests of indirect pairs since participants’ first responses were a more accurate representation of their performance in this experiment. d’ was noted to be significant in Person Overlap (t(24)=2.54, p=.02, *d*=0.51), Location Overlap (t(24)=2.10, p=.047, *d*=0.42) and Object Overlap events (t(24)=5.12, p<.001, *d*=1.02) as well as all events of overlapping structure (t(24)=3.80, p=.001, *d*=0.76). These results demonstrated that participants were able to infer indirect associations from their memories of overlapping events when explicitly asked to do so, but performance was best for Person Overlap events across repetition conditions and worsened across all overlapping events when tested again.

To see if d' in Overlap events differed amongst direct pairs, false memory pairs and indirect pairs (only first tests analysed for the latter two; see **Fig. 13a**), a one-way repeated measures ANOVA of the three d' types was performed. A significant difference in d' between direct pairs, false memory pairs and indirect pairs was detected (F(1.59,38.1)=21.1, p<.001, ηP^2=.47). To investigate the difference, further paired samples t-tests were carried out, finding the highest d' for direct associations which was significantly greater than d' for false memory associations (t(24)=6.06, p<.001, *d*=1.21) and d' for indirect associations (t(24)=4.23, p<.001, *d*=0.85). d' for indirect pairs was in turn better than for false memory pairs (t(24)=3.07, p=.01, *d*=0.61). Thus, memory for direct pairs was strongest, followed by memory for indirect pairs and then erroneous memory for false memory pairs.

8.2.2 Confidence

Mean confidence scores across participants regardless of accuracy during trials on direct pairs, false memory pairs, unrelated pairs in test phase I, indirect pairs and unrelated pairs in test phase II were measured, as well as mean proportions of confident accurate (hit/CR), unsure accurate, confident inaccurate (miss/FA) and unsure inaccurate responses (see **Table 4**). Confidence scores during correct recognition of encoded associations, incorrect recognition of false associations (i.e. false memory pairs and unrelated pairs in test phases I and II) and correct recognition of inferred associations were additionally assessed to study metamemory processes amid the different types of retrieval (see **Fig. 13b**).

I analysed confidence judgements for hits on direct associations (see **Fig. 13b**) and tested for differences amongst overlap conditions (Person Overlap, Location Overlap, Object Overlap) in a one-way repeated measures ANOVA. There was a significant effect of overlap type (F(2,48)=5.13, p=.01, ηP^2=.18) which, paired samples t-tests reported, was due to the least amount of confidence indicated for Person Overlap events, falling behind that for Location Overlap (t(24)=-2.20, p=.04, *d*=-0.44) and Object Overlap events (t(24)=-3.49, p=.002, *d*=-0.70). Confidence scores between Location Overlap and Object Overlap events were not different (t(24)=-0.81, p=.43). Meanwhile, according to a one-way ANOVA, confidence for hits on direct associations in overlapping events did not vary from that in unique events (t(24)=0.18, p=.86; see **Fig. 13b**).

As for confidence scores for inaccurate recognition of false memory pairs, defined by FAs (see **Fig. 13b**), a 3X2 repeated measures ANOVA (overlap type x first versus second tests) demonstrated no main effect of overlap type (F(2,14)=0.65, p=.54) or testing order (F(1,7)=0.47, p=.51), and the interaction between them was also not significant (F(2,14)=0.46, p=.64).

Subjective confidence reports were also explored during mistaken recognition, or FAs, of unrelated pairs in test phase I (see **Fig. 13b**) and their differences between Person, Location and Object Overlap events. Using a one-way ANOVA, I did not observe overlap type to have a significant effect on confidence (F(2,16)=1.74, p=.21). Confidence on FAs for unrelated pairs across all overlapping events was then compared with confidence on FAs for unrelated pairs in Unique events (see **Fig. 13b**), a one-way ANOVA showing no significant difference between them (F(1,24)=0.20, p=.66).

Participants' confidence when committing hits on indirect pairs in test phase II (see **Fig. 13b**) were then examined through a 3X2 ANOVA (overlap type x first versus second tests). Confidence scores did not differ among different types of overlap (F(1.61,30.6)=0.79, p=.44) and there was no main effect of testing order (F(1,19)=2.28, p=.15). The interaction between the two factors was not significant either (F(2,38)=1.83, p=.18).

In assessing confidence on FAs of unrelated pairs in test phase II (see **Fig. 13b**), a one-way ANOVA on confidence in Person, Location and Object Overlap events found the effect of overlap type to be non-significant (F(1.03,4.10)=0.16, p=.72). I then contrasted confidence judgements in FAs for unrelated pairs from the Overlap condition with that in FAs for unrelated pairs from the Unique condition (see **Fig. 13b**) and identified no difference using a one-way ANOVA (F(1,24)=2.28, p=.14).

Confidence in the Overlap condition was next evaluated if it varied among memory for encoded, false and inferred associations by analysing confidence reports during hits on direct associations, FAs for false memory pairs and FAs for unrelated pairs in test phase I as well as hits on indirect associations and FAs for unrelated pairs in test phase II (i.e. response type; see **Fig. 13b**). Only first tests of false memory and indirect pairs were studied. A one-way ANOVA demonstrated that response type had a main effect (F(3.10,71.3)=3.98, p=.01, ηP^2=.15), and follow-up paired samples t-tests discerned higher confidence for hits on direct associations than for FAs for false memory associations (t(23)=2.88, p=.01, *d*=0.59), FAs on unrelated pairs in the same test phase (t(24)=2.36, p=.03, *d*=0.47), hits on indirect pairs (t(24)=2.84, p=.01, *d*=0.57) and FAs for unrelated pairs in test phase II (t(24)=3.58, p=.002, *d*=0.72). FAs for false memory associations were made with the same degree of certainty as FAs for unrelated pairs in test phase I (t(23)=-1.76, p=.09), hits on indirect pairs (t(23)=-0.83, p=.41) and FAs for unrelated pairs in test phase II (t(23)=0.27, p=.79). FAs for unrelated pairs in test phase I induced the same level of confidence as hits on indirect pairs (t(24)=1.08, p=.29) but higher than FAs for unrelated pairs in the other test phase (t(24)=2.90, p=.01, *d*=0.58). In test phase II, participants' confidence when recognising indirect pairs was no different than when wrongly endorsing unrelated pairs (t(24)=0.88, p=.39). These figures suggest that in overlapping events, confidence was greatest when correctly recognising direct associations while it was the same when wrongly recognising false memory associations, wrong recognising unrelated associations in any test phase and correctly recognising indirect associations, though confidence for unrelated associations in test phase I was higher than in test phase II.

For Unique events, differences in confidence among response types (hits for direct pairs in test phase I, FAs for unrelated pairs in test phase I and FAs unrelated pairs in test phase II) which altogether signal observed, false and inferred memories were examined (see **Fig. 13b**) and shown by a one-way ANOVA to be significant (F(1.54, 37.0)=11.3, p<.001, ηP^2=.32). Post-hoc paired samples t-tests were undertaken to explore the significant effect of response type and revealed that confidence scores during successful recognition of direct pairs were comparable with scores during false recognition of unrelated pairs in test phase I (t(24)=0.89, p=.38) but exceeded scores during false recognition of unrelated pairs in test phase II (t(24)=4.19, p<.001, *d*=0.84). Unrelated pairs were wrongly accepted with greater confidence in test phase I than in test phase II (t(24)=3.13, p=.01, *d*=0.44).

The extent to which participants' metamemory accuracy represented actual memory accuracy was studied in a within-subjects analysis in an attempt to compare cognitive awareness among veridical, false and inference-related memory. γ correlations between confidence ratings and response accuracy were found within each participant, for each pair type and for the Overlap as well as Unique conditions (see **Table 5**). The γ coefficients were afterwards Fisher's Z-transformed and tested for significance in one-sample t-tests. I observed that confidence scores in Overlap events proportionally varied with hit rate for direct associations (t(24)=4.78, p<.001, *d*=0.96), CR rate for unrelated pairs in test phase I (t(24)=3.70, p=.001, *d*=0.79) and CR rate for unrelated pairs in test phase II (t(24)=2.78, p=.01, *d*=0.56). However, confidence was not significantly related to correctly rejecting false memory associations (t(24)=1.34, p=.19) or recognising indirect associations (t(24)=0.78, p=.45). Confidence sustained its positive relationship with accuracy for direct pairs in non-overlapping events (t(24)=3.79, p=.001, *d*=0.76) but the association between them was absent during trials on unrelated pairs in test phase I (t(24)=1.44, p=.16) and test phase II (t(24)=-0.95, p=.35). I then contrasted γ coefficients for all pair types with each other within Overlap and Unique conditions using one-way ANOVAs, which saw no main effect of pair type in Overlap events (F(4,96)=1.19, p=.32) though it was significant in Unique events (F(2,48)=5.57, p=.01, ηP^2=.19). In examining the main effect of pair type in Unique events, post-hoc paired samples t-tests revealed that γ coefficients for direct and unrelated pairs in test phase I were not different (t(24)=0.82, p=.42) but coefficients for direct pairs surpassed those for unrelated pairs in test phase II (t(24)=4.15, p<.001, *d*=0.83) and so did those for unrelated pairs in test phase I (t(24)=2.04, p=.05, *d*=0.41). When comparing correlations for overlapping events with those for non-overlapping events using paired samples t-tests, γ coefficients did not differ for direct pairs (t(24)=-0.81, p=.43) and unrelated pairs in test phase I (t(24)=0.59, p=.56) though coefficients for unrelated pairs in test phase II were greater in Overlap events (t(24)=3.02, p=.01, *d*=0.60).

Table 5. Correlations between confidence and accuracy for Experiment 5.

Test phase I on direct associations: ***'Have you seen these two (items) together?'***

Type of event	Type of test pair	Within subjects (z-transformed γ)	Between subjects (*r*)
Overlap	Direct pairs	0.96*** (0.70)	.41*
	False memory pairs	0.52 (0.70)	.43*
	Unrelated pairs	1.16** (1.46)	.41*
Unique	Direct pairs	1.21** (1.59)	.31
	Unrelated pairs	0.78 (2.72)	.29

Test phase II on indirect associations: ***'Are these two (items) indirectly linked?'***

Type of event	Type of test pair	Within subjects (z-transformed γ)	Between subjects (*r*)
Overlap	Indirect pairs	0.35 (0.59)	.47*
	Unrelated pairs	1.21* (2.18)	.15
Unique	Unrelated pairs	-0.44 (2.32)	.42*

Pearson correlations and mean gamma correlations (with standard deviation) between confidence and accuracy, performed for each type of test pair within test phases I and II as well as for Overlap and Unique events. * within a column reflects a significant difference from zero. ***p < .001; **p < .01; *p < .05. *N*=25.

To investigate the confidence-accuracy association across subjects, I correlated their mean hit rates for direct associations, CR rates for false memory associations, CR rates for unrelated pairs in test phase I, hit rates for indirect associations and CR rates for unrelated pairs in test phase II with their mean confidence scores in the respective pair type (see **Table 5**). Separate correlations were carried out for Overlap and Unique events. Confidence was found to positively correlate with hits for direct associations (*r*=.41, n=25, p=.05), CRs for false memory associations (*r*=.43, n=25, p=.03), CRs for unrelated pairs in test phase I (*r*=.41, n=25, p=.04) and hits for indirect associations (*r*=.47, n=25, p=.02) in the Overlap condition, but not with unrelated pairs from test phase II (*r*=.15, n=25, p=.47). In Unique events, however, no confidence-memory accuracy relation was displayed for direct associations (*r*=.31, n=25, p=.14) and unrelated pairs in test phase I (*r*=.29, n=25, p=.16), though it was positive for unrelated pairs in test phase II (*r*=.42, n=25, p=.04).

8.2.3 Dependency Across Direct Associations

To confirm whether performance in recognising directly observed associations depended on performance on other direct associations from the same event (see **Fig. 14a**), dependency across within-event direct associations was assessed, comparing it first among the different types of overlapping events – Person Overlap, Location Overlap and Object Overlap – in a one-way ANOVA. No main effect of overlap condition was seen (F(2,48)=0.65, p=.53), prompting me to undertake a one-way ANOVA to contrast dependency in all Overlap events with that in Unique events. The difference in dependency across direct pairs was not significant (F(1,24)=0.01, p=.95) despite d' for direct pairs being stronger in Unique events than in overlapping events (see **Fig. 13a**). One-sample t-tests revealed that dependency was significant in both Overlap (t(24)=4.01, p=.001, *d*=0.80) and Unique events (t(24)=3.25, p=.003, *d*=0.65), suggesting that in both conditions, retrievals of direct associations were statistically dependent on the other direct retrievals from the same event.

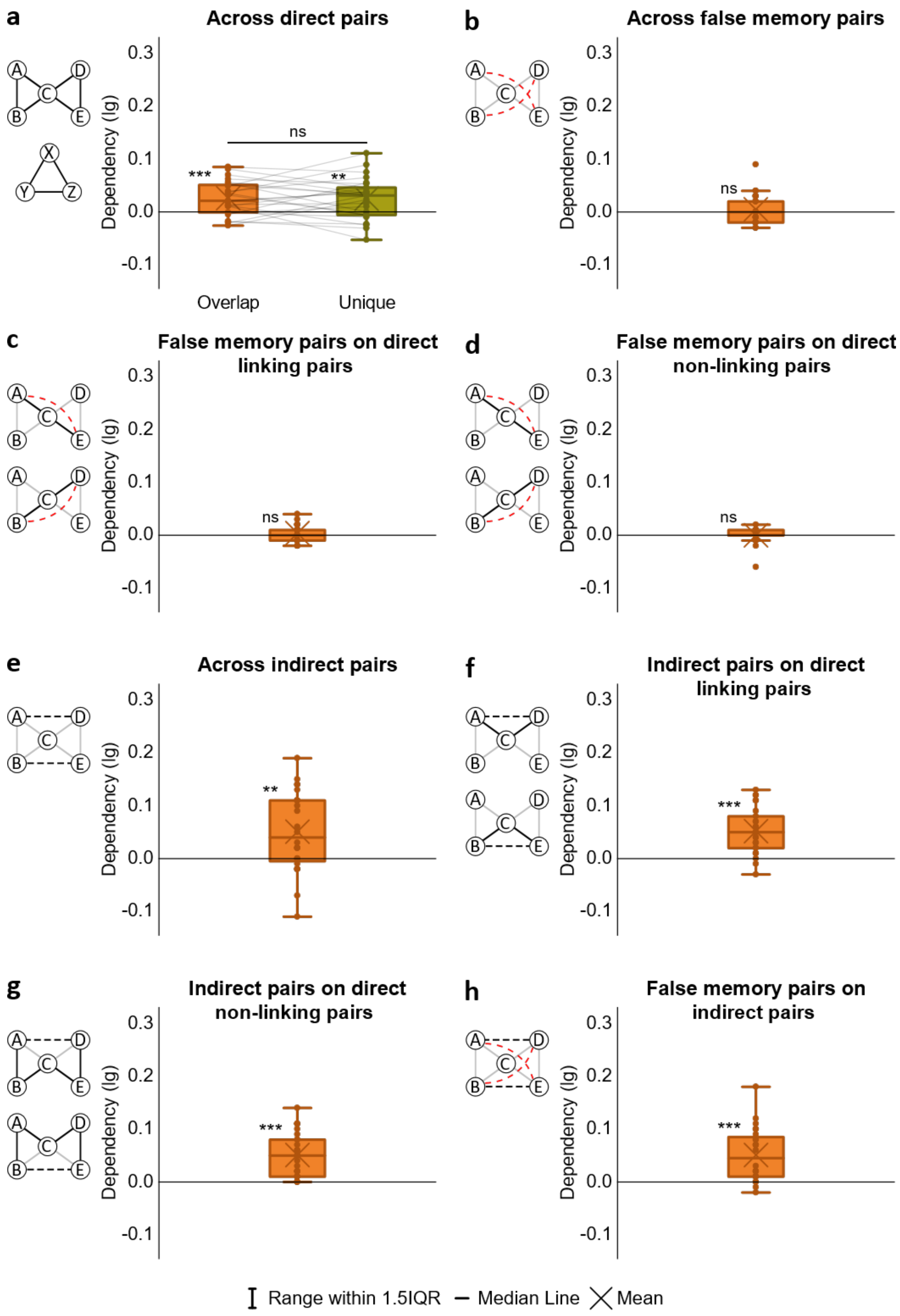

Figure 14. Dependency results for Experiment 5. (**a**) Dependency of direct pairs on other direct pairs from the same event for Overlap and Unique events, log-transformed. (**b**) Dependency of false memory pairs (first tests) on other false memory pairs within the same pair of overlapping events,

log-transformed and averaged across all Overlap events. (**c**) Dependency of false memory pairs (first tests) on all related direct pairs within the same pair of overlapping events, log-transformed and averaged across all Overlap events. (**d**) Dependency of false memory pairs (first tests) on all unrelated direct pairs within the same pair of overlapping events, log-transformed and averaged across all Overlap events. (**e**) Dependency of indirect pairs (first tests) on other indirect pairs within the same pair of overlapping events, log-transformed and averaged across all Overlap events. (**f**) Dependency of indirect pairs (first tests) on all related direct pairs within the same pair of overlapping events, log-transformed and averaged across all Overlap events. (**g**) Dependency of indirect pairs (first tests) on all unrelated direct pairs within the same pair of overlapping events, log-transformed and averaged across all Overlap events. (**h**) Dependency of false memory pairs (first tests) on indirect pairs (first tests) within the same pair of overlapping events, log-transformed and averaged across all Overlap events. Each point represents a participant. * within a column reflects a significant difference from zero. ***p < .001; **p < .01; ns not significant. *N*=25 for **a**-**h**.

8.2.4 Dependency Across False Memories

False memory associations, which are pairs of elements of different types (e.g. person-place) from overlapping events (AE, BD see **Fig. 12a** for an illustration of event structure), were examined on how they depended on each other within the same pair of overlapping events (see **Fig. 14b**) in a 3X2 repeated measures ANOVA that looked at overlap type (person versus location versus object) and testing order (first versus second tests). No significant result was obtained for effect of type of element in common (F(2,48)=0.23, p=.79) nor for effect of test repetition (F(1,24)=0.02, p=.89) and overlap type x testing order interaction (F(2,48)=0.65, p=.53). Despite no effect of repeated retrieval, it was appropriate to only assess the first tests for dependency analyses in general since they were a more accurate representation of participants' memory than second tests. Across all overlap types but considering only first tests, dependency between the two false memory associations in each pair of overlapping events was not significant according to a one-sample t-test (t(24)=0.69, p=.50). These figures implied that false memory for one pair of elements merged from overlapping events (e.g. AE) did not depend on false memory for the other pair of elements merged from the events (e.g. BD), and retrieval repetition had no importance in such dependency.

8.2.5 Dependency of False Memory Associations on Direct Linking Associations

I next sought to establish if misremembering false memory pairs depended on correct retrievals of the direct pairs which linked that pair of elements (see **Fig. 14c**) – that is, whether FAs for AE depended on correctly remembering the pairs AC and CE, and similarly the dependence of pair BD on pairs BC and CD (see **Fig. 12a** for an illustration of event structure). In a 3X2 ANOVA probing Person Overlap, Location Overlap and Object Overlap events in first and second tests of false memory pairs, there were no main effects of overlap condition (F(2,32)=0.83, p=.45) and testing order (F(1,16)=0.04, p=.84). The interaction between the two factors was also not significant (F(2,32)=0.96, p=.39). A one-sample t-test was conducted on dependency in Overlap events (first tests only) and reported non-significant dependency (t(24)=1.76, p=.09). This indicates that false memories of co-occurrence of elements from overlapping events did not depend on correct memory for the direct associations linking them, whether they were tested once or twice.

8.2.6 Dependency of False Memory Associations on Direct Non-Linking Associations

While false memory pairs in an overlapping pair of events might have not depended on linking direct associations for retrieval, they might instead be contingent on the other direct associations which were non-linking. For inferred pair AE, the non-linking direct pairs were AB, BC, CD and DE, and for inferred pair BD, the non-linking direct pairs were AB, AC, CE and DE (see **Fig. 12a** for an illustration of event structure). Thus, the dependency between false memory pairs and unrelated direct associations was explored (see **Fig. 14d**), averaging the FAs for both inferred associations AE and BD together. After a 3X2 ANOVA (overlap type x first versus second tests), it was shown that the effects of overlap condition (F(2,26)=0.36, p=.71) and test repetition (F(1,13)=0.31, p=.59) were not significant. The interaction between them was also not significant (F(2,26)=0.47, p=.63). In assessing first retrievals alone in a one-sample t-test spanning all overlap types, no dependency of false memory pairs on direct non-linking associations from the same pair of overlapping events was observed (t(24)=0.52, p=.61). Taking this together with results from analyses on dependency of false memory pairs on direct linking pairs, I derived that the retrieval of the false memories did not hinge on explicit memory of direct pairs, irrespective of whether they linked the elements in the false memories or not. Repeated testing, moreover, did not have a bearing on dependency.

Seeing that the retrieval of false memories did not appear to depend on the recollection of any individual direct association, it is important to also consider that the retrieval outcome of certain types of direct associations might bring about false memories in different ways. In particular, the accurate recollection of direct associations that linked the elements constituting false memory associations (AC and CE for false memory AE; BC and CD for false memory BD) and the retrieval failure of true alternatives to the false memories (AB and DE for both false memories AE and BD) are possible prerequisites of false memory formation (see **Fig. 12a** for an illustration of event structure). To explore this hypothesis, I carried out a paired samples t-test on the proportion of pairs of overlapping events with incorrect recognition of at least one false memory pair in pairs of overlapping events where both the relevant direct linking associations (AC and CE for false memory AE; BC and CD for false memory BD) were remembered (BDL Remembered), versus in all other pairs of overlapping events with one or more such false memories (BDL Remembered’; see **Fig. 15**). Each of the proportions was the average across the corresponding proportions for AE and for BD. One-way ANOVAs found no difference in the BDL Remembered proportion between Person, Location and Object Overlap conditions (F(2,22)=0.90, p=.42) and also none in the BDL Remembered’ proportion (F(1.70,40.9)=0.35, p=.68). A one-tailed paired samples t-test on all Overlap events demonstrated that there was a higher proportion of BDL Remembered events than BDL Remembered’ events (t(18)=2.39, p=.01, *d*=0.55). Similarly, the proportion of pairs of overlapping events with incorrect recognition of one or more false memory pairs in pairs of overlapping events where both AB and DE were retrieved (ABDE Remembered) was contrasted with the proportion of such false memory occurrences in all other pairs of overlapping events (ABDE Remembered’; see **Fig. 15**). The comparison was done across Overlap events since one-way ANOVAs revealed no main effect of overlap condition in the ABDE Remembered proportion (F(2,48)=0.72, p=.49) as well as in the ABDE Remembered’ proportion (F(2,48)=0.41, p=.67). Using a one-tailed paired samples t-test examining the prediction that the ABDE Remembered’ proportion was greater than the ABDE Remembered proportion, I observed a nearly significant result (t(24)=-1.69, p=.052, *d*=-0.34). Therefore, within two overlapping events, recollecting both direct linking associations promoted false

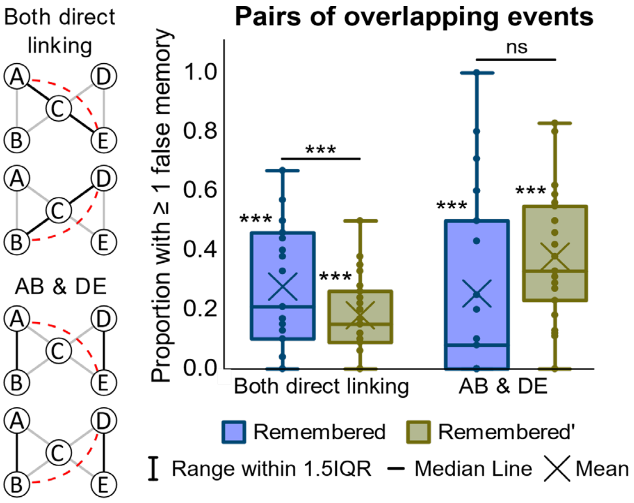

Figure 15. Proportions of pairs of overlapping events with false memories for Experiment 5.

Proportion of pairs of overlapping events with at least one false memory pair wrongly recognised (AE or BD) where both the relevant direct linking associations for that false memory (AC and CE for false memory AE; BC and CD for false memory BD) were remembered (BDL Remembered) and proportion of pairs of overlapping events with at least one false memory pair wrongly recognised in all other cases (BDL Remembered‘, i.e. where only one or none of the direct linking associations were remembered), as well as proportion of pairs of overlapping events with at least one false memory pair wrongly recognised where both the direct associations contradicting the false memories (AB and DE) were remembered (ABDE Remembered) and proportion of pairs of overlapping events with at least one false memory pair wrongly recognised in all other cases (ABDE Remembered’, i.e. where only one or none of AB and DE were remembered). Proportions were each averaged across pairs of events for false memory AE and for false memory BD. Each point represents a participant. $^{***}p < .001$; ns not significant (p=.10; one-sample t-test p=.052). *N*=25.

memories whereas remembering both of the associations that negated the false memory showed an almost significant tendency towards fewer false memories. No dependency between false memory pairs and their respective direct linking pairs was seen because that would require both sets of pairs to be dependent on each other; in this case, only false memory pairs appeared to rely on their direct linking pairs (i.e. for false memories to be formed, their direct linking pairs should also be recalled) whilst the direct linking pairs did not appear to rely on the false memory pairs (i.e. for the direct linking pairs to be recollected, the false memories did not need to be retrieved).

8.2.7 Dependency Across Indirect Associations

Dependency between retrievals for the two indirect associations from the same overlapping pair of events (AD and BE; see **Fig. 12a** for an illustration of event structure) was next analysed in test phase II (see **Fig. 14e**). Using a 3X2 ANOVA which assessed events that shared a person, a place or an object in first and second tests, neither type of overlap (F(2,46)=0.55, p=.58) nor test order (F(1,23)=0.61, p=.44) had a main effect. Their interaction was also found to not significant (F(2,46)=0.66, p=.52). I observed, via a one-sample t-test on first tests on indirect pairs, that dependency in overlapping events regardless of the identity of the common element was significant (t(23)=3.32, p=.003, *d*=0.68). Indirect associations therefore relied on one another during retrieval and such dependency was impervious to repeated testing.

The three dependency analyses on direct pairs, false memory pairs and indirect pairs were then contrasted with each other, examining first tests in Overlap events. Through a one-way ANOVA, a main effect of dependency analysis was noted (F(1.6, 36.9)=5.50, p=.01, ηP^2=0.19). Further paired samples t-tests on dependency in non-unique events revealed dependency to be greatest across direct and indirect associations, with no difference between them (t(23)=-1.9, p=.07), and poorest across false memory pairs, behind dependency among direct (t(24)=-2.22, p=.04, *d*=-0.44) and among indirect associations (t(23)=-2.76, p=.01, *d*=-0.56). This was agreeable with my finding that dependency was significant among direct pairs and indirect pairs but not so much for false memory pairs. Hence, indirect associations from a pair of related events were retrieved with a comparable degree of coherence as directly perceived associations, and in both cases the level of retrieval interdependency was significantly greater than the non-significant interdependency of false memories.

8.2.8 Dependency of Indirect Associations on Direct Linking Associations

Does the retrieval success of indirect associations depend on accurately retrieving the direct pairs that link the two elements? In other words, would correctly remembering the indirect pair AD hinge upon the retrievals of direct pairs AC and CD, and the indirect pair BE upon the retrievals of direct pairs BC and CE (see **Fig. 12a** for an illustration of event structure)? I thus measured the dependency of indirect associations on related direct pairs in overlapping events (see **Fig. 14f**) and subjected it to a 3X2 ANOVA to reveal any differences among Person Overlap, Location Overlap and Object Overlap events and among first and second tests. While no significant effect of overlap condition was detected (F(2,48)=0.65, p=.53), there was a main effect of test repetition (F(1,24)=18.4, p<.001, $\eta P^2=0.43$) whereby dependency fell when indirect associations were retrieved the second time. The interaction between overlap type and test order was not significant (F(2,48)=0.49, p=.62). Thereupon, a one-sample t-test was run on dependency (for first tests) across overlapping events and noted it to be significant (t(24)=5.92, p<.001, *d*=1.18). It was thus found that accurately retrieving indirect associations was related statistically to the retrieval success of associations that connected the elements in the indirect associations, but repetitive testing of indirect pairs led to a drop in dependency though not to non-significant levels.

8.2.9 Dependency of Indirect Associations on Direct Non-Linking Associations

The strong dependency of indirect associations on direct linking associations from the same pair of overlapping events prompted me to also examine their dependency on the retrieval of non-linking direct associations (see **Fig. 14g**), which were encoded associations that were not expected to support the corresponding inferences. For indirect pair AD, direct pairs which were non-linking were AB, BC, CE and DE, while for indirect pair BE, the non-linking direct pairs were AB, AC, CD and DE (see **Fig. 12a** for an illustration of event structure). I analysed statistical dependency of retrievals for indirect pairs on retrievals for direct non-connecting pairs in a 3X2 ANOVA with factors overlap type (Person Overlap, Location Overlap and Object Overlap) and test order (first and second tests). There was no effect of overlap type (F(2,48)=0.96, p=.39) but a main effect of test order was observed (F(1,24)=14.7, p<.001, ηP^2=0.38) caused by a decline in dependency by the second retrieval, and the interaction between factors was non-significant (F(2,48)=1.47, p=.24). Next, a one-sample t-test was performed on dependency in Overlap events in participants' first retrievals of indirect associations and found that it was significant (t(24)=5.51, p<.001, *d*=1.10), similar to the dependency of indirect pairs on direct related associations. In light of these results, recognition success of indirect associations was observed to be contingent on that of any direct association, linking or non-linking, present across a pair of overlapping events. Furthermore, when indirect associations were tested again, their retrievals became more independent of explicit memory for the overlapping events.

8.2.10 Dependency of Indirect Associations on False Memory Associations

I then investigated if the misguided endorsement of false memory associations statistically related to the successful retrieval of indirect associations within the same pair of overlapping events (see **Fig. 14h**). Given that both groups of associations were tested twice in test phases I and II respectively, dependency was first probed in a 3X2 ANOVA (overlap type x first versus second tests) that yielded no effect of overlap condition (F(2,36)=0.76, p=.48). There was a main effect of retrieval order (F(1,18)=1.09, p=.002, ηP^2=.44) in which dependency diminished upon the second test, but no interaction between type of overlapping element and test order (F(2,36)=0.51, p=.60). A one-sample t-test was then conducted on dependency across all overlap conditions, analysing first retrievals exclusively. Dependency measured significantly (t(24)=5.05, p<.001, *d*=1.03), indicating that retrievals for false memory and indirect associations were dependent on each other, though dependency reduced when both were retrieved the second time. The decrease was likely caused by unfavourable changes to dependency for indirect associations upon repeated testing, as their dependency on direct linking and non-linking associations showed the same trend but false memory associations did not.

8.3 Summary

Experiment 5 reproduced findings from previous experiments and the hippocampal model on the coherent retrieval of unseen inferred associations. Directly learned associations within an event were dependent on each other for retrieval as reported in closed-loop events in all the other experiments (i.e. Experiments 1-4; see Chapters 2, 3, 5, 7 respectively) as well as the computational model (see Chapter 6), and equally so in overlapping and unique conditions. Because there was no equivalent of open-loop events in this experiment, it was not possible to contrast the results here with those on open-loop events in the earlier experiments. Nevertheless, indirect associations in this experiment could be equated with the indirect associations in open-loop events in Experiments 1-3 and the memory model (Experiment 4 did not test for inferences) since they were both inferred across overlapping but disparate stimuli. In this aspect, indirect pairs showed within-event dependency on retrieving other indirect pairs and on linking encoded pairs as they did in Experiments 1-3 and the simulated data, but unlike in the experiments and the simulations, indirect pairs also relied on non-linking pairs.

Here I also provided novel results on false memories that are caused by overlapping associations and discerned how inferential mechanisms could lead to undesirable repercussions on the credibility of an episodic memory. Participants were prone to erroneously acknowledging elements from two overlapping events as having been seen together, more often than elements from unrelated events, despite being able to remember directly observed and indirectly inferred associations reasonably well. However, participants remembered encoded associations from overlapping events more poorly than those from non-overlapping events. No dependency was detected among false memory associations from a pair of overlapping events and none between false memories and individual observed associations that either linked or did not link the elements in the false associations. However, the prospect of forming false memories in a pair of overlapping events increased when both direct linking associations were remembered and showed a nearly significant inclination to decrease when both direct associations inconsistent with the false memory associations were remembered. Retrieving false memory pairs also depended on the retrieval success of indirectly learned associations.

Highest confidence in overlapping events was indicated during recollection of directly observed associations while false memories caused by overlapping events evoked the same amount of self-belief as false memories binding elements from nonrelated events in any test phase as well as correct recognition of indirect associations. Inaccurate endorsement of unrelated pairs in test phase I was accompanied by the same amount of confidence as accurate recognition of indirect pairs but greater than that of FAs for unrelated pairs in test phase II. In the second test phase, confidence when making hits for indirect pairs was also not different than when making FAs for unrelated pairs. For Unique events, confidence when recognising direct pairs was no different than when recognising direct pairs in the Overlap condition. It also did not vary from confidence when endorsing wrong unrelated pairs in the same test phase, and both types of responses were made with higher confidence than accepting wrong unrelated pairs in test phase II. Confidence ratings within participants correlated with memory for direct associations in Overlap and Unique events, as observed in closed-loop events in Experiment 4, and additionally with dismissal of mispairings of elements from unrelated events in the Overlap condition during both test phases. Although there was no correlation for false memory and unrelated pairs in Overlap events, confidence-accuracy relation in the condition did not significantly vary across all pair types. On the other hand, within Unique events, confidence was related to accuracy equally for direct and unrelated pairs in test phase I, and on both accounts more strongly than it was for unrelated pairs in test phase II. Nevertheless, between overlapping and non-overlapping events, correlations for direct pairs and unrelated pairs in test phase I were not different but were higher in both cases than for unrelated pairs in test phase II. Compared to those with lower confidence, participants with stronger confidence during response on overlapping events showed better memory for direct and indirect associations along with greater likelihood of rejecting false associations of elements from overlapping or unrelated events in the first test phase. Subjective confidence in the non-overlapping condition was only indicative of the CR rate for unrelated pairs in test phase II.

The impact of repetitive testing and type of overlap on episodic retrieval of overlapping events was also demonstrated. Testing false memory and indirect associations twice did not alter performance, subjective confidence and dependency save for dependency of indirect pairs on direct linking, direct non-linking pairs and false memory pairs, where the second turn of testing showed weaker dependency. Type of event overlap also did not have an effect on accuracy, confidence and dependency except for performance on indirect associations, which was best for Person Overlap events and the same for Location Overlap and Object Overlap events, and confidence when recognising direct associations, which was weakest in Person Overlap events and equivalent in Location Overlap and Object Overlap events.

Taking together the results from all experiments and the simulations in this thesis, there is consistent evidence for an all-encompassing auto-associative framework of episodic memory that stores events alongside unperceived associations inferred from encoded memories which may or may not be episodic. However, inferential processes could at times produce misguided combinations of elements from overlapping episodes, in which case pattern completion is not engaged proper when retrieving the illusory memories although it is when retrieving inferences formed across the overlapping events. Confidence during recognition of learned associations reveals conscious awareness of its recollection, while retrieval of false memories and inferences, which are never attended to, is linked to a decreased level of conscious experience and exhibits impaired calibration between self-estimated and actual accuracy. Metamemory accuracy for different types of memory varies from one individual to another.

9 Comparing Experiment 2 and Experiment 5

In terms of design, the earlier experiments that presented events as serial overlapping associations (Experiments 1-4; see Chapters 2, 3, 5, 7 respectively) varied in many ways from the most recent experiment in which events were viewed as single images (Experiment 5; see Chapter 8). It was no surprise given that the experiments were deliberately conceived for distinct purposes; in addition to studying false memories, Experiment 5 sought to examine episodic memory retrieval through a different paradigm. There were three major aspects in which they differed, i.e. the associative organisation of the tested events (closed and open loops versus overlapping closed loop-like events), the modality of the stimuli (text versus pictures), and the mode of presentation of associations from the same event (sequential versus simultaneous), while other factors such as the type of test implemented (forced choice cued recognition versus yes/no recognition) might not be expected to produce divergent results in the experiments. Despite that, the experiments all shared the common aim of investigating the retrieval pattern of encoded and inferred associations, and it would still be interesting to see if they provided distinct or similar results. The differences, if any, might demonstrate to some extent how dependency for direct and indirect associations varied when events were learned sequentially as overlapping word associations or simultaneously as pictures that might overlap with another. Previous research has investigated differences in the memorability of pictures and words (Snodgrass et al., 1972; Paivio and Csapo, 1971; Noldy et al., 1990; Grady et al., 1998) but none has categorically looked at how they differentially affected the relatedness among retrievals of associations within an event.

Out of Experiments 1-4, I decided to contrast performance and dependency outcomes from Experiment 2 with those from Experiment 5, considering that Experiment 2 was most alike Experiment 5 compared to the other experiments – both Experiments 2 and 5 separated retrievals for direct and indirect associations (unlike Experiment 1, which intermixed them, and Experiment 4, which only studied retrieval of direct associations) and did not repeat the encoding of any event (unlike Experiments 3 and 4, where some events were repeatedly learned).

9.1 Method

9.1.1 Inter-experiment analysis

The event structures tested in Experiment 2 and the testing protocol were different from those in Experiment 5, calling for different analyses within the corresponding experiments, but their similarities in some respects permitted comparison between the experiments. Comparing accuracy was not possible between Experiments 2 and 5 because the former experiment, where participants were subjected to a cued recognition task, used accuracy scores as indicator of performance (see Chapter 3 – Method), whilst performance in the latter experiment, which employed a yes/no recognition paradigm, was better represented as d’ (see Chapter 8 – Method). As for dependency, all events in Experiment 5 were analogous to closed-loop events in Experiment 2 since both groups of events were fully encoded unlike open-loop events in Experiment 2, so dependency across direct associations in closed-loop events in Experiment 2 was compared with dependency across direct associations in Overlap and Unique events in Experiment 5. However, indirect associations in overlapping pairs of events were contrasted with those in open-loop events of Experiment 2 since inferences were only possible in open-loop events. Dependency across indirect associations in open-loop events in Experiment 2 was contrasted with dependency across indirect associations in pairs of overlapping events in Experiment 5, dependency of indirect associations on direct linking associations in open-loop events in Experiment 2 with dependency of indirect associations on direct linking associations in pairs of overlapping events in Experiment 5, and dependency of indirect associations on direct non-linking associations in open-loop events in Experiment 2 with dependency of indirect associations on direct non-linking associations in pairs of overlapping events in Experiment 5. All Overlap events regardless of the type of overlapping element they shared in Experiment 5 were assessed here.

Because the sample size varied in Experiments 2 (33; see Chapter 3 – Method) and 5 (25; see Chapter 8 – Method), each comparison started with a Levene's test to determine if the variances in the samples in Experiments 2 and 5 were equal, similar to analyses made across Experiments 1 and 2 (see Chapter 4 – Method). If the variances did not differ, a one-way ANOVA would be carried out to compare the two samples, otherwise a Welch's test would be performed.

9.2 Results

9.2.1 Dependency Across Direct Associations

First, direct associations were examined on how dependent their retrievals were on the retrieval success of other direct associations within the same event – that is, within closed-loop events of Experiment 2 (see **Fig. 5a**) and Overlap events of Experiment 5 (see **Fig. 14a**). Dependency was almost significant in the former experiment (p=.07) and significant in the latter experiment, though unequal variances were found according to a Levene's test (F(1,56)=25.2, p<.001). A Welch's test then saw greater dependency in Experiment 5 (t(30.5)=3.12, p=.004, *d*=0.87). When dependency in closed-loop events of Experiment 2 was analysed with dependency in Unique events of Experiment 5, where it was significant (see **Fig. 14a**), a Levene's test again showed heterogeneous variances (F(1,56)=25.0, p<.001). Dependency was higher in Experiment 5, as noted by a Welch's test (t(28.5)=6.59, p=.02, *d*=0.72). Hence, encoded associations in an event relied on each other more for retrieval when they were presented together in a single image that might or might not overlap with another image, rather than sequentially as pairwise word associates.

9.2.2 Dependency Across Indirect Associations

Retrieval dependency across indirect pairs was significant within open loops in Experiment 2 (see **Fig. 5b**) and within overlapping pairs of events in Experiment 3 (see **Fig. 14e**), but a Levene's test showed that it had different variances across the experiments (F(1,56)=22.1, p<.001). A Welch's test was thus carried out, following which I saw dependency in Experiment 5 to exceed that in Experiment 2 (t(24.3)=2.93, p=.01, *d*=0.84). As with within-event dependency of direct pairs on each other, dependency of indirect pairs on one another was stronger across overlapping events seen as pictures than across overlapping associations seen as words and within a single event.

9.2.3 Dependency of Indirect Associations on Direct Linking Associations

Dependency of indirect associations on their corresponding direct linking associations was then investigated in Experiment 2 (see **Fig. 5c**), where the direct linking associations were within the same open-loop event as the indirect associations they supported, and Experiment 5 (see **Fig. 14f**), where the direct linking associations spanned over two overlapping events to connect elements in the associations inferred across the events. In both experiments, dependency was significant. Upon performing a Levene’s test, variances were found to be unequal (F(1,56)=33.4, p<.001) so comparison was done through a Welch’s t-test. Dependency was higher in Experiment 5 than in Experiment 2 (t(27.3)=4.76, p<.001, *d*=1.33), suggesting that indirect associations were more dependent on their direct linking associations for retrieval when they were inferred across two overlapping pictorial events than across two overlapping word associations within an event.

9.2.4 Dependency of Indirect Associations on Direct Non-Linking Associations

In Experiment 2, inferred associations in an open-loop event were not significantly dependent on direct non-linking associations (see **Fig. 5d**) but the opposite result was produced in the overlapping event pairs of Experiment 5 (see **Fig. 14g**). Nonetheless, further analyses were administered to confirm if dependency was indeed different in the two experiments. To compare their dependency, I began by conducting a Levene’s test, once again observing significantly different variances (F(1,56)=52.9, p<.001). A Welch’s test later demonstrated that dependency in Experiment 2 was weaker than it was in Experiment 5 (t(27.4)=5.17, p<.001, *d*=1.45). Thus, statistical dependency of indirect associations on non-linking direct associations was indeed higher when inferences were forged across two overlapping pictures than when they were yielded by overlapping word pairwise associates within an event.

9.3 Summary

All the dependency comparisons between Experiments 2 and 5 (see Chapters 3, 8 respectively) were unanimous in reporting higher dependency in Experiment 5. Directly observed associations depended more on each other for retrieval in Experiment 5 than in Experiment 2, and dependency across inferred associations was also more prominent in Experiment 5. Experiment 5 also presented stronger dependency of indirect pairs on linking direct pairs and on non-linking direct pairs compared to Experiment 2. Results from my analyses allude to greater pattern completion during retrieval of stimuli from an event that were learned together in a single picture than when the elements were studied as overlapping word pairs presented in series. Inferences made across two related, visually represented events were also retrieved using stronger and more comprehensive pattern completion of encoded associations as opposed to inferences formed across overlapping word associations within an event.

The idea that inference within and between events evokes different levels of pattern completion is up to discussion; what stipulates an event is still debatable (see Chapter 10 – Definition of an episodic event) and it is plausible that each of the attended overlapping associations in Experiment 2 might be an event on its own. If that is the case, then indirect associations were essentially deduced across events in both Experiments 2 and 5. Hence, differences between the two experiments in dependency concerning indirect associations were led less by the varying retrieval pattern of inferences in diverse associative structures but more by other reasons such as the display of elements as words or pictures.

Another potential factor driving higher dependency for direct and indirect associations in Experiment 5 in comparison to Experiment 2 is the concurrent delivery of stimuli during the presentation of each event. Upon being shown a picture depicting all the associations that comprised an event, coupled with the instruction to imagine the event occurring in real life as vividly as possible, participants might be able to encode each association under the same provision and with the same imagery processes (e.g. with the same imagined narrative uniting the elements). As a result, the connections between the elements could be strongly and more coherently induced. On the other hand, seeing pairwise associates one by one might cause each association in an event to differ in strength due to probable variations in processing (e.g. attention, awareness) across the encoding of each association. The inconsistency in the associations' strengths could prevent the associative links from being coherently established within the event. However, previous experiments have noted no difference in retrieval dependency amongst direct associations in closed- and open-loop events when the pairs were simultaneously studied versus when they were separated (Horner and Burgess, 2014). The difference in pattern completion-related findings between Experiments 2 and 5 could therefore be down to other causes. Nevertheless, it remains unknown whether dependency during the retrieval of inferences would be affected, especially since their retrieval pattern was distinct from that of encoded associations.

There is also a possibility that other differences in experimental design such as test procedure had contributed to the higher dependency seen in Experiment 5. For instance, adopting a forced choice recognition test with three alternatives might have required less pattern completion for accurate retrieval than the perhaps more difficult yes/no recognition task where a retrieval had to rely more on other retrievals to be successful. However, the encoding variations introduced in Experiment 5 are more crucial and thus might have played a bigger role in inflating dependency than changes made to the testing protocol.

The results overall could be attributed to the manner in which events were encoded – learning multielement events visually, some overlapping with another, could induce greater pattern completion when studied associations were recollected and when inferred associations were retrieved across overlapping events. On the other hand, less pattern completion might occur when the events were in the form of multimodal overlapping associations perceived as text and inferences were made across the associations within the same event.

10 Discussion

This thesis sought to explore how inferences within episodic memory and false memories mediated by inference are retrieved as well as the factors influencing their retrieval. Across all experiments and simulations, I provide evidence that unseen associations inferred across overlapping multielement associations or events depend on encoded associations and on each other for retrieval, corresponding to a pattern completion form of retrieval where successfully retrieving one inferred association also retrieves others including directly observed ones. However, illusory memories wrongly combining elements from similar events are retrieved by partial pattern completion of specific encoded associations together with failure to retrieve other direct associations within those events. Subjective confidence in directly seen and indirectly inferred associations as well as false memories that bind contents from overlapping episodes varies, demonstrating different levels of cognitive awareness that accompanies their processing. Results from the thesis bear important implications on our knowledge of episodic memory and anticipate how we can move forward in uncovering more about inference and false memories.

10.1 Retrieval pattern of encoded, inferred and false associations

10.1.1 Dependency of associations during retrieval

Here I demonstrated that when a multimodal ‘event’ consisting of a location, a person, an object and/or an animal is presented fully as serial pairwise associates (AB, BC, AC in an A-B-C event; as in Experiments 1-4, see Chapters 2, 3, 5, 7 respectively), retrievals of the associations were statistically dependent on each other (dependency in Experiment 2 was almost significant at p=.07 but not different than when it was significant in Experiments 1 and 3, see Chapters 4 – Results, 5 – Summary respectively). However, when not all associates were displayed (AB, BC, CD only in an A-B-C-D event), dependency was not observed among the retrievals, though non-presented inferred associations (AC, BD, AD) in the partially observed event exhibited dependency when explicitly retrieved (as in Experiments 1-3). This is attributed to their dependency on linking trained associations (e.g. AB and BC for inferred association AC) which included a common direct association (BC) that was relied on by all the inferred associations.

When overlapping multielement ABC-DEC events were presented (as in Experiment 5; see Chapter 8), I reported similar results with additional findings. Memory performance for encoded (e.g. AB) and inferred (e.g. AD) associations was good but participants also tended to falsely recognise elements adjoined from overlapping scenes (e.g. AE) especially if events shared the same place. Significant dependency persisted across explicitly recollected studied and inferred associations, but unlike in experiments where events were displayed as pairwise associates (as in Experiments 1-4; see Chapters 2, 3, 5, 7 respectively), inferred associations were on all direct associations from both events, linking and non-linking. False memory associations, which were made up of elements from events that overlapped each other and were incorrectly deemed as presented, did not exhibit dependency on direct associations. However, they happened more often when direct associations linking together the elements within the false memory associations were recollected (e.g. AC and CE for false memory AE) and direct associations which were correct alternatives to the false memories were forgotten (e.g. AB and DE for false memory AE).

10.1.2 Dependency reflects pattern completion

Statistical dependency observed between associations amid retrieval resembles pattern completion, since successfully retrieving a target association coincides with retrieving other non-target associations from the same event (Horner and Burgess, 2013, 2014; Horner et al., 2015). In cases where events were perceived as pairwise associates (as in Experiments 1-4; see Chapters 2, 3, 5, 7 respectively), direct associations within an open-loop event were independent of each other for retrieval because they could only be recollected individually. In a closed-loop organisation, however, pattern completion occurred as activity spread through multiple pathways to retrieve an association (e.g. retrieving AB via AC and BC), causing all of them to be retrieved in parallel. This holistic pattern of recollection also applied to the retrieval of directly learned associations that were presented simultaneously as an event (as in Experiment 5; see Chapter 8). Both Overlap and Unique conditions also did not differ in retrieval dependency across observed associations within event. The automatic spread of activity from the target to the non-targets within the same episode has been demonstrated previously in the fMRI scanner where activity in regions implicated in the encoding of non-target elements were reinstated along with those of target elements from the same event (Horner et al., 2015).

Inferences formed across overlapping material (associations or events) were never presented so they could not be retrieved on their own. Their retrieval was only possible via pattern completion of trained associations that guided the inference (e.g. AB and BC for inferred association AC in open-loop event A-B-C-D; AC and CE for inferred association AE in event pair ABC-DEC), and, for overlapping events, also those that did not (e.g. BC for inferred association AE in event pair ABC-DEC). Retrievals of inferred associations appeared to be interdependent due to their shared reliance on certain associations – it was BC for open-loop events (inferred pair AC depended on AB and BC, inferred pair BD depended on BC and CD, and inferred pair AD depended on AB, BC and CD) and all encoded associations for overlapping events.

Further dependency of indirect associations on non-linking direct pairs was described in Experiment 5, where overlapping events were studied, which was not found in other experiments which presented overlapping associations. The sweeping dependency that indirect associations had on all trained associates was potentially down to pattern completion being promoted by the encoding of all associations from each event (described as a ‘closed loop’ in Experiments 1-4). Therefore, retrieving an indirect link drawn between two complementary events would be accompanied by a spread of activity to all direct associations in the events involved. On the other hand, events in Experiments 1-4 were observed as sequential pairwise associates (i.e. AB, BC etc.), and for the events to afford inference, not all associations were shown (defined as having an ‘open-loop’ structure in Experiments 1-4, though Experiment 4 did not test for inferences). The retrieval of indirect associations, because they were non-presented, necessitated the spread of activity along encoded associations that supported the inference (e.g. AB and BC for indirect pair AC) but direct associations outside the inferential pathway (i.e. CD) did not allow for activity to propagate and help infer the indirect association.

Encoding events as single pictures that each consists of multiple types of elements (as in Experiment 5) seems to involve more prominent dependency and thus pattern completion when the observed associations are recollected and inferences across overlapping events are retrieved, compared to when the events are encoded as overlapping word associations viewed in series and inferences are formed across pairwise associates within each event(as in Experiments 1-4). Upon comparing Experiment 5 and with Experiment 2 (see Chapter 9), which was more similar to Experiment 5 than the other experiments that displayed events as overlapping associations (Experiments 1-3), dependency was consistently noted to be higher in Experiment 5. The distinction between presenting all associations (‘closed loops’) or only a subset (‘open loops’) might also explain the fact that in Experiment 5 where all events had a closed loop-like associative structure, dependency was similar across indirect pairs as it was across direct pairs, whilst in Experiment 2 where the events that allowed for inferences were open loops, dependency across indirect pairs was greater than that across direct pairs.

As for false memory associations (as in Experiment 5), the absence of pattern completion in their retrieval was expected due to their non-veridical nature. Instead, partial pattern completion was noted where successfully retrieving direct associations that connected the constituents of the false memory pairs (e.g. AC and CE for false memory pair AE) and failing to remember direct associations that contradicted the false memory pairs (i.e. AB and DE for both false memory pairs AE and BD) raised the likelihood of making an FA on the false memory pairs. Furthermore, because these false memory associations did not rely on a common direct linking association, proper dependency amongst their retrievals was absent.

10.1.3 Testing arrangements affect retrieval pattern

While encoded associations in an open-loop event are retrieved independently and its inferred associations are retrieved via pattern completion, encoded associations in closed-loop events can either be recollected through pattern completion or via independent means. Furthermore, because retrieval dependency could exist between different types of associations (e.g. between direct and indirect associations), the retrieval of one of them could affect the retrieval of others. The precise retrieval pattern for these types of associations can vary according to how they are tested and explains the results obtained in my experiments. Comparisons across Experiments 1 and 2 (see Chapters 2, 3 respectively) present a plausible speculation of what happens during episodic memory retrieval (see Chapter 4).

In Experiment 1, where direct and indirect associations were tested in an interleaved order and indirect associations in an open-loop event were probed first before direct associations in that event, direct associations belonging to closed loops were recollected via within-event pattern completion. Indirect associations, because they had never been seen, had to rely on pattern completion of direct linking associations that facilitated the inference (e.g. direct linking pairs AB and BC for indirect pair AC). This unintentional recollection of the direct linking associations enhanced the linking associations' memory traces such that when they were tested afterwards, they could all be retrieved more easily and accurately. The retrieval success of one of the direct linking associations in an open-loop event was therefore coupled with that of the other(s) (e.g. recollecting AB co-occurred with recollecting BC, both of which were direct linking pairs for indirect pair AC), creating a degree of dependency across direct associations in open-loop events that led it to be statistically on par with dependency in closed-loop events. This was especially true when the retrieval of indirect pair AD inadvertently recollected its direct linking pairs which were also all direct pairs in the open loop (AB, BC, CD), resulting in the coordinated retrieval of all the direct pairs. Dependency, nevertheless, was not significant in open-loop events since the dependence amongst encoded associations was contingent on retrieving inferences while dependency in closed-loop events was not similarly conditional.

When testing was split into two sessions, the first on direct associations and the second on inferred associations (as in Experiment 2), direct associations from closed loops recruited within-event pattern completion as before for recollection (dependency was only almost significant at $p=.07$ but it did not vary from that in Experiment 1 where it was significant). Direct pairs from open loops were still retrieved independently (although dependency was significantly negative, implying that retrievals of direct pairs in an event inhibited each other, it was no different from the non-significant dependency in Experiment 1) but their recollection further induced the retrieval of the inferred associations they supported (e.g. indirect pair AC for direct pairs AB and BC) since significant dependency existed between indirect pairs and their direct linking pairs. This strengthened the memory traces for the indirect associations enough for their eventual retrieval in the second test session to be more independent of the direct linking associations. What resulted was weaker retrieval dependency of indirect pairs on linking direct pairs, including that of indirect pair AD on all direct linking pairs, and in turn on other indirect pairs since indirect pairs were all reliant on the same linking direct pair (BC).

Ultimately and admittedly, the application of two manipulations to the testing procedure, namely the order of retrieving direct and indirect pairs relative to each other and the extent to which their retrievals are separated, had prevented a clearer attribution of an effect to a particular factor. Various explanations could be derived to interpret the disparities in the dependency results in Experiments 1 and 2. For instance, although dependency across direct associations in open-loop events did not differ between Experiments 1 and 2, it dropped significantly below zero in Experiment 2, suggesting that the retrievals of the pairs interfered with one another. This ‘anti-dependency’ might be a consequence of testing the non-dependent direct pairs ahead of the highly interdependent indirect pairs from the same open loop, or it might be attributed to the sequestering of the non-dependent direct pairs from open-loop events and the dependent direct pairs from closed-loop events in distinct retrieval sessions, or even both; either way, the exact culprit could not be pinpointed. I will address the ambiguity in defining the effects of testing conditions on retrieval in a later section where I will also propose a solution (see Chapter 10 – Criticisms and how to improve the experiments).

10.1.4 Repeated presentation weakens dependency if repetition is massed

Repetition of overlapping associations during encoding was assessed in Experiments 3 and 4 (see Chapters 5, 7 respectively) to learn if the resulting improvement in memory for indirect associations to perhaps the same level as that for direct associations, or nearly, could ‘close’ the open loop and retrieve all of them with significant interdependency as how it is in a closed loop that has all its associations well-recollected. Repeatedly viewing overlapping pairs has, after all, been demonstrated to profoundly boost the retrieval of inferences formed across the pairs (Zeithamova et al., 2016). Empirical data in the thesis, however, showed that repetition of pairwise associates spaced throughout the retrieval phase (as in Experiment 3) did not alter dependency for all types of association (direct or indirect) and associative structure (closed- or open-loop). Nevertheless, a more temporally condensed form of repetitive encoding where associations were repeated within an encoding session (as in Experiment 4) and not across several of them eliminated any dependency present among the studied associations. These results implied that repeating overlapping associations throughout the study phase and thus strengthening their memory traces such that performance for repeated events was greater versus single events did not make pattern completion more likely nor less so for both directly learned and inferred associations. However, constricting repetition of associations within one session in the study phase, still driving higher accuracy rates for repeated than for single events, would be enough to retrieve the associations on their own, separate from retrievals of other associations in the event.

It appears that when a pairwise associate is learned multiple times within a short enough time frame, memory for it will be salient enough for it to be retrieved independently without needing to rely on pattern completion that involves other related associations. This did not take place when repetition was more spread out, perhaps because the temporal gap between each repeated association was too large for memory to improve enough for independent retrieval. To establish whether memory performance was indeed better when repetition was compressed than when it was distributed, I compared accuracy scores in both conditions. According to Levene’s tests, variances did not differ in single closed (F(1,75)=0.39, p=.53), single open (F(1,75)=0.01, p=.91) and repeated closed events (F(1,75)=2.19, p=.14) so one-way ANOVAs were conducted for these conditions, but unequal variances were found in repeated open loops (F(1,75)=3.97, p=.05), calling for a Welch's test instead. Accuracy was higher with mass repetition than with spaced repetition for single closed (F(1,75)=9.24, p=.003, ηP^2=.11), single open (F(1,75)=5.64, p=.02, ηP^2=.07) and repeated closed events (F(1,75)=4.63, p=.04, ηP^2=.06), and was nearly significantly so for the repeated open events (t(74.8)=1.82, p=.072, *d*=0.41). It was therefore possible that repetition during encoding would only impair dependency of associations if it succeeded in enhancing memory across a certain threshold.

10.1.5 Repeated testing decreases dependency relating to inferred associations

When the retrieval of overlapping events was studied (as in Experiment 5; see Chapter 8), the double testing of false memory and indirect associations within their test phase was imposed to inspect the effect of repeated retrieval on coherence of recollection (denoted by dependency) of false memories and on inferential processes. What I encountered was that retrieving these associations twice had no impact in almost all memory performance and dependency analyses except for memory for indirect associations as well as dependency of indirect associations on viewed pairs, linking and non-linking, and on false memory pairs. In these cases, d' and dependency diminished by the second retrieval but remained significant. A potential reason for the worsening of d' when inferred associations were tested again is reconsolidation, where the reactivation of a stored memory returns it temporarily to a labile, vulnerable state that needs time to stabilise (Lee et al., 2017; Alberini and LeDoux, 2013; Walker et al., 2003). Repeated retrieval thus makes it harder to properly consolidate and recognise an indirect association again.

False memory associations were relatively rare and hence probably without strong neural representation that could be disrupted by reconsolidation, so d’ and dependency relating to false memories (other than their dependency on indirect pairs) was not reduced on the second test.

Reconsolidation studies have demonstrated how less effective initial learning could drive memory extinction (Eisenberg et al., 2003; Lee et al., 2006; Flavell and Lee, 2013), suggesting that inferences are more easily jeopardised by reconsolidation than encoded memories due to weaker memory traces. The amnestic effects of reconsolidation may also extend to associative relations that the inferences formed with other stored associations within their corresponding event, be it direct or false memory associations, resulting in the observed decline in dependency. Research has pointed to the candidacy of the hippocampal CA_3, which possibly supports recollection of inferences via pattern completion (as in Experiments 1-3, 5; see Chapters 2, 3, 5, 8 respectively), as a substrate for reconsolidation (Osan et al., 2011; Artinian et al., 2007), but nothing has yet hinted that this causes inferred associations to be especially impaired by the process. While repeated testing of learned material has been said to encourage the recovery of memory accuracy (Roediger and Payne, 1982; Wiklund-Hörnqvist et al., 2014), in the broader context of eyewitness memory where remembering an event is a reconstruction of veridical and inferential information, retrieving a memory again might only contaminate it (Wixted et al., 2021; Chan et al., 2011 but see Bornstein et al., 1998). Future studies could expand repetitive testing to encoded associations to confirm if the differences between false memory and indirect associations in their sensitivity to repeated retrieval is down to the explicit versus implicit distinction in recollection or the peculiar encoding, consolidation and/or retrieval mechanisms underlying false versus true memories.

10.1.6 Memory for inferred associations best for events with person in common

Experiment 5 on overlapping events (see Chapter 8) also saw that performance, confidence and dependency trends did not vary as a function of category of overlapping element (person, location or object) except for the ability to infer explicitly across overlapping events. It is easier to remember inferences made across events that have a person rather than a place or an object in common possibly because people in an event are very often associated with other elements such as a place and an item whereas places and objects are not as frequently connected to other elements when in an event. Meeting Albert Einstein will prompt attention towards where he is and what he is with, but seeing a basketball court will not trigger as immediately questions of who and what else are there, and neither will a book. Existing literature has not looked at how the type of overlap between two events influences retrieval, and studies examining confidence-accuracy relation for items of the same modality even present opposing results (e.g. Nguyen et al., 2018 showing correlation during face recognition versus Busey et al., 2000 showing non-correlation). The partiality in memory for indirect associations favouring events sharing a person also failed to translate into higher confidence during inferential decisions on Person Overlap events versus other events, and this is potentially due to the unconscious nature of the bias. The lack of effect of overlap type elsewhere in this experiment could possibly be because participants paid an equal amount of attention to the person, location and object available within each scene in an effort to imagine the event on screen occurring as in real life, as instructed during the study, so veridical recollection was equally well for all the elements. More experiments could be carried out to test the prediction that attentional preferences and pre-existing schemas favour the assembly of information around a central figure and not other element types.

10.1.7 Behavioural data supported by hippocampal memory model

A neural network model of hippocampal memory function was able to reproduce the thesis's empirical findings on memory accuracy and dependency concerning encoded overlapping associations (see Chapter 6). The model was initially designed to simulate Experiment 3, which assessed the effect of encoding repetition on the retrieval of observed and inferred associations (see Chapter 5), and it succeeded in replicating empirical findings not only from the experiment but also from the other experiments which explored similar objectives, i.e. Experiments 1, 2, 4 and 5 (see Chapters 2, 3, 7, 8 respectively). Generally, it affirms the findings that closed-loop events were associated with retrieval dependency and open-loop events with its absence, and that inferred associations were dependent on related direct associations and in turn on each other. Closed-loop events were also better remembered than open-loop events, and memory for both was enhanced by repeated presentation. The corroboration of empirical data by the simulation confirms an auto-associative network in charge of holistically reinstating learned associations only in closed-loop events as well as inferred associations in open-loop events.

Nevertheless, on some points, the neurocomputational model diverged from behavioural data in Experiment 3, likely because the model did not incorporate other features of episodic memory. In one such occasion, the neural network showed how repetitive encoding boosted dependency of inferred associations on each other and inferred association AD on all direct linking associations while repetition effects in Experiment 3 were non-significant. Additionally, unlike Experiment 3 which found no effect of repetition on the disparity between dependency of indirect associations AC and BD on their direct linking associations and that of indirect association AD on all direct linking associations, the hippocampal model demonstrated that when associations were repeatedly learned, the gap widened. These outcomes were justified by the probability that overall, as a consequence of repetition-mediated increase in performance, there were fewer answers that were guesses (and were hence independent) compared to those that could be explained by pattern completion (and so showed dependency), thus enhancing dependency in the simulations. However, it does not resolve why other dependency analyses involving indirect pairs, i.e. dependency of indirect pairs on direct linking pairs and on direct non-linking pairs, were uninfluenced by repetition in the simulated data. Furthermore, considering that repeated learning did not change dependency of indirect pairs AC and CD on their linking direct pairs but strengthened dependency of indirect pair AD on all linking direct pairs, and that the former dependency was still greater than the latter dependency, the increased gap between the two that was caused by repetition, when it should have been decreased, needed more investigation. Perhaps the multiple presentation of the same association triggered pattern separation processes in the hippocampus (Leutgeb et al., 2007; Yassa and Stark, 2011; Zotow et al., 2020), encoding the repetitions as slightly varied memory traces and boosting performance without enhancing dependency among associations within event. However, this discriminability did not inform the model, which assumed that the repetitions were identical representations. Dependency therefore was estimated by the neural network to increase proportionately with every repetition, while in fact it should remain resistant to recurrence.

While my computational model was designed to be a canonical account of hippocampal pattern completion, it could be further refined to encompass other critical aspects of coherent and flexible episodic memory which might also enable it to better fit empirical data. Events are typically encoded, retrieved and inferred across using substrates other than simple recurrent processing in the hippocampus. Pattern separation in the dentate and CA_3 (Leutgeb et al., 2007; Yassa and Stark, 2011; Zotow et al., 2020), familiarity in the perirhinal cortex (Henson et al., 1999), prefrontal and parietal areas (Yonelinas et al., 2005), and salience via bottom-up modulation in the insula (Menon and Uddin, 2010) are some of the components that are at play amid learning, while inference was thought to be aided by working memory in prefrontal cortical regions (Kojima et al., 1982) as well as parieto-occipital areas (Berti et al., 2000) among other functions. Because the role of encoding and retrieval mechanisms in inference was not yet clarified, models that could test to what extent the two processes mediate inferential decisions could also be developed.

10.1.8 Relationship between dependency and performance

Retrieval dependency is believed to facilitate recollection of associations in an event since retrieving one association will retrieve the other associations as well. For example, in response to a trial testing memory for an association AB from a closed-loop event ABC, retrieving AB would automatically recollect BC and AC too, strengthening the memory engrams of the two latter associations and raising the likelihood of accurately retrieving them when they were later tested. In all the experiments that presented associations in open-loop and closed-loop configurations (Experiments 1-4; see Chapters 2, 3, 5, 7 respectively) and echoed by results from the computational model (see Chapter 6), memory for direct pairs was observed to be higher in closed loops than in open loops. Considering that both loop types were encoded under the same circumstances, and that dependency was implicated in closed loops but not in open loops, this finding confirms the presumption that within-event dependency promotes memory for associations in the event.

For each of the experiments involved, Pearson correlations were conducted to better evaluate the relationship between memory accuracy and statistical dependency in each loop type. Experiment 1 showed no significant correlation in closed-loop (*r*=-.23, n=24, p=.29) and in open-loop events (*r*=.01, n=24, p=.97), and neither did Experiment 2 in closed-loop (*r*=.15, n=33, p=.42) and in open-loop events (*r*=.04, n=33, p=.85). In Experiment 3, correlations were also absent in all event types – single closed (*r*=.03, n=42, p=.85), repeated closed (*r*=.01, n=42, p=.93), single open (*r*=-.17, n=42, p=.27) and repeated open loops (*r*=.04, n=42, p=.79). The neural network simulating Experiment 3, however, reported that performance corresponded with dependency in the single closed condition (*r*=.38, n=43, p=.01) – though this anomaly might be attributed to the absence of other episodic memory functions, including non-hippocampal ones, in the model (see Chapter 10 – Behavioural data supported by hippocampal memory model) – but no correlation in the rest of the events, i.e. repeated closed (*r*=-.07, n=43, p=.64), single open (*r*=.03, n=43, p=.86) and repeated open loops (*r*=-.16. n=43, p=.30). Experiment 4 continued the pattern of no relation between memory and dependency for direct associations, noting none in single closed (*r*=-.22, n=32, p=.24), single open (*r*=-.34, n=32, p=.054), repeated closed (*r*=-.08, n=32, p=.66), and repeated open events (*r*=.15, n=32, p=.41). Reconciling these correlation data with the observation that closed loops were often associated with better performance, it seems probable that the general relationship between performance and retrieval dependency follows a positive, nonlinear profile where closed-loop structures are better in both measures than open-loop structures. Other explanations include the prospect of a different performance-dependency relation for events that display significant dependency compared to events that do not, resembling a sigmoidal description that changes when a certain threshold is achieved. Further studies should be carried out to confirm how exactly associative memory varies as a function of dependency.

With respect to multielement events learned as images (as in Experiment 5; see Chapter 8), no proper deduction could be made on the effect of dependency across encoded associations on memory performance (indicated by d’ for direct pairs). All events in the experiment showed within-event dependency so I was not able to note what would happen to performance if dependency was absent, contrary to the other experiments where some events exhibited dependency (closed loops) and others did not (open loops). Still, Pearson correlations were run between performance and dependency to observe how the two were related within events that demonstrated dependency. Given that d’ for direct pairs and dependency across direct pairs in Person Overlap, Location Overlap and Object Overlap events did not differ, correlations were carried out across all overlapping events irrespective of overlap type. d’ for direct associations was reported to correlate with dependency across direct associations (*r*=.59, n=25, p=.002) and so did d’ in Unique events (*r*=.45, n=25, p=.03). Therefore, events where associations were concurrently encoded and were interdependent retrieval-wise showed a consistent relationship between accuracy and dependency unlike their analogous counterpart, the closed-loop events, which also had such dependency.

Similarly, for associations inferred across overlapping associations or events, it is not feasible to probe if dependency facilitated retrieval accuracy. Where inferences were examined (Experiments 1-3, 5 and computational model), none of the conditions tested were devoid of dependency and so the consequence of possessing no dependency on performance in an inference test could not be studied. Correlations were nevertheless conducted to identify any link between accuracy for indirect pairs and dependency across the pairs in events which already presented such dependency. A significant correlation was not seen in Experiment 1 (*r*=.28, n=24, p=.18) but it was in Experiment 2 (*r*=.42, n=33, p=.02) as well as in the single (*r*=.56, n=42, p<.001) and repeated events of Experiment 3 (*r*=.45, n=42, p=.003). Simulations by the memory model noted a correlation only in singly presented events (*r*=.50, n=43, p=.001) but not in repeated ones (*r*=.26, n=43, p=.09). Because there was a main effect of overlap type in memory for inferences in Experiment 5, performance was analysed by overlap condition, revealing that it did not vary with dependency in Person Overlap (*r*=.29, n=24, p=.17), Location Overlap (*r*=.09, n=25, p=.67) and Object Overlap events (*r*=.06, n=25, p=.76). Seeing that dependency among indirect associations was significantly lower in Experiment 2 than in Experiment 1 (see Chapter 4) and in Overlap events of Experiment 5 (see Chapter 9; overlap type had no effect on dependency so all Overlap events were examined), and that significant correlations were detected in Experiment 2, one possibility is that dependency only begins to linearly influence performance when it reaches a high enough level. To assess if dependency across indirect associations in single events of Experiment 3 was also poorer than that in the singly presented events of Experiment 1, a Levene's test was conducted beforehand to determine if variances in both experiments were different. They turned out to be equal (F(1,64)=2.69, p=.11) so a one-way ANOVA was performed, indicating no difference in dependency between the experiments (F(1,64)=0.01, p=.91). Dependency in Experiment 3 was then contrasted with that in Experiment 5, a Levene's test observing different variances (F(1,64)=36.9, p<.001). A Welch's t-test consequently found dependency to be significantly greater in Experiment 5 (t(26.6)=-2.22, p=.04, *d*=-0.62). It thus could not be said that a linear relationship exists between performance on inferred associations and the statistical dependency across them when dependency is sufficiently strong. Further investigation is necessary to understand the link between memory for inferences and the retrieval dependency among them.

10.1.9 Greater pattern completion when retrieving events encoded simultaneously as pictures than sequentially as word associations

It also appears that learning multielement events in the form of single pictures (as in Experiment 5; see Chapter 8) induces stronger pattern completion amid retrieval than encoding the events as a series of overlapping word associations (as in Experiments 1-4; see Chapters 2, 3, 5, 7 respectively). In a comparison between the two approaches using Experiments 2 and 5 (see Chapter 9), directly observed associations from the same event were reported to be more dependent on each other if they were simultaneously learned as images. Indirect associations inferred across two overlapping visual events were also more reliant on direct associations for retrieval than indirect associations inferred across two overlapping word pairs were, in addition to displaying more extensive dependency that encompassed all direct associations within the events involved as opposed to just the linking direct associations. Although the type of test used in the two protocols could be responsible for the variation in dependency results (cued forced choice recognition with three alternatives in Experiment 2 versus yes/no recognition in Experiment 5), it would not be expected to produce such stark differences in dependency. The manner in which associations were delivered during study is instead likely to be more influential in determining how they would be retrieved.

Thus, the possible source for the high dependency shown by studied and inferred associations in Experiment 5 compared to Experiment 2 could be the presentation of elements as images, the concurrent display of associations from the same event, or, where indirect associations were concerned, the formation of inferences across events and not within them. However, neither of these could be conclusively verified as the cause. Mixed findings could be observed in studies that compare memory for pictures and for words, with some saying that pictures are better remembered (Jenkins et al., 1967; Snodgrass et al., 1972; Noldy et al., 1990; Grady et al., 1998) and others showing the contrary (Paivio and Csapo, 1971) but no experiments have yet demonstrated their differential effects on holistic retrieval of events. An earlier study had also ascertained no change in dependency across encoded associations in closed- or open-loop events whether the associations were learned together or separately (Horner and Burgess, 2014), though nothing was yet known about pattern completion during retrieval of indirect associations. Lastly, forging inferences across overlapping associations within an event might actually be the same as inferring across overlapping events, considering that overlapping associations were learned at different time points and thus could be events themselves. It hinges on what an episodic event really is, which is still a topic under research (see Chapter 10 – Definition of an episodic event). If each presented pairwise associate was itself an event, then the stronger dependency that existed between indirect associations and learned associations in Experiment 5 than in Experiment 2 could not be pinned down to differences in the structural organisation of the associations. Further study seems necessary to confirm which of the proposed encoding-related factors boosted dependency measures in Experiment 5.

10.2 Inference

10.2.1 Inference reveals reconstructive nature of memory

The coherent retrieval of indirect associations within an event emphasises the reconstructive aspect of episodic memory which stores information as well as flexibly infers across retained memories. Findings from Experiments 1-3 and the computational model, where overlapping associations were learned (see Chapters 2, 3, 5, 6 respectively), pointed to the successful inference of unencoded associations through pattern completion of direct linking associations despite no pattern completion of encoded associations within the same event. Experiment 5, which presented overlapping events (see Chapter 8), also demonstrated how unseen associations inferred across overlapping events were retrieved through pattern completion of all directly studied associations in both events, linking or non-linking. False memories of associations binding elements from overlapping events were also not encoded but they only engaged limited pattern completion that built upon retrieving and forgetting specific associations since they were inherently inauthentic. These observations support a retrieve-and-integrate account of associative inference (Banino et al., 2016; Kumaran and McClelland, 2012; Wu and Levy, 2001; Carpenter and Schacter, 2017; Schacter and Addis, 2007a, 2007b; Zeithamova et al., 2012a, 2012b) whereby inferential reasoning pivots on the independent retrieval of trained associations via pattern completion.

10.2.2 Does inference occur during encoding or retrieval?

Based on earlier literatures and findings from this thesis (as in Experiments 1-3, 5, hippocampal model; see Chapters 2, 3, 5, 8, 6 respectively), inference is perhaps governed by both encoding and retrieval operations. One view speculated that events might have been recorded as individual memory traces and when later recollected, are recalled and recombined for inferential interpretation (Banino et al., 2016; Kumaran and McClelland, 2012; Wu and Levy, 2001; Carpenter and Schacter, 2017, 2018). The retrieval of the relevant overlapping stimuli AB and BC might have taken place to make an inference AC. Indeed, computational models that undertake retrieval-based inferential operations whereby AC is retrieved through the recollection of AB and BC fit behavioural accounts best (Banino et al., 2016). On the other hand, inference might have been mediated by dynamic learning interactions whereby overlapping past events are retained as unified mnemonic representations (O'Reilly and Rudy, 2000; Shohamy and Wagner, 2008; Howard et al., 2005; Schlichting et al., 2014). The learning of an association BC, which overlaps with a previously studied association AB, might activate integrative mechanisms that recollect the old AB association and incorporate it with the new BC association to form the assimilated ABC memory. There are studies reporting that amid exposure to the second overlapping pair BC, activity was observed in the hippocampal CA_1, which is implicated in memory integration, and in areas responsive during the encoding of the first overlapping pair AB, correlating with inference success (Schlichting et al., 2014; Zeithamova et al., 2012a). What my findings and hippocampal model suggest is that inference emerges from pattern completion engaging the relevant direct associations during retrieval but I am unable to further disambiguate the timepoint at which inference occurs. However, if indeed indirect associations developed pre-retrieval, they were too ineffectual to generate dependency between direct associations from open-loop events, let alone dependency to the extent of that in closed-loop events. In addition, the variation in dependency results that was brought about by modifying test arrangements, namely the order of retrieving direct and indirect associations relative to each other and the extent to which their retrievals are separated (as in Experiments 1 and 2), alludes to the influence of diverse retrieval processes on one another (see Chapter 10 – Testing arrangements affect retrieval pattern). Being tested on an indirect pair, for example, could compel the recall of direct pairs that it depended on for retrieval and hence strengthen the pairs' memory traces such that when they were tested later, their retrievals might be less reliant on each other (as in Experiment 1). Taking together findings from this thesis and previous works, it is possible that this dynamic also takes place during encoding when overlapping associations are learned, retrieved and integrated, though retrieval-related mechanisms might be more crucial for inference formation. When exactly inferences are formed along the timeline of an episodic memory is a topic for further research.

10.2.3 Inference in experiments versus in real life

There was a categorical instruction in Experiments 1-3 and 5 (see Chapters 2, 3, 5, 8 respectively) to deduce any indirect connection between a cue and its test options, so inferential reasoning was licensed. This is in contradiction to congruous real-life experiences where such inferences might not always transpire. While encountering the associations ‘Obama-Kitchen’ and ‘Kitchen-Hammer’ in Experiments 1-3 would compel participants to associate ‘Obama’ and ‘Hammer’ indirectly, coming across such events in real life would not necessarily prompt them to infer any relationship between Obama and the hammer. Similarly, events-wise (as in Experiment 5), if someone did meet Alicia Keys at a basketball court and later returned to the same spot to see Albert Einstein in her place, the observer might not naturally assume that Keys and Einstein were related. However, in the retrieval phase of Experiment 5, indirect links between the two events such as ‘Keys-Einstein’ were specifically asked to be formed. In the real world, making inferences may be controlled by various determinants that were not scrutinised in my experiments, such as context (Bransford and Johnson, 1972; Godden and Baddeley, 1980; Smith and Vela, 2001), memory interference (Shapiro and Olton, 1994; Anderson and Neely, 1996; Robertson, 2012), prior knowledge (Alba and Hasher, 1983; Preston and Eichenbaum, 2013; Wang and Morris, 2010; van Kesteren et al., 2010) and schemas (Tse et al., 2007; Ghosh and Gilboa, 2014). To more precisely investigate inferential decisions made across complementary associations or events, a future study could look at when the inferences are specifically licensed, when they are not alluded to in the instructions, and when they are prohibited.

10.2.4 Different conditions make for different inferential processes

Although inferences were explicitly asked for in my experiments, the intentionality underlying them might be varied by retrieval conditions and might modulate how much pattern completion was recruited during retrieval. Where test trials for direct and indirect associations were alternating (as in Experiment 1; see Chapter 2), participants were unable to prepare for the type of upcoming retrieval, prompting them to rely on a more automatic kind of inference that relates to already bound representations. There might consequently be stronger reliance on pattern completion, which is crucially known for being automatic. However, isolating the retrievals into two predictable blocks (as in Experiment 2; see Chapter 3) could allow for a more voluntary retrieve-and-integrate approach whereby individual associations were recalled and merged, and this might engage less pattern completion. This proposed narrative is supported by the greater dependency of inferences on related direct associations in Experiment 1 than in Experiment 2 (see Chapter 4) and abides by the component process model (Moscovitch et al., 2016) which speculates that cued retrieval first triggers quick hippocampal processing that may lead to slower and deliberate mechanisms in the frontoparietal networks for conscious reactivation of a memory. In Experiment 5 (see Chapter 8), illusory memories mixing up elements from similar experiences were implicitly queried and so were a form of automatic, subconscious inference, but they were retrieved through weaker and less extensive pattern completion than when explicitly tested indirect associations were. This could be due to the essential nature of the false memories, being the likely result of stunted pattern completion which, if allowed to be fully instantiated, would not generate such errors. The effect of voluntary control during retrieval on the involvement of pattern completion might hence only be prominent in inference-guided memories and less so in inauthentic ones. An interesting area to explore would be the difference in the amount of pattern completion engaged based on whether retrieval, for inferred as well as learned material, is intentional or not.

10.3 False memories caused by overlapping events

10.3.1 Causes of false association of elements from overlapping events

Retrieving false memory associations seems to rely on limited pattern completion that is contingent on remembering some directly learned associations while forgetting others (as in Experiment 5; see Chapter 8). There are several situations in which elements from two overlapping events could be mistaken as belonging to a single episode including the accurate recognition of direct associations that connect elements in the false memory association (i.e. AC and CE for false memory AE; BC and CD for false memory BD). Indeed, when this condition was fulfilled, more illusory memories occurred in Experiment 5. Mistaken re-combinations of elements from two overlapping events could also arise from forgetting the encoded associations that contradict with the false associations (i.e. AB and DE, disproving both false memories AE and BD). When these direct associations were not correctly remembered, recollecting fabricated memories became almost significantly more likely. In sum, results in Experiment 5 indicate that the retrieval of both direct linking associations and the failure to recall of both alternatives to the false memories may contribute to the development of the false memories.

Another way to think about the occurrence of false memories is that they form when two overlapping events interfere with one another amid retrieval (Roediger and McDermott, 2000). In this view, strong direct linking associations and weak associations to the alternative answers would more often than not cause interference of a kind that results in a false memory, even though it is not always necessary that genuine memories need to be corrupted for this to happen (Kopelman, 1999).

In literature, false memories ascribing content from one event to another overlapping event have been linked to the inference of indirect associations between events, but whether this inference contributes to the occurrence of false memories has not been precisely substantiated. There is some evidence for the idea that retrieval-related operations which help recombine encoded materials across similar content are also culpable of erroneously upholding them as genuine experiences (Devitt et al., 2016; Carpenter and Schacter, 2017, 2018; de Araujo Sanchez and Zeithamova, 2020). In Experiment 5, however, false memories were detected in the associative memory test (test phase I) ahead of the test of explicit inferential memory (test phase II), demonstrating that inference is not a prerequisite for such memory errors even if both depended on similar processes. It is also possible that false memories could result from inferential processes during encoding and/or consolidation. Indeed, there are studies suggesting that mix-ups over similar but distinct episodes could be driven by deficient encoding (Okado and Stark, 2005; Abe et al., 2008; Ecker et al., 2011), influenced by delays in retention (Payne et al., 1996; Nessler and Mecklinger, 2003) or instigated by reconsolidation (Hupbach et al., 2007, 2009; Bryant et al., 2020). Future experiments could introduce more manipulations to the protocol in Experiment 5 to find out when precisely fictional memories are falsely believed as genuine experiences and whether they develop at the same rate before and after inferential judgements are made.

10.3.2 False association of elements from overlapping events versus from unrelated events

One point of interest is the distinction in retrieval mode between the two kinds of memory failure detected in Experiment 5 (see Chapter 8) – misattributions of elements to the overlapping event (such that element A from event ABC is said to belong with element E from event DEC) and mispairings of elements from unrelated events (for instance A with Z from an unconnected event). Participants recorded a significant d’ for false memory pairs, which from its calculation (see **Equation 6**) meant that FAs for pairs of elements from overlapping events significantly surpassed FAs for pairs of elements from nonrelated events. It is also likely that false memories combining elements from two unlinked events would have less retrieval dependency on each other than inference-mediated false memories blending two related events since the latter relies on legitimately encoded associations while the former does not. Further examination of retrieval dependency across FAs for unrelated pairs within a pair of overlapping events could substantiate if this speculation is true.

10.4 Inference versus false memories caused by overlapping events

Comparisons in terms of retrieval between true memories of inferred associations and fictional memories binding elements that belonged to distinct but overlapping events were explored in Experiment 5 (see Chapter 8). Although both engaged inferential reasoning across similar events, they illustrated varying degrees of pattern completion amid retrieval. In a pair of overlapping events, retrievals for indirect associations were dependent on all associations – direct, false, indirect – in both events, whereas recollecting false memory associations relied only on recognising certain direct associations and not others as well as inferred associations within the same event pair. Thus, the extent to which inferences are explicitly made, i.e. specifically confirming whether two items were from overlapping events versus implicitly mistaking them for having been seen together, may determine what processes occur, with explicit inference displaying pattern completion via other associations much more robustly than unconscious false memories.

Despite differences in their retrieval, inferred associations were dependent on false memory associations for retrieval success. This is perhaps because the illusory associations (e.g. AE) aided in connecting the indirect associations (AD and BE) within a pair of overlapping events and supported the inference underlying the indirect associations (see **Fig. 12a** for an illustration of event structure). In a similar way, retrieving false memories conjoining elements from overlapping events (e.g. AE) depended on retrieval of inferences made across the events potentially due to the indirect associations (AD and BE) linking the elements comprising the false associations (e.g. AE). Although reliant on recalling indirect associations, false memory associations did not exhibit retrieval dependency on individual direct associations as indirect associations did within the same pair of overlapping events. However, the false memories were, as explained earlier, preferentially boosted by the recall of certain directly observed associations.

A prospective area of research is on how the dependence of indirect associations on false memories reflects the order of the test phases in Experiment 5. It may be that false positive responses in the first test phase about items from overlapping events bolster the ability in the later test phase to forge clear-cut inferences about indirect associations, or that false memories and explicit associations implicate some common aspect of memory for the overlapping events which is not properly captured by their dependency on encoded associations, in which they vary. These observations highlight how a memory can present itself differently under particular testing conditions, as shown by my findings on testing arrangements (see Chapter 10 – Testing arrangements affect retrieval pattern) and double testing (see Chapter 10 – Repeated testing decreases dependency relating to inferred associations) and as reported by studies on the effects of retrieval context on false memory (Jacoby and Whitehouse, 1989; Matzen and Benjamin, 2009; Tehan et al., 2004; Tamminen and Mebude, 2019). Enforcing a sensitive testing protocol is therefore vital.

Another similarity shared by inferences and false memories derived from overlapping events is that their retrieval implicates the reinstatement of encoding activity that is related to their constituent elements, though this is an area that my thesis was not able to examine. Both types of memory are deduced from genuinely encoded stimuli and hence call upon processes resembling those that carry out true recollection although the memories have never strictly taken place. Brain activity during learning has been seen to be reinstated when retrieving knowledge inferred from the studied material (Schlichting et al., 2014; Horner et al., 2015) and some studies hint at a similar reinstatement underlying the retrieval of source misattributions (Hupbach et al., 2009; Gershman et al., 2013; Carpenter et al., 2021). Although Experiment 5 is grounded on behavioural data and therefore could not study reinstatement phenomena, I would expect that, if this thesis incorporated a neuroimaging investigation, retrieving associations inferred across two overlapping events would reinstate the neural activity that accompanied the encoding of all direct associations in both events. Meanwhile, retrieving erroneous combinations of elements from two overlapping events would reinstate neural activity observed during the retrieval of direct associations that linked the elements (e.g. AC and CE for false memory AE) but not direct associations that contradicted the false memories (AB and DE for both false memories AE and BD). My predictions are built on the results in Experiment 5 which noted that retrieval of inferences induced complete pattern completion of all studied associations in the events involved whilst retrieval of false associations of elements from overlapping events hinged upon recalling linking direct associations and not the true alternatives to the false memories.

10.5 Confidence

10.5.1 Confidence may indicate memory strength

Variations in confidence among memory for encoded, false and inferred associations (as in Experiment 5; see Chapter 8) were explained by the view that metamemory accuracy draws from strength of memory (Wixted and Mickes, 2010; DeSoto and Roediger, 2014; Roediger and DeSoto, 2014). Subjective confidence was strongest when recollecting encoded information compared to retrieving false memories and inferences because all directly observed associations, regardless of whether they were from overlapping or non-overlapping events, had more robust memory traces than the rest of the tested associations which were never encoded and were thus grounded in weaker memory traces. This complemented the finding that performance on direct associations was better than on other association types within both overlapping and non-overlapping conditions. Similarly, inaccurate conjunctions of elements from overlapping or unrelated events in both test phases were wrongly recognised with the same level of certainty as each other and as when inferences were correctly recognised since all of them were never observed and so had feeble or even non-existent memory engrams. It should be noted that participants' higher performance on indirect pairs than on false memory pairs and greater inclination to incorrectly endorse pairs of elements merged from overlapping events than those from unrelated events (as reflected by significant d' for false memory pairs; see Chapter 8 – Method) do not mean that inferred pairs had stronger memory traces than false memory pairs which in turn had stronger memory traces than unrelated pairs. The production of inferences and false memories after observing overlapping events was instead driven by reconstructive mechanisms which were missing during the retrieval of unrelated pairs in any test phase, explaining better memory for inferred and false memory pairs than for unrelated pairs. Performance on the various pair types, therefore, was not representative of confidence in their recognition. Element pairs from unrelated Overlap events in each test phase were also wrongly recognised with the same amount of confidence as pairs from unrelated Unique events in each test phase, seeing that they were both encoded under similar circumstances and so had equally robust memory traces.

The importance of memory strength as a subjective estimator of accuracy was also demonstrated in the study of closed-loop and open-loop events (as in Experiment 4; see Chapter 7). Overlapping pairwise associates irrespective of the loop configuration they belonged to were encoded under the same provision and hence predicated on memory engrams that were no different in strength. Consequently, the associations were retrieved with equivalent levels of confidence in closed-loop and in open-loop events. Memory for associations from closed loops did surpass that from open loops but it was not due to differences owing to stability of memory traces. Instead, it was attributed to within-event dependency in closed loops which increased the chances of all associations being retrieved accurately after one had been recollected. Dependency was absent in open-loop structures, resulting in no similar facilitation in retrieval, but associations in either loop type had memory engrams that were similar in strength and thus deemed by metamemory appraisal processes to be equally reliable.

Repeatedly learning associations had a favourable effect on confidence and its relation to performance on the associations (as in Experiment 4), attributed to metacognitive operations that evaluated strength of engrams. Encoding information multiple times increased the durability of memory traces, enhancing memory for repeated events compared to non-repeated events. Subsequently, self-reported confidence was greater than when associations were presented only once.

Confidence amid retrieval of encoded stimuli furthermore correlated with performance within participants (as in Experiments 4 and 5; see **Tables 3**, **5** respectively), consistent with metacognitive mechanisms assessing the robustness of memory engrams to judge their legitimacy (Wixted and Mickes, 2010; DeSoto and Roediger, 2014; Roediger and DeSoto, 2014). Correlations between evoked confidence and performance have been widely described (Brewer and Wells, 2006; Deffenbacher, 1980; DeSoto and Roediger, 2014; Roediger and DeSoto, 2014; Brewer and Sampaio, 2006; Rimmele et al., 2012; Nguyen et al., 2018) and an fMRI study found confidence to be linked to accurate versus inaccurate recognition and correlated with MTL activity which in turn corresponded with performance (Kim and

Cabeza, 2007). Accordingly, these findings were corroborated by the bulk of the within-subject correlation data in Experiments 4 and 5. Confidence displayed a positive relationship with memory accuracy for overlapping associations in closed- and open-loop events. When the events were repeatedly encoded, their memory engrams increased in robusticity and the confidence-accuracy correlation grew. In overlapping events, the ability to recognise encoded associations and dismiss incorrect pairs of elements from unrelated events in test phases I and II was related to confidence. Confidence was similarly indicative of performance on direct associations from Unique events. Moreover, because associations from Overlap and Unique events were all learned under the same encoding conditions, their memory traces were equally durable and confidence exhibited the same level of correlation with accuracy in both event types. The same reasoning accounted for similar correlation strengths in closed and open loops.

10.5.2 Confidence may be influenced by metacognitive beliefs

Besides hinging on memory strength, metamemory processes also feed on other evidence that help gauge the legitimacy of a memory, especially where false memories caused by overlapping events and inferences were concerned in this thesis (as in Experiment 5; see Chapter 8, **Table 5**). Heuristics such as estimating the vividness of a memory or ascertaining ease of retrieval are at times applied to deduce memory accuracy when immediate access to memory traces is hindered (Koriat, 1993; Metcalfe, 1993). Two prominent approaches to interpreting these metacognitive mechanisms are the cue utilisation theory (Koriat, 1997, 2006) and the reality monitoring (or source monitoring) framework (Johnson and Raye, 1981). According to the cue utilisation account (Koriat, 1997, 2006), self-assessing the genuineness of a memory is influenced by the individual's knowledge, perceptions and experience regarding how memory operates. The reality monitoring argument, meanwhile, posits that prior knowledge on what is real and what is not, i.e. externally generated or internally generated, is used to resolve the source of a memory (Johnson and Raye, 1981). When confidence reports did not coincide with memory strength in Experiment 5, cognitive processes that judge a memory according to personal notions on what a genuine memory is versus a fabricated one could be responsible for the divergence. Importantly, confidence for false memories composed of content from overlapping events and confidence for inferences did not conform with the respective actual memory performance – no within-subject correlation was noted between confidence and rejection rate of false memory pairs and between confidence and recognition success of indirect pairs. Consistent with the cue utilisation and reality monitoring theories, there was possibly a compelling misunderstanding in participants on how both forms of memories were truly retrieved, causing participants to misinterpret the validity of the memories. These types of memories presented conflicting evidence on their authenticity, making it difficult for them to be evaluated. They were never observed but because they were inferred from encoded material, their retrieval was thought to mobilise mechanisms similar to those responsible for veridical memories (Schlichting et al., 2014; Horner et al., 2015; Hupbach et al., 2009; Gershman et al., 2013; Carpenter et al., 2021). A feeling of conscious recollection might hence transpire despite the absence of memory traces for the false memory (Leippe, 1980; Brigham and Bothwell, 1983; Holmes et al., 1998; Shaw and Porter, 2015; Brewer and Sampaio, 2006; Sampaio and Brewer, 2009) and indirect pairs (Smith and Squire, 2005, though inference could also be unconscious, see Greene et al., 2001), impairing the capacity to accurately appraise them. In overlapping events, the lack of a significant difference in confidence-accuracy γ coefficients across false memory, inferred, direct and unrelated pairs of either test phase, although confidence did track accuracy for the direct and unrelated pairs, showed how close confidence was to measuring actual accuracy for the false memory and inferred pairs, though it eventually fell victim to misguided metamemory perceptions. Little has been documented about the confidence-accuracy association for inferences though plenty of studies have shown it to be disrupted in illusory memories (Holmes et al., 1998; Murdock, 1982; Gillund and Shiffrin, 1984; Humphreys at al., 1989; Clark and Gronlund, 1996; Ye et al., 2016).

Metamemory beliefs are also potentially responsible for the mismatch between confidence and accuracy concerning false memories that bind elements from nonrelated events. Specifically, in the Unique condition, confidence did not coincide with probability of rejecting incorrect combinations of elements in both test phases of Experiment 5, although it significantly did in the Overlap condition. An explanation for it is that at 3s, the encoding time for each event might feel too short to induce a stable memory trace such that subjects failed to discern whether the ambiguity felt when faced with a pair of elements during the test on encoded associations (test phase I) was because it was really a foil pair or because it was a poorly remembered correct pair with unstable engrams. Confidence exhibited by participants when incorrectly endorsing unrelated pairs in the test phase was therefore the same as when correctly recognising direct pairs. Their confidence-accuracy correlations were also of comparable strengths though it was significant amid recognition of direct pairs since the encoded pairs had durable memory traces. The unrelated pairs had no engrams and theoretically could be readily rejected, as how the unrelated pairs in the Overlap condition were, but the misinterpretation of the uncertainty sensed when perceiving the pairs interfered with the ability to evaluate a memory. Nevertheless, because the memory traces for the direct associations in Unique events still inherently existed, correlation between confidence and accuracy during recognition of direct pairs and rejection of incorrect pairs was both statistically not different than in Overlap events where significant correlations were presented for both pair types. The perplexity over unrelated element pairs from Unique events grew amid the test on inferred associations (test phase II) where recognition was no longer simply veridical but additionally required inferential reasoning. At this point, incorrect foil associations were rejected less confidently than they were in the first test phase and when direct pairs were endorsed, and the relationship between confidence and accuracy deteriorated compared to how it was for direct and unrelated pairs in the earlier test phase. The unrelated pairs also felt almost as certain as correct inferred associations (*r*=-.44 for unrelated pairs, *r*=.35 for indirect pairs; see **Table 5**, Chapter 10 – Confidence may be influenced by metacognitive beliefs), leading them to be erroneously accepted as ‘old’ with relatively high confidence and rightly dismissed as ‘new’ with relatively low confidence. The confidence-accuracy correlation for incorrect pairs in the Unique condition thus became negative albeit non-significant. It was, however, significantly stronger in the Overlap condition of the same test phase and in fact positive perhaps because the unrelated pairs in Overlap events were less vague than those in the Unique condition. For every pair of elements from nonrelated Overlap events, participants needed only to remember that one of the events overlapped with some other event to reject the pair. There was thus greater reliance on the strength of memory for the unrelated Overlap events in the pair and less dependence on other cues that were used to decide on an incorrect pair of elements from distinct Unique events. As noted with inferences and false memories caused by overlapping events, these cues, such as the intensity of the recollection experience, were in fact detrimental to judging a memory's genuineness accurately. Metacognitive processes were consequently able to precisely signal the accuracy of erroneous pairings of elements from unrelated Overlap events but not from unrelated Unique events in both test phases.

Retrieval complexity also played a part in regulating confidence since participants wrongly acknowledged mispairings of elements from unrelated events more confidently in the direct associations test than in the inferred associations test (as in test phases I and II respectively in Experiment 5) although the false memories in both test phases were equally inferior in strength. This might further clarify why successfully recollecting direct associations coincided with higher subjective confidence than successfully inferring indirect associations despite both being true memories. Associative inference might be perceived to be more demanding than veridical recollection – and rightly so, with significantly lower performance on indirect pairs than on direct pairs – especially since subjects were not told before test to remember indirect links between events. As a result, any affirmative response to the question of whether two items were indirectly connected was made with less assurance than when the direct association between the items was queried, no matter the accuracy of the answer. This is consistent with the cue utilisation theory

(Koriat, 1997, 2006) that postulates that confidence can be shaped by certain conceptions on how memory works, which may include the assumption that retrieval ease hints at credibility. Earlier literatures have demonstrated that subjective retrieval effort negatively corresponded to confidence (Robinson et al., 1997) and confidence was proportional to efficiency in retrieval even when the response was inaccurate (Kelley and Lindsay, 1993).

Confidence when recognising direct associations in overlapping events (as in Experiment 5) varied as a function of category of overlapping element (person, location or object) possibly due to misled metamemory mechanisms. Least confidence was perceived during the recognition of direct associations in Person Overlap events while confidence was the same for events with a location or an object in common, although performance did not differ across overlap types. In Experiment 5, famous people were incorporated in the presented events, resulting in a potential confusion over whether participants' memory of seeing the figures in certain situations (e.g. Alicia Keys at a basketball court) were events viewed during study or obtained from various other sources such as social media. The complication was perhaps greater when the person was observed twice in two overlapping events rather than once in a non-overlapping event. As a result, there was a difficulty in classifying the source of a memory (Johnson and Raye, 1981) and Person Overlap events were responded to with less certainty than other events. The effect of overlap condition on inferential ability could have also driven the bias in confidence. Proficiency in inferring across two events that had a person in common (see Chapter 8 – Results) might have already been enhanced before the first test on direct associations, so when it was time to decide if a directly observed association such as

AB had indeed been from the same event, uncertainty could result since memory for inferences such as AD, which contradicted the direct association, might be retrieved as well (though performance was eventually uniform across overlap types). The presence of a conflicting account might cast doubt on the authenticity of the veridical memory and undermine confidence in it, and because inferential processes were most efficient across events with the same person, confidence in these events was disproportionately affected.

While the results in my thesis are generally coherent with studies that have demonstrated subjective confidence to be a largely steady indicator of memory accuracy (Brewer and Wells, 2006; Deffenbacher, 1980; DeSoto and Roediger, 2014; Roediger and DeSoto, 2014; Brewer and Sampaio, 2006; Rimmele et al., 2012; Nguyen et al., 2018), they are contradictory to those that have shown otherwise (Fischhoff et al., 1977; Busey et al., 2000; Penrod and Cutler, 1995; Tomes and Katz, 2000), possibly because of differences in the stimuli used or analysis adopted. For instance, Fischhoff et al. (1977) were investigating confidence reports in a task testing general knowledge, whilst Busey et al. (2000) employed an ‘over-conditions’ measure where both confidence and accuracy were probed for changes after manipulating specific experimental parameters. Elsewhere, Penrod and Cutler (1995) reviewed studies that analysed confidence and accuracy primarily across participants under specific cross-examination circumstances. On the other hand, Experiments 4 and 5 studied confidence upon episodic memory recognition after a normal learning session and assumed a within- and between-subject evaluation of it. Tomes and Katz (2000), however, did examine confidence from a within-subject perspective and still reported that confidence ratings did not appropriately indicate accuracy.

Participants in the study had been answering questions about a video snippet of a crime they watched such as a robbery, so it could be that the unique characteristics of an eyewitness situation activate memory-related mechanisms differently as opposed to the encoding of neutral events. Memory phenomena such as the weapon focus effect where witnesses tend to remember sharp details of the threatening tools used by the perpetrator but not other features of the incident (Steblay et al., 1992; Loftus et al., 1987; Kramer et al., 1990) and the fluid effects of stress amid the event, after it and during recall (Deffenbacher et al., 2004; Christianson et al., 1992) are special to eyewitnesses, and therefore metacognitive processes for examining the integrity of a memory might or might not be impacted. This thesis tested people's ability to remember neutral events in a safe lab environment, so its findings are more representative of everyday memory operations. There are, though, other eyewitness studies that concur with my results on confidence's positive relation to accuracy (for review, see Deffenbacher, 1980; Brewer and Wells, 2006) but that is perhaps down to differences between their protocol and Tomes and Katz's (2000). The visual material used in these studies was not comprehensively described and thus it is unsettled if some presented more compelling stimuli than others to the extent that participants' metamemory was affected differently.

10.5.3 Cognitive awareness and pattern completion

The correlation between confidence scores and actual accuracy during recognition of encoded pairs in overlapping and non-overlapping events (as in Experiment 5; see Chapter 8, **Table 5**) may also signify metacognitive awareness that demonstrates conscious processing of a memory. Autonoetic consciousness, which describes a person’s self-awareness as a being that exists along the passage of time and grants the capacity to remember and imagine experiences at different places and points in time, is believed to be a hallmark of episodic memory recollection (Tulving, 1985; Wheeler et al., 1997; Naito et al., 2003), and confidence is considered to be an index of conscious retrieval (Tulving, 1985; Yonelinas, 2001). The association between confidence and cognitive awareness also complements earlier ideas about conscious awareness matching stable ‘attractor states’ (Mathis and Mozer, 1995; Rumelhart et al., 1986; Smolensky, 1988; McClelland and Cleeremans, 2009) that reflect recurrent rather than feed-forward processing (Battaglia and Treves, 1998; Rolls, 2010), are consistent with pattern completion (which is caused by recurrent processing), and are associated with activity in the hippocampus (Wills et al., 2005; Rolls, 2013; Lee et al., 2015; Knierim and Neunuebel, 2016; Seung, 1998; Horner et al., 2015). The holistic quality of the pattern completion-mediated recollection of direct associations from Overlap and Unique events, reflected by significant within-event retrieval dependency across the associations, could have therefore given rise to a stronger conscious experience which in turn engendered a more profound feeling of certainty in the authenticity of the memory. Seeing that direct associations depended on each other for retrieval equally in overlapping and non-overlapping events, comparable amounts of confidence were predictably expressed during the associations’ retrieval in both event types. The link between conscious awareness and pattern completion might also explain why metamemory could not be trusted when it comes to fictional associations derived from limited pattern completion.

However, there were conditions in which the occurrence of pattern completion did not relate to confidence, and this contradicts the idea that metacognitive awareness reflects pattern completion and instead perhaps supports the view that confidence indicates subjective assumptions of memory processes (Koriat, 1997, 2006; Johnson and Raye, 1981). In one such observation, participants retrieved direct associations as confidently in closed loops as they did in open loops (as in Experiment 4; see Chapter 7) although statistical dependency was found only in closed loops. Confidence scores also coincided with accuracy with equal precision in both closed- and open-loop conditions. One possible reason for why all overlapping associations felt equally convincing regardless of how much pattern completion their retrievals induced was that the associations were encoded in the same manner and so there was no reason to suspect that they would be remembered differently. Additionally, inferences made across overlapping events (as in Experiment 5) recruited full pattern completion – denoted by dependency on each other and on all direct and false memory associations within the events – but were retrieved with the same amount of confidence as illusory memories formed from overlapping events, which only engaged partial pattern completion – indicated by dependency on inferred and only specific direct associations. The strength of the relation between confidence and accuracy for inferred pairs also did not significantly vary from that for direct and unrelated pairs in any test phase in Overlap events despite inferior levels of pattern completion for the latter two pair types (dependency during retrieval of unrelated pairs was not assessed in this thesis but was expected to be minimal, see Chapter 10 – False associations of elements from overlapping events versus from unrelated events). Metacognitive accuracy failed to represent actual accuracy for inferences possibly because metamemory perceptions were unable to reconcile the contradictory evidence for and against the existence of such memories (see Chapter 10 – Confidence may be influenced by metacognitive beliefs). Furthermore, if indeed pattern completion predicts confidence, incorrect unrelated pairs in either test phase should theoretically be rejected more confidently than when they were accepted since the pairs did not trigger pattern completion mechanisms. However, this only materialised in Overlap events while in Unique events no correlations were found. As explained earlier (see Chapter 10 – Confidence may be influenced by metacognitive beliefs), metamemory processes struggled in ascertaining the validity of false memories adjoining elements particularly from nonrelated Unique events, and this is potentially due to the failure to accurately interpret the sense of ambiguity that the unrelated pairs evoked. Supporting the view that metacognitive awareness during memory retrieval engages more than hippocampal operations is Moscovitch et al.'s (2016) framework for cue-mediated retrieval where awareness only comes in when the neocortex is recruited alongside the hippocampus. Indeed, frontal areas are implicated in metamemory accuracy (Pannu and Kaszniak, 2005; Fleming et al., 2010; Molenberghs et al., 2016).

It is, nevertheless, still plausible that pattern completion-based retrieval does have an influence on conscious processing but results that showed otherwise mark situations where the process was overruled by metamemory beliefs in determining metacognitive awareness and hence confidence. For example, the retrieval of inferences might have been supported by full pattern completion but it could also be mired with evidence against their existence such as the absence of stable engrams, pulling confidence down. Whether pattern completion does or does not translate to conscious awareness, these findings demonstrate that pattern completion during retrieval does not always predict cognitive awareness and thus confidence, and more research is necessary to confirm if attractor dynamics are linked to metamemory accuracy.

10.5.4 Confidence-accuracy relationship is unpredictable across subjects

Between-subject analyses on the association between confidence and memory, which were performed to determine if confident individuals were more accurate than less confident ones, were reflective of analyses within subjects to some extent. As found in within-subject analyses, participants who were more confident in their response were also more successful at recognising direct associations from closed-loop and open-loop events (as in Experiment 4; see Chapter 7, **Table 3**) or from overlapping events (as in Experiment 5; see Chapter 8, **Table 5**). Similarly, confident participants were more likely than less confident individuals to rightly reject false associations of elements from nonrelated Overlap events amid the test on direct associations. Such correlations imply that in these conditions, the ability to match confidence with memory accuracy was shared by all participants in general. However, unlike the correlation results within participants, confidence corresponded across participants with accurate rejection of false memory pairs, retrieval of indirect associations and accurate rejection of unrelated Unique events in the indirect associations test (test phase II). Contrarily, previous research noted no correlation across subjects between confidence and CRs for lures that were semantically related to targets (DeSoto and Roediger, 2014). However, the lures in DeSoto and Roediger's (2014) paradigm were 'new' items that were never encoded before, and because they did not possess pre-existing engrams, CRs for them as expected did not establish a relationship with subjective confidence. Another instance where within- and between-subject examination did not match is when no confidence-accuracy relationship was identified across subjects for direct and unrelated pairs in Unique events in test phase I as well as unrelated pairs in Overlap events in test phase II. Discrepancies between within- and across-subject analyses overall suggest that metamemory of subjects varied in the affected aspects due to individual differences (Thompson and Mason, 1996) and these should be studied further.

10.5.5 False memories caused by overlapping events can be expressed with confidence

Although illusory memories formed from overlapping events were recognised with lower confidence than genuine memories for directly observed stimuli (as in Experiment 5; see Chapter 8), they could still invoke a substantial sense of belief. The reconstructive, inferential experience during recollection of false memories in general, which assimilate information from distinct sources, could boost confidence by conjuring a convincingly realistic illusion of an unseen event (Leippe, 1980; Brigham and Bothwell, 1983; Holmes et al., 1998; Shaw and Porter, 2015 but see Wade et al., 2018), and that is perhaps why one can believe a false memory as if it was real. This is especially pertinent to fictional memories that merge elements from overlapping episodes compared to those combining elements from nonrelated events. The reconstructive processes that bring about recollection might create an unconscious, deceptive impression of a veridical event out of information inferred from separate but similar experiences (Leippe, 1980; Brigham and Bothwell, 1983; Holmes et al., 1998; Brewer and Sampaio, 2006; Sampaio and Brewer, 2009). Indeed, the amount of episodic content shared by fabricated memories can modulate participants’ belief in their recollection. Several studies on illusory memories have lent support to this idea, detailing how a greater global similarity between the lure and stored memory traces of other items elicits higher false recognition rates for the lure (Holmes et al., 1998; Murdock, 1982; Gillund and Shiffrin, 1984; Humphreys at al., 1989; Clark and Gronlund, 1996; Ye et al., 2016).

10.5.6 Memory strength versus recollection and familiarity

Although confidence is often expected to predict memory strength, a related view is that confidence actually indicates whether a recognition is properly recollected or merely deemed as familiar. Extensive research has characterised two qualitatively separable processes in recognition memory – a proper recollection of the experience with its details vividly remembered, and familiarity, i.e. a general feeling of being acquainted with the presented stimulus (for reviews, see Yonelinas, 2002, 2010; Mandler, 1980; Tulving, 1985; Aggleton and Brown, 2006). Recollection is frequently associated with high confidence while familiarity is linked to low confidence retrievals. This dual-process perspective counters the single-process theory which states that all memories are recognised via the same mechanisms but just differing in strength, causing some to be recollected intensely and others less so (Dunn, 2004; Donaldson, 1996). Future studies can exploit confidence to ascertain the soundness of the hypotheses. For example, one contentious distinction between recollection and familiarity is that unlike the latter, recollection is hippocampal-dependent (Cohen and Eichenbaum, 1993; Fortin et al., 2004), while other investigations found the hippocampus to be involved in both (Wais et al., 2006; Smith et al., 2011; Merkow et al., 2015). If indeed the hippocampus mediates recollection and not familiarity, retrievals that were supported by pattern completion, which is believed to occur in the hippocampus (Wills et al., 2005; Rolls, 2013; Lee et al., 2015; Knierim and Neunuebel, 2016; Seung, 1998; Horner et al., 2015), should all fall under the category of recollection. Nonetheless, inferences, which were reported to engage thorough pattern completion (as in Experiment 5; see Chapter 8), were recognised with lower confidence than directly observed associations, which made use of less extensive pattern completion, and the same degree of confidence as false memories, which concerned minimal pattern completion. There are plenty of speculations to be made and considerations to deliberate, such as the findings that both the dual-process account and the single memory strength process are supported by neuroimaging evidence (Hayes et al., 2011) and that both recollection and familiarity are facilitated by the hippocampus if the memories are sufficiently strong (which pertains to the original question of whether confidence gauges memory strength or a difference in retrieval mechanism; Smith et al., 2011). However, all these can be examined better in subsequent experiments that should be specifically designed to address the single-process versus dual-process issue. While some studies use high/low confidence reports to infer the type of recognition process at play, other studies employ a Remember/Know procedure (Tulving, 1985; Gardiner, 1988) or a source memory test (Yonelinas, 1999), which may be more appropriate in order to avoid confounding the significance of confidence in metamemory (Wixted and Squire, 2011a, 2011b, but see Diana et al., 2008, Diana and Ranganath, 2011).

10.6 Implications for episodic memory

10.6.1 Definition of an episodic event

Whether overlapping pairwise associates should be characterised as distinct episodes or as associations within the same extended episodic event is a matter for further deliberation. Earlier studies with similar paradigms (Horner and Burgess, 2013, 2014; Horner et al., 2015) together with Experiments 1-4 of this thesis (see Chapters 2, 3, 5, 7 respectively) regarded overlapping associations from closed-loop structures as belonging to the same episodic event. Although the associations were encountered at different timepoints, they exhibited retrieval dependency similar to when they were displayed together (Horner and Burgess, 2013; Experiment 5, see Chapter 8). However, no dependency was detected among associations in open-loop structures according to earlier studies (Horner and Burgess, 2013, 2014; Horner et al., 2015) and Experiments 1-4 of this thesis. Earlier literatures on overlapping associations (Zeithamova et al., 2016; Shohamy and Wagner, 2008; Schlichting et al., 2014; Banino et al., 2016; Shohamy and Adcock, 2010; Zeithamova et al., 2012a, 2012b) moreover did not specify overlapping pairs of associations as 'events'. An episodic event, in this context, is defined by the presence of pattern completion reflected by statistical dependency among retrievals even when constituent elements were encoded separately. However, retrieval dependency of indirect associations on each other and on direct linking pairs was observed in spite of no dependency across direct pairs in the same event (as in Experiments 1-3), suggesting that open loops were also events. It is thus possible to induce pattern completion, and thus construe a chain of associations as an 'event' on this premise, through the recollection of connections within closed loops or through associative inference that is in turn mediated by pattern completion of linking direct associations or other inferred associations from the same event. Alternatively, the presence of pattern completion during the retrieval of several associations does not necessarily mean that the associations belonged to a single event – it could also imply that the associations were distinct but related events, as was what happened in Experiment 5 where inferences across two overlapping events depended on each other as well as on all direct and false associations in the events for retrieval. Based on this description, a presented pairwise associate could constitute an event on its own. Either way, more studies should be carried out to ascertain the boundaries of an episodic event.

Another important consideration on what establishes an event within the parameters of my experiments is what participants decide to do with the liberal instructions for encoding. In Experiments 1-4, subjects were simply told to imagine two elements in a presented pair interacting meaningfully with each other. The free rein to visualise stimuli however subjects desired could motivate some of them to encode overlapping associations, regardless of the similarity, as discrete events and thus separate memories. For example, the pair Kitchen-Obama could be visualised as Barack Obama in a simple white kitchen, while the pair Kitchen-Hammer could conjure a mental picture of another kitchen, a spacious blue one in a restaurant perhaps. The overlapping pairs would therefore be remembered as distinct episodes which could minimise the involvement of pattern completion amid recollection. When associations were repeatedly displayed (as in Experiments 3 and 4), repetitions of the same association could also be imagined as different scenarios. However, if participants were liable to such variations in visualisation across associations, I would expect associations from closed- and open-loop events to not diverge in dependency across subjects, given that it was impossible to tell the loop types apart and encode them differently until the last association for those events was seen (the last association for closed loops links back to the first-studied association while that for open loops involves a novel element that does not connect to any previously learned association). The contrast in retrieval dependence between closed- and open-loop structures throughout Experiments 1-4 asserted that subjects generally encoded overlapping associations within closed-loop events as related representations, retrieving them with statistical interdependency. It is nevertheless advisable to limit the probability of inconsistent imagery as much as possible by ordering participants to associate each element, regardless of its pair in any presentation, with a specific mental image. This would ensure that overlapping associations could possess linked representations, not unique traces, that could be assimilated into an expanded representation and retrieved through pattern completion.

When a present experience shares commonality with another from the past, either the memory representation for the preceding event grows to include the subsequent one such that they are interdependent for retrieval, or they compete with one another such that recollecting one of them will deter retrieving the other. Reinforcing the first possibility is studies demonstrating a pattern completion form of recollection in memory for overlapping pairwise associates which were in some way events on their own, since they were temporally separated (Horner and Burgess, 2014; Horner et al., 2015; Experiments 1-4). The second possibility, however, is consistent with studies on hippocampal pattern separation in discriminating similar experiences (Leutgeb et al., 2007; Yassa and Stark, 2011; Zotow et al., 2020). To assess this spread of dependency from one event to its overlapping pair, I calculated dependency of retrievals for direct associations on retrievals of direct associations from the overlapping event (see **Fig. 16**). A one-way ANOVA that probed dependency

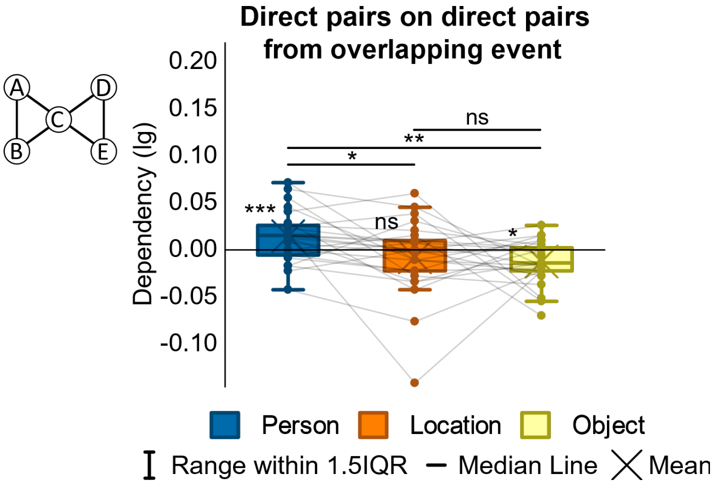

Figure 16. Supplementary dependency results for Experiment 5. Dependency of direct pairs on direct pairs in the overlapping event for Person Overlap, Location Overlap and Object Overlap events, log-transformed. Each point represents a participant. * within a column reflects a significant difference from zero. ***p < .001; **p < .01; *p < .05; ns not significant. *N*=25.

among Person Overlap, Location Overlap and Object Overlap events revealed that type of overlap element had an effect on dependency (F(2,48)=5.41, p=.01, ηP^2=0.18) which post-hoc paired samples t-tests indicated was led by stronger dependency in Person Overlap than in Location Overlap (t(24)=2.57, p=.02, *d*=0.51) and Object Overlap events (t(24)=3.60, p=.001, *d*=0.72). Dependency did not significantly differ between Location Overlap and Object Overlap events (t(24)=0.48, p=.64). A one-sample t-test on dependency in each condition found that dependency was significant in Person Overlap (t(24)=2.68, p=.01, *d*=0.54) and Object Overlap events (t(24)=-2.62, p=.02, *d*=-0.53) unlike in Location Overlap events (t(24)=-0.92, p=.37). However, dependency was negative in Object Overlap as opposed to Person Overlap events where it was positive. Because the dependency measure in the thesis is the dependency derived from data subtracted by that estimated by the Independent model (see Chapter 2 – Method), a negative dependency value alludes to competition amongst associations whereby one association retrieved impedes the recollection of others within an event or pair of overlapping events. Hence, accurately retrieving an event coherently reinstates other events involving the same person but thwarts the retrieval of other events involving the same object. These data suggest that an event would be organised in the same associative network as other discrete episodes if all the events implicate the same person, but would be independent of each other if they implicate the same place, and would antagonise one another if they implicate the same object. It would be good to explore associated questions as to how a new episode is merged into a broader representation and how the type of common element that a group of events share affects their retrieval pattern.

10.6.2 Associative memory in the hippocampus and neocortex

It is thought that the hippocampus prompts the immediate creation of new memories and subsequently facilitates the slow formation of semantic knowledge (Scoville and Milner, 1957; Marr, 1971; Tulving, 1985; McClelland et al., 1995; but see also Squire and Zola-Morgan, 1991). Nevertheless, when incoming material complements and adds to previously stored information or 'schema', it can be incorporated immediately into the cortex (Tse et al., 2007) just upon the constrained reactivation of related data, according to computational models (McClelland et al., 2020). My findings that associative inference (AC, BD) amounts to pattern completion of encoded associations (AB, BC, CD) in the open-loop events of Experiments 1-3 and 5 (see Chapters 2, 3, 5, 8 respectively), supported by results from the neurocomputational model (see Chapter 6), could illustrate neocortical integration along with hippocampal associative memory.

10.7 Future directions

10.7.1 Criticisms and how to improve the experiments

The experiments in this thesis can be further improved to assess episodic memory more effectively. Firstly, the protocols, especially Experiments 1-4 (see Chapters 2, 3, 5, 7 respectively) which employ similar paradigms (i.e. studying overlapping associations in closed and open loops), can be made more consistent with one another for more rigorous comparisons between experiments and with previous work (Horner and Burgess, 2014; Horner et al., 2015). Comparing Experiment 1, for example, which tested for inference across overlapping associations, with Horner and Burgess's (2014) study, which did not, reveals that inferred associations depended on linking encoded associations for retrieval. However, it is possible that the inferred associations were also dependent on non-linking encoded associations if only deeper encoding was allowed by increasing the encoding duration from 3s to 6s and reducing the number of events from 60 to 36 as in Horner and Burgess's (2014) design. There had been efforts to follow earlier studies as closely as possible (Horner and Burgess, 2014; Horner et al., 2015) but changes were made to the experimental design either to accommodate new manipulations or to make it more convenient. For instance, the number of presented 'events' was 60 in Experiments 1-3, up from 36 in prior work (Horner and Burgess, 2014; Horner et al., 2015) to gain more data. It later decreased to 48 in Experiment 4 in a compromise between competing needs for more data and for more precise reflection of previous studies (Horner and Burgess, 2014; Horner et al., 2015), seeing that the experiment was more alike to these studies than Experiments 1-3 which additionally assessed inference. The same reasoning – that Experiment 4 resembled prior studies more than Experiments 1-3 – also justified why the encoding trials in Experiment 4 lasted for 6s and its test trials had six alternatives, ended with a 1.5s blank and included a confidence rating, as in those studies (Horner and Burgess, 2014; Horner et al., 2015). To enhance the efficiency of the procedure, these specifications were altered in Experiments 1 and 2 where encoding trials were reduced to 3s each and test trials had fewer alternatives (i.e. three), ended with a shorter 0.5s blank and did not enquire about confidence. Experiment 3 kept faithful to earlier studies (Horner and Burgess, 2014; Horner et al., 2015) wherever possible by maintaining the same encoding trial duration and number of test options. However, the inclusion of repeated stimuli led to a lengthy experimental session, so to cut it down, the intertrial interval was 0.5s instead of 1.5s and confidence was not probed.

To ensure greater coherence across experimental protocols in the future, the same design should be retained as much as possible but reformed when necessary or ideal. As an example, all experiments in this thesis could present the same number of stimuli – perhaps 50, which was about mid-range of the number used in prior work, i.e. 36 (Horner and Burgess, 2014; Horner et al., 2015) and the maximum used in the thesis, i.e. 60 (as in Experiment 3). Forty-eight is the median of 36 and 60, but based on the specific division of events in Experiments 3 and 4 where the ratio of repeated to non-repeated events was 60:40 within each of the two equally split loop types, it does not allow for a mathematically viable way of allocating events to their conditions (the number of events calculated for the smallest condition is 7.2). In another example, earlier studies had included a 1.5s intertrial interval and a 6s encoding trial, but since pilot investigations had indicated that a shorter intertrial interval (0.5s) and encoding trial (3s) did not harm performance (as seen in Experiments 1-3), all experiments in the thesis could adopt the time-saving changes. More prudent planning of experiments would also help address questions on episodic memory more seamlessly.

It would also be clearer if the differences in the experiments examining the retrieval manner of directly and indirectly observed associations (as in Experiments 1 and 2) were dissociated by performing an additional experiment. Two aspects of retrieval manner were explored in Experiments 1 and 2 – which of the two types of associations were retrieved earlier, and whether they were retrieved in a single phase or segregated sessions. Experiment 1 tested for direct and inferred associations in an interleaved procedure, with indirect pairs probed first before the direct pairs from the same event, whilst direct associations in Experiment 2 were retrieved in one session and the indirect associations in the next. Because both variables were manipulated in these protocols, comparing the experiments to deduce something about each variable is less effective. Any variation in findings between Experiments 1 and 2 could not be pinned on a specific factor. To surmise unequivocal conclusions about a manipulation, another experiment with the same procedure as Experiment 1 but with only one manipulation imposed should be undertaken; for example, indirect associations could be retrieved first in one session before direct associations in another session. By contrasting Experiment 1 with this new experiment, I can more positively attribute any differences in results to the fact that retrievals were separate, and by contrasting this new experiment with Experiment 2, any differences in results could be more accurately attributed to the testing of direct pairs first before indirect pairs.

However, even if the modifications to the test protocol were assessed in different experiments, it could be challenging to determine the exact impact of the changes. Multiple accounts could serve to rationalise the results. As an example, if dependency across indirect associations was greater in an experiment with interleaved testing of direct and indirect pairs than in another experiment identical to the first one except that it involved separate testing, it could mean that the testing style in Experiment 2 increased dependency, or that the testing style in Experiment 1 weakened dependency Nevertheless, studying the manipulations to the testing procedure individually could narrow down the possible explanations for an effect.

In Experiments 3 and 4, which probed repetition effects, the mean interval between the last encoding trial and test was longer for singly presented events than it was for repeated trials, possibly undermining memory for single events. The arrangement of trials during study was such that single trials in the last session were randomly slotted into one of the three blocks in that session while repeated trials were found throughout. This period between final learning and test could be equalised for both conditions by displaying single events in the last block.

Experiment 4, which showed that displaying associations multiple times within each presented event reduced their interdependency for retrieval, could also benefit from testing repetition effects on participants’ memory for indirect associations. It remained unknown whether inferences would act the same way as encoded associations amid retrieval, in light of the finding in Experiments 1-3 that the two types of associations within the same event could recruit different amounts of pattern completion and thus distinct retrieval mechanisms. What I expect, nevertheless, is that inferred associations would still rely on pattern completion of attended associations since that is the only route for their retrieval (see Chapter 10 – Dependency of associations during retrieval).

As for Experiment 5 where participants viewed overlapping events (see Chapter 8), a few design-related details should be rectified in future reproductions. The study lag, which is the number of study trials between any two events featured in each test trial, should be equalised among the different types of test trials (i.e. direct, false memory and unrelated pairs; see Chapter 8 – Method). Repetitive retrieval should be imposed on directly encoded pairs as well and not just false memory and indirect associations to identify its impact on diverse types of memory. Repetition effects could also be better represented if associations were tested more times instead of just two; three is perhaps ideal. Moreover, initiating a longer interval of at least 24 hours between learning and test would allow for a more ecologically valid representation of false memories and more opportunity for them to develop as they might also be caused by consolidation-related factors. There is, after all, evidence that memory updating and organisation processes during sleep, which aid in integrating related information such as overlapping events (Ellenbogen et al., 2007; Werchan and Gomez, 2013), could also corrupt a memory (Straube, 2012; Diekelman et al., 2010 but see Newbury et al., 2019).

There might be some scepticism in comparing confidence analysis results obtained from experiments that used different ranges for confidence judgements, but research has found it to be unjustified. Experiment 4 utilised a 4-point scale for subjects to report their confidence while Experiment 5 posed a binary sure/not sure confidence question, so the differences in how sensitive the scales are to nuances of self-belief might render comparisons across the experiments to be imprecise. Studies, however, have indicated that the association between confidence and performance did not significantly change according to the confidence scale used (Tekin et al., 2018; Tekin and Roediger, 2017). It is thus not inappropriate to compare confidence findings from Experiments 4 and 5, but it would make a more fitting comparison if both experiments were to implement the same system for estimating confidence.

For the study of associative memory to be more ecologically valid in the thesis, a delay of at least one night's sleep between the study and test phase should ideally be added to all the paradigms. Earlier reports have highlighted the advantage of offline processing during sleep in strengthening memory for relationships among stimuli and inferential ability (Ellenbogen et al., 2007; Werchan and Gomez, 2013). An opportunity for subjects to sleep would offer greater ecological validity, resembling real-life associative inference after similar experiences with possibly long periods in between.

10.7.2 Studying the neural correlates of false memories

The results from the thesis could be further investigated in the fMRI scanner to establish the neural bases underlying the memory function of interest. One potential study could take up the finding that false memories of associations paired from overlapping events (AE and BD from overlapping events ABC-DEC) are more likely to develop if linking direct associations (e.g. AC and CE for false memory AE) are remembered and direct associations that contradict the false memories (e.g. AB and DE for false memory AE) are not (as in Experiment 5; see Chapter 8, **Fig. 15**). My predictions are that 1) such false memories form when linking direct associations were properly encoded by the MTL but the alternative direct associations were less so, 2) successfully retrieved associations were properly encoded by the MTL, and 3) false pairings of elements from unrelated events form when all associations with the elements involved were weakly encoded. This hypothesis could be investigated in a neuroimaging experiment which adapts the paradigm in Experiments 1-4 (see Chapters 2, 3, 5, 7 respectively) for an objective similar to that of Experiment 5. Multimodal A_1-B-C-A_2 person-location-object-person ‘events’ (e.g. Obama-Kitchen-Hammer-Madonna) would be presented as sequential overlapping associations (i.e. A_1B, BC, CA_2) and 72 hours later tested in a three-alternative cued recognition test. Retrieval trials that cue an overlapping element (e.g. B) would also implicitly test for illusory memories of seeing inferred associations (A_1C, BA_2) by providing the correct target (e.g. A_1), a foil (e.g. A from another event) and the element that is indirectly related to the cue (i.e. A_2) as options. If the indirectly related element is chosen, the participant is deemed to have had a false memory where they had mistaken an indirect association as an encoded one. The remaining trials would test for direct associations alone and their options would consist of the target and two foils from distinct events. The study phase would be imaged while the retrieval phase would be undertaken outside the scanner. For indirect associations wrongly recognised as encoded (e.g. A_1C), the presentation of associations that link the elements in the indirect association (i.e. A_1B and BC) would implicate strong MTL response whereas the encoding of associations that contradict the wrongly recognised indirect association (i.e. A_2C) would be coupled with weak MTL response. As for false recognition of foil associations (e.g. A_1C where A_1 and C are from distinct events), lower MTL activity would accompany the learning of associations pertaining to the cue and the foil (i.e. A_1B and BC in both events).

11 Conclusion

All in all, my results demonstrate that episodic retrieval is usually a dynamic, constructive and holistic process. Inferred knowledge is retrieved through pattern completion, a process indicated by statistical dependency among retrievals, even when the recollection of encoded information might not summon that same process. Directly encoded overlapping associations which build up into a multimodal event depend on each other for retrieval when all of them in the event have been fully observed, as is the case with simultaneous encoding of associations within a multimodal event. However, when not all of the associations have been viewed, such dependency will not be detected, but retrieval of unseen associations inferred across studied associations will still recruit pattern completion via the recall of encoded associations that forge the inference (e.g. AB and BC for inference AC). Holistic retrieval of the observed and inferred associations could be influenced by differences in organising their retrievals. In addition, repeatedly encountering associations within an encoding session will lead them to be more independent in their retrieval, regardless of whether the event had been fully or partly seen. When the repetition is distributed over several sessions, however, no impact on retrieval dependency concerning studied and inferred associations will be observed. The same dependency trends will be seen among directly observed associations and among inferred indirect associations when overlapping events are studied, though interdependency between indirect associations in a pair of overlapping events engages full pattern completion via all associations in both events. Despite remembering direct and inferred associations well, the chances of wrongly recombining elements from disparate but overlapping events can be significant, illustrating how reconstructive mechanisms facilitating episodic retrieval could also bring about false memories. The retrieval of these false associations is accompanied by partial pattern completion that is driven by memory for certain direct associations which support the illusory memories and not others which contradict them.

Metamemory accuracy has also been shown to calibrate with actual memory accuracy where encoded stimuli were concerned, but the relationship was impaired when false memories derived from overlapping events and inferences were retrieved. The findings imply that when retrieval becomes more complicated, metamemory beliefs are used as heuristics to judge the reliability of a memory, but the ability to precisely evaluate its validity is undermined as a result. Metacognitive awareness also does not appear to indicate pattern completion since the presence of dependency, which is believed to represent pattern completion, did not ensure higher confidence than when it was absent. Specifically, closed- and open-loop events were retrieved with the same level of confidence despite higher within-event dependency in the former, and inferences across overlapping events were recognised with equivalent amounts of confidence as encoded and false associations although the latter two association types displayed less extensive pattern completion.

This thesis therefore presents evidence that an auto-associative network, most probably in the hippocampus, recollects seen and inferred associations altogether via pattern completion as how the hippocampus does with encoded episodic events (Marr, 1971; McClelland, 1995; Gardner-Medwin, 1976; Wills et al., 2005; Nakazawa et al., 2002), and that false memories from overlapping events can be caused when this process is incomplete. Studies in the future could set out to specify if the disparity in pattern completion between observed and inferred associations is qualitative or because inferred material is simply weaker than directly encoded information. More investigation could also be conducted to ascertain how exactly cognitive awareness varies when processing inferences and false memories.

12 Appendix

12.1 Reaction time analyses

More light can be shed on the intricacy of the processes mediating retrieval by analysing reaction times (RT) across events. In comparing two associations, a longer RT when retrieving one of them may denote several things including the involvement of additional processes such as recall of other associations, a weaker memory trace or a less accessible engram (Ratcliff, 1978). RT data could be compared across diverse conditions relating to associative structure, association type, encoding and test repetition as well as type of element shared by overlapping events to further clarify what their retrievals entailed in different contexts.

When pairwise associates were learned and retrievals of direct and indirect associations interleaved (as in Experiment 1; see Chapter 2), recollection of direct associations in closed-loop events took the same time as in open-loop events (t(24)=0.47, p=.65). This could reflect the statistically similar amounts of dependency across direct associations in closed-loop and in open-loop events, where direct pairs primarily engaged pattern completion in closed-loop events for recollection while in open-loop events their coordinated recollection was assisted by the earlier retrieval of the inferences they supported (see Chapter 10 – Testing arrangements affect retrieval pattern). Hence, retrievals of direct pairs in both loop configurations were equally efficient. Although participants remembered closed loops better, this facilitation was less demonstrative of stronger memory traces but more of a pattern completion-mediated advantage where correctly retrieving one association would bring about the successful retrieval of other associations in the event. Meanwhile, amid the testing of direct and indirect associations in distinct sessions (as in Experiment 2; see Chapter 3), recollecting direct associations was faster in closed-loop than in open-loop events (t(33)=-2.44, p=.02, *d*=-0.42). Although agreeable with the higher accuracy scores found for closed-loop events, this outcome might be due to more prominent dependency across direct pairs in closed-loop than in open-loop structures. The ability to recollect an association through routes other than relying on itself – the retrieval of a studied association AB in a closed-loop ABC event, for instance, could occur independently or by recalling other studied associations AC and CB – might make for a faster retrieval.

RT data for directly and indirectly studied associations in open-loop events were also contrasted with one another in Experiments 1 and 2 (closed-loop events were not analysed as they did not produce indirect associations). Interleaved testing of direct and indirect associations (as in Experiment 1) is linked to quicker retrievals of direct associations in open-loop events than of inferred associations (t(24)=-6.49, p<.001, *d*=-1.30). This might mean that retrieving inferred associations concerned a more complicated pathway and illustrate the further recollection of their linking direct associations, rather than its straightforward retrieval through independent means resembling how direct associations in open loops were retrieved. However, differences in memory strength could have also caused the disparity in RT – performance was worse for the unseen indirect associations compared to the attended direct associations, so reduced memory strength might have contributed to longer retrieval latencies. Contrariwise, upon the separate testing of direct and indirect associations (as in Experiment 2), the duration of their retrieval was found to not differ (t(33)=-0.85, p=.40) despite higher accuracy scores for direct associations.

Retrieving indirect associations compelled the recollection of their direct linking associations, and hence RT for indirect associations should be longer than RT for encoded associations which were independently retrieved. No difference in retrieval time was seen, however, possibly because all retrievals for indirect associations were clustered together within one session. The continuous recruitment of similar mechanisms for all retrievals in the session enhanced processing speed such that subsequent retrievals using the same processes took place faster than the ones before (Loftus and Loftus, 1974).

RT was then analysed as a function of encoding repetition. Retrieving overlapping associations which were repeated throughout the study phase in a distributed fashion (as in Experiment 3; see Chapter 5) was faster than retrieving associations presented once (t(42)=6.38, p<.001, *d*=0.97), and the same was observed when repetition occurred concisely within one of the sessions in the study phase (as in Experiment 4; see Chapter 7; t(33)=5.75, p<.001, *d*=0.99). In both situations, stronger memory and better access to memory traces could be behind the faster RTs for repeatedly encoded stimuli than for stimuli viewed once, since higher accuracy rates were seen for repeated associations in each case.

For recollection of overlapping events (as in Experiment 5; see Chapter 8), response times for recognising directly observed, false and inferred associations were assessed. A one-way ANOVA on recognition latencies for direct associations showed an effect of overlap type (F(1.73,41.4)=3.93, p=.03, ηP^2=.14) which post-hoc paired samples t-tests explained to be caused by fastest retrieval for Location Overlap events, ahead of Person Overlap (t(24)=-2.53, p=.02, *d*=-0.51) and Object Overlap events (t(24)=-2.21, p=.04, *d*=-0.44) with the latter two overlap types not differing in RT (t(24)=-0.67, p=.51). Averaging over all overlapping events, retrieval times were comparable with those for Unique events based on a one-way ANOVA (F(1,24)=0.26, p=.62). During erroneous endorsement of twice-tested false memory pairs, a 3X2 ANOVA (overlap type x repetition) revealed no significant effects of overlap condition (F(2,14)=1.78, p=.21) and test repetition (F(1,7)=0.10, p=.76) and neither was there an interaction between them (F(2,14)=1.58, p=.24). Meanwhile, using one-way ANOVAs, FAs for foil unrelated pairs in test phase I were examined. Overlap type did not have a significant effect (F(2,18)=0.03, p=.97), and between overlapping and non-overlapping conditions, FAs for unrelated pairs were made with equivalent pace (F(1,12)=0.39, p=.55). By performing a 3X2 ANOVA, I then looked at RT differences among Person Overlap, Location Overlap and Object Overlap events and between non-repeated and repeated conditions when inferred associations were recognised. Overlap type had a main effect (F(2,48)=7.79, p=.001, ηP^2=.25) – as shown by paired samples t-tests, retrieval of indirect pairs was slowest for Object Overlap events, lagging behind Person Overlap (t(24)=3.30, p=.003, *d*=0.10) and Location Overlap events (t(24)=2.81, p=.01, *d*=0.56) while no variation in RT was detected when events shared a person or a location (t(24)=-0.49, p=.63). There was also a significant effect of repetition (F(1,24)=9.61, p=.01, ηP^2=.29) where retrieval became faster the second time, along with an interaction between repetition and overlap type that converged towards significance (F(2,48)=3.06, p=.056, ηP^2=.11). As for the time taken to wrongly recognise unrelated pairs in test phase II, one-way ANOVAs noted that overlap type did not have an effect on retrieval times (F(1.65,36.2)=2.20, p=.13) and unrelated pairs from overlapping events were associated with slower RTs than those from Unique events (F(1,16)=20.95, p<.001,

ηP^2=.57). Using a one-way ANOVA, the five response types within the Overlap condition (hits for direct pairs, FAs for false memory pairs, FAs for unrelated pairs in test phase I, hits for indirect pairs, and FAs for unrelated pairs in test phase II) were reported to not have different latencies (F(1.53,35.1)=1.68, p=.21), whereas in another one-way ANOVA on the three response types within the Unique condition (hits for direct pairs and FAs for unrelated pairs in test phase I as well as II), RTs were again comparable (F(1.21,12.1)=3.86, p=.067, ηP^2=.28).

Altogether, results on RT data in Experiment 5 presented that the type of element that overlapping events had in common did not affect retrieval times for any kind of false memories in any test phase but was important for explicit memory of events. Recognition of encoded associations was fastest if they were from Location Overlap events although performance (measured as d’) and dependency among direct associations were not varied across overlap types while confidence was only the same as for Object Overlap events though stronger than for Person Overlap events. Perhaps the typical occurrence of real-life events at the same place led to more accessible memory traces for these events than events with a person or an object in common, allowing for more rapid retrieval. In this case, strength of memory, the relatedness among retrievals and confidence were not vital in deciding retrieval speed for encoded associations. On the other hand, indirect pairs from Object Overlap events were recognised at the slowest rate despite participants remembering the pairs with the same accuracy as those from Location Overlap events and weaker than those from Person Overlap events, and no effect of overlap type on dependency among the associations and on confidence was seen. It might be harder to access memory traces for events with an object in common as opposed to events with an overlapping person or location, potentially because of the ubiquitous nature of objects whilst people and locations tend to be more exclusively connected to certain events. RT therefore did not reflect how stable the memory traces were, how reliant the retrievals were on others and how assured participants felt. In addition, repeated testing cut down the time needed to recognise inferences, which was expected given that repetition enhances ease of processing (Grill-Spector et al., 2006). However, it was not as influential on RT when retrieving false memories caused by overlapping events possibly because the retrieval process remained equally challenging on both rounds of retrieval, especially since they were not represented by proper memory traces, hence requiring the same amount of time. Overall, the speed at which memory for direct, false and indirect associations were retrieved did not vary within their respective Overlap or Unique condition, contrary to differences in d' and dependency results among the memory types. This implies that RT was regulated by factors other than memory strength and coherent retrieval of associations. The open-loop events in Experiment 2, which was most alike Experiment 5 out of the experiments using events in open-loop form (Experiments 1-4), also displayed no difference in retrieval time between direct and indirect associations, and the possible explanation for it might account for the same finding seen in Overlap events of Experiment 5. That is to say, RT for retrieval of indirect pairs in Experiment 5 should have been higher than when recollecting direct pairs within the same overlapping pair of events because retrieving unencoded indirect pairs necessitated the recall of linking direct pairs while encoded direct pairs could be retrieved on their own. Nevertheless, the prolonged engagement of retrieval-related mechanisms during the test session on indirect pairs, uninterrupted by retrievals of direct pairs, aided the retrieval process and made it as fast as recollecting direct pairs. Direct associations in Overlap and Unique events were also recognised with the same latency despite greater d’ for Unique events, though their comparable RTs could be down to them having the same amount of within-event dependency across direct associations. No difference in RT between Overlap and Unique conditions was also found when incorrectly recognising unrelated associations in test phase I – d’ and dependency were not calculated for unrelated pairs so it was not possible to draw parallels with performance and dependency. Nonetheless, the similar amounts of confidence subjects reported when wrongly recognising unrelated pairs in test phase I for Overlap and Unique conditions might have indicated that retrieval latency was determined by the same metamemory processes governing confidence (see Chapter 10 – Confidence). This, however, does not explain why in test phase II, false recognition of nonrelated pairs in the Overlap condition was slower than it was in the Unique condition despite subjective confidence not differing between the two event types. Encountering an unrelated pair which combined two distinct events that in turn overlapped with other events and deciding if the events in the pair were indirectly linked might be a complex process, and so, whether the pair was eventually accepted as true or rejected as false, a longer time was needed to arrive to such a decision. For unrelated pairs combining events that did not overlap with other events, the evaluation process was easier and thus quicker.

All in all, analysing RT data invited a lot of theoretical speculation over what caused any differences or similarities in response latency among various conditions. Even the proposed justification for the observations on RT here cannot satisfactorily rationalise the results – for example, if indeed confidence and RT were influenced by the same processes, why were unrelated pairs in test phase I inaccurately recognised at the same speed as the pairs in test phase II, although confidence when recognising the former was higher than the latter? Moreover, other factors such as similarity between test and lure elements have a hand in affecting RT (Seward, 1928; Juola et al., 1971; Ratcliff, 1978) but are not probed in my experiments. Paradigms that aim to categorically address RT and further analyses such as correlations between RT and performance would allow me to better identify what underlies the retrieval speed of different types of events and associations studied in this thesis.

13 References

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