# Contrasting the effects of schematically related versus unrelated interference on complex, episodic memories

Azara Lalla

Department of Psychology

McGill University, Montreal

April, 2020

A thesis submitted to McGill University in partial fulfilment of the requirements of the degree of Master of Science.

**Acknowledgements**: I would like to recognize the invaluable advice and assistance provided to me by my supervisor, Dr. Signy Sheldon. I would also like to thank Jennifer Bilbul and Caterina Agostino for their help collecting data and scoring transcripts.

**Remerciement**: J'aimerais faire part des précieux conseil et de la grande assistance de ma superviseur, Dr. Signy Sheldon. Je voudrais aussi remercier Jennifer Bilbul et Caterina Agostino pour leur aide à récolter les informations et évaluer les transcriptions.

Table of Contents

## Abstract

Episodic memory functioning relies on the interaction between specific details of an episode and semantic prior knowledge. Schemas are one form of prior knowledge thought to influence the way that specific details are forgotten or remembered from an episodic memory. The present study tested how the schema congruency of details within a memory change their susceptibility to forgetting due to different forms of post-encoding interference. In a between-subjects design, participants encoded complex videos and then were exposed to either an unfilled delay, an interfering narrative related to the schema of the encoded video or a narrative unrelated to the video schema. They then freely recalled half of the videos immediately and the remaining videos after 24-hours to test how sleep-dependent consolidation processes affected the results. Their recollections were scored for central details, relating to the events and activities in the video, and peripheral details, relating to perceptual information from the videos. Central details were further classified as schema-congruent or incongruent with the overarching theme of the video. Our results show that only unrelated interference affected the amount of central and peripheral details that were forgotten. However, when the schema-congruency of the central details were considered, there were similar and distinct effects of both types of interference on the relationship between central and peripheral details contained within the recollection. Our findings implicate the interdependency of episodic memory and one form of semantic prior knowledge, schemas, as a major factor in how interference causes the forgetting of details from episodic memories.

Abstract (French)

La mémoire épisodique repose à la fois sur l'accès aux détails spécifiques d'un événement et sur l'accès aux connaissances sémantiques. Une forme de connaissance sémantique, les schémas, peuvent influencer la raison et la manière dont certains détails liés aux souvenirs épisodiques sont oubliés tandis que d'autres sont préservés. Cette enquête a tester comment la congruence entre un schéma et les détails liés une mémoire change leur susceptibilité à être oublier lorsque ces informations interférentes sont liées ou non liées à cette mémoire. Après avoir encodé des vidéos, les participants ont été exposés à une pause au cours de laquelle ils n'ont rien fait, ont écouté une narration liée à la vidéo qu'ils ont encodée ou ont écouté une narration sans rapport avec la vidéo encodée. Immédiatement après, ils ont rappelé la moitié des vidéos et la moitié restante a été rappelée 24 heures plus tard. Leurs souvenirs ont été analyses pour noter le nombre des détails centraux, concernant les événements et les activités dans la vidéo, et pour noter le nombre des détails périphériques, concernant les informations perceptuelles des vidéos. Les détails centraux ont ensuite été classés comme congruents ou non congruents au schéma en relation avec le thème de la vidéo. Nos résultats ont démontré que seule l'interférence non liée a influencer l'oubli des détails centraux et périphériques. En plus, nos résultats ont démontré des effets similaires et distincts des deux types d'interférence sur la relation entre les détails centraux et périphériques lorsque l'on considère la congruence du schéma. Nos résultats impliquent l'interdépendance de la mémoire épisodique et sémantique comme un facteur important qui joue un rôle dans la façon dont les informations interférentes influencent l'oubli des détails des mémoires épisodiques.

Contrasting the effects of schematically related versus unrelated interference on complex, episodic memories

It has happened to us all: in conversation with a friend, you find yourself unable to recall certain details of a shared experience. To provide these details, you are relying on your episodic memory, which is your conscious awareness of past events and experiences, and its interactions with your semantic memory, which catalogues your general knowledge of facts and concepts (Greenberg & Verfaellie, 2010; Tulving, 2002). The creation of a coherent episodic memory trace and its use in everyday life involves access to an array of information types, ranging from semantic-dependent prior knowledge to episodic-specific event and perceptual details (Anderson & Conway, 1993). But, at times, episodic memory can fail—a common experience is that certain elements of a memory are no longer accessible, resulting in forgetting (Roediger, Weinstein, & Agarwal, 2010). How and why forgetting occurs for some information and not others—for example, remembering that you ordered a meal while out to lunch with a friend, but not what you wore—remains unclear. Here, we explore how one mechanism of forgetting, interference, interacts with prior knowledge to affect the kinds of details lost from complex, episodic memories.

**The Influence of Semantic Memory on Episodic Memory Processing**

Although the distinction between episodic and semantic memory has been long understood (Tulving, 1985) and established through neuropsychological work with patients (Chan et al., 2001; Greenberg & Verfaellie, 2010; Hodges, Graham, & Patterson, 1995; Manns, Hopkins, & Squire, 2003), memory researchers are only beginning to elucidate how these two systems interact. Not only is there evidence to suggest that episodic memory facilitates learning of new semantic information (Verfaellie, 2000), but semantic memory may also support both encoding and retrieval of new episodic memories. A study compared healthy controls to medial temporal lobe amnesic patients on a task where they learned new episodic memories that were either congruent or incongruent with their semantic prior knowledge. They found that an intact semantic store enhanced episodic memory performance for congruent memories in both healthy controls and patients (Kan, Alexander, & Verfaellie, 2009). The clear interplay between episodic and semantic memory is further underscored by how one form of semantic information, schemas, influences episodic memory processing.

Schemas are a form of prior knowledge containing common features abstracted from multiple related episodes, with few details remaining that are unique to a specific event (Richards et al., 2014; Jessica Robin & Moscovitch, 2017). Importantly, the schema congruency of an event, or how concordant it is with prior knowledge, can influence how it is processed at each stage of the episodic memory system (Bonasia et al., 2018). Encoding and retrieval are two key component processes of the episodic memory system (Dolan & Fletcher, 1997; Renoult & Rugg, 2020; Tulving, 1984) where schema congruency may come into play. Encoding describes the acquisition of a memory trace, which begins with the perception of an event (Tulving, 1984) and necessitates that attention be directed to the to-be-encoded information (Aly & Turk-Browne, 2016; Minarik, Berger, & Sauseng, 2018). Schema-congruent information is often encoded more deeply than schema-incongruent information (Barry & Maguire, 2019; Renoult & Rugg, 2020; Yassa & Reagh, 2013). Importantly, a distinction must be made between the encoding of simple, perceptual events and the more complex, extended events akin to everyday experience. Whereas both can be encoded into episodic memories, encoding of complex, extended events also engages semantic processing which imbues it with meaning and situates it within the context of prior knowledge (Renoult & Rugg, 2020; Tulving, 1984), thus leading to better memory for this information.

Retrieval of an episodic memory, defined by the reactivation of the memory trace (Rugg, Otten, & Henson, 2002), entails an interaction between the episodic memory system and prior knowledge (Renoult & Rugg, 2020; Tulving, 1984). It commences with the internal or external perception of a retrieval cue and often involves a recollective experience of the event (Renoult & Rugg, 2020; Tulving, 1984), which includes the reinstatement of representations present at encoding (O'Reilly & Rudy, 2001; Waldhauser, Braun, & Hanslmayr, 2016). At retrieval, the importance of schema congruency is reflected in research investigating the utility of cues, which are pieces of semantic information related to the to-be-remembered event. Such studies find that cues enhance access to encoded information during retrieval and improve memory accuracy (Guerin, Robbins, Gilmore, & Schacter, 2012). Thus, schema-congruent memories are not only encoded more strongly and consolidated more readily, but are more accessible at retrieval, emphasizing the importance of taking into account schema congruency when testing complex memories, which may contain varying levels of such information. However, the schema congruency of an encoded event has never been considered in the context of how it may interact with the forgetting of detailed information from episodic memories.

## The Forgetting of Different Details from Episodic Memories

In general, episodic memories for everyday experiences are recognized to contain both *central* or gist-related information and more *peripheral* or detailed information. Gist relates to the events or main storyline of a particular episode, whereas detail contains the rich, perceptual information absent in gist-like representations (Jessica Robin & Moscovitch, 2017; Rumelhart & Ortony, 1977). These detail types may differentially relate to prior knowledge. Schemas, by virtue of being devoid of details unique to any one event (Bonasia et al., 2018), are relatively more likely to be congruent with central detail information, which is more conceptual in nature, than peripheral detail information. This may relate to findings in the literature on forgetting which claim that central and peripheral details are subject to different rates of forgetting (Furman, Dorfman, Hasson, Davachi, & Dudai, 2007; Sekeres et al., 2016). A study by Sekeres et al., (2016) found specifically that central details are resistant to forgetting over time, while peripheral details are rapidly lost. Since events which activate schematic prior knowledge may be subject to less forgetting (Bonasia et al., 2018; Renoult & Rugg, 2020), it can thus be predicted that central information is resistant to forgetting insofar as it is schema congruent; by contrast, peripheral information, as it is rarely relevant to schemas, is quickly forgotten.

The distinct forgetting rates for central and peripheral details further suggest that these aspects of a memory trace may be subject to different forgetting mechanisms. Two mechanisms proposed to underlie the forgetting process are *decay*, in which memories are forgotten due to the passage of time, and *interference*, in which memories are forgotten due to exposure to other information around the time of learning (Roediger et al., 2010; Sadeh, Ozubko, Winocur, & Moscovitch, 2014). Importantly, while investigations into the neural pathways of interference and decay have established both the individual and overlapping contributions of these mechanisms to forgetting (Frankland, Kohler, & Josselyn, 2013; Sadeh et al., 2014; Winocur, Becker, Luu, Rosenzweig, & Wojtowicz, 2012), behavioral studies often fail to disentangle the separate effects of these mechanisms on forgetting (Furman et al., 2007; Sekeres et al., 2016). Furthermore, research has yet to investigate how prior knowledge and interference may interact to cause forgetting.

**Forgetting by Interference**

The kinds of interfering information encountered in everyday life can vary in how related they are to a previously encoded event, in that they may or may not activate the same schema. However, the schema-relatedness of interfering information has never been investigated, despite evidence that interference that is qualitatively similar to encoded information may influence forgetting (Keppel & Underwood, 1962). Rather, research in the field of interference has tended to use psychometric testing, which is both non-schematic and unrelated to the encoded information, as a form of post-encoding interference. Such work in both healthy and amnesic populations have identified a profound negative effect of post-encoding interference on memory retention for oral narratives (Dewar, Della Salla, Beschin, & Cowan, 2010), which is prevented in both populations by minimizing interference after encoding (Della Sala, Cowan, Beschin, & Perini, 2005). These effects are likely due to the neural representation of a new memory trace being labile and unstable shortly after encoding. Synaptic consolidation acts to stabilize the representation through the synthesis of new proteins during this post-encoding period (Dudai, 2004; Haubrich, Bernabo, Baker, & Nader, 2020; Morris, 2006). If synaptic consolidation is disrupted, whether through molecular or behavioral intervention, retrieval of the memory trace is often impaired (Haubrich et al., 2020). Thus, the post-encoding period is a critical time during which forgetting occurs, and it is predicted that encountering interfering information during this window will accelerate forgetting. However, it is still unclear how encountering more naturalistic post-encoding interference, varying in schematic relatedness to an encoded event, might impact the forgetting rates of different detail types.

For complex episodic memories, the conceptual or schematic overlap with interfering information is of particular importance to understanding how forgetting by interference occurs. Seminal as well as more contemporary work on schemas and concepts emphasize that humans naturally organize incoming information within a framework of prior knowledge, which allows a coherent and unified representation to be formed (Alba & Hasher, 1983; Bartlett, 1932; Bonasia et al., 2018). As interfering information is processed in this way, its relatedness may affect the extent to which ongoing synaptic consolidation of the previously encoded memory is disrupted (Sosic-Vasic, Hille, Kröner, Spitzer, & Kornmeier, 2018). According to predictive coding models of memory, interference that is schematically related to the memory may be processed less by virtue of being highly expected or familiar, whereas unrelated interference will be processed to a greater degree due to its novelty or unexpectedness (Friston, 2005; Henson & Gagnepain, 2010; Van Kesteren, Ruiter, Fernández, & Henson, 2012). Thus, schematically related interference is predicted to cause less forgetting than schematically unrelated interference. To test this prediction, it is critical to contrast how interference occurs when the interfering information is more or less schematically related to the memory.

## Current Study

The objective of the present study was twofold: to test how two kinds of interference, schematically related and unrelated, cause forgetting of complex, episodic memories and, to account for how the schema-congruency of the details within a memory change their susceptibility to forgetting. Based off of findings from Sekeres et al. (2016), we predict that peripheral details will be subject to higher rates of forgetting than central details, particularly over time. We also predict that the forgetting of central details will depend on their congruency to the overarching schema of the memory. Schema-congruent central details will be resistant to forgetting regardless of whether interfering information is related to the schema or unrelated. These predictions emerge from the research described above, which suggests that schema congruency can enhance memory performance (Alba & Hasher, 1983; Bonasia et al., 2018). Our third prediction is that the relatedness of post-encoding interference to the schema of the memory will influence the forgetting of schema-incongruent central details. Schema-incongruent central details will be forgotten disproportionately when interfering information is schematically unrelated. This emerges from work suggesting that novel information is processed differently than familiar information (Friston, 2005; Henson & Gagnepain, 2010; Van Kesteren et al., 2012) and may disrupt synaptic consolidation of previously learned memories (Sosic-Vasic et al., 2018). We tested these predictions with a between-subjects experiment in which all participants encoded four complex video clips depicting everyday events. Video stimuli were used in order to mimic naturalistic experiences, and to allow for the testing of both central and peripheral details simultaneously—an assessment which is not afforded by using more simplistic stimuli (Koen & Rugg, 2016; Roediger et al., 2010; Wixted, 2004). During a subsequent post-encoding forgetting period, participants in the interference groups listened to narratives that were either schematically related or unrelated to the videos whereas participants in the control group experienced an unfilled delay. All participants recalled two of the videos in detail immediately after this period and the details from the other two videos after 24 hours. Contrasting memory performance between these groups will shed light on how interferences underlies the forgetting of complex memories.

# Methods

## Participants

Ninety-four young adult participants from the McGill University SONA Participant Pool and Montreal community participated in the study. Inclusion criteria were no history of psychiatric, neurological, and learning disorders as well as no loss of consciousness for more than a few seconds in the recent past. Participants provided informed consent and all procedures were in accordance with the Research Ethics Board Office at McGill University. Participants were compensated with course credit or $20 for their time.

Participants were randomly assigned to one of three groups: a control group (n = 33), a related interference group (n = 31), or an unrelated interference group (n = 30). Five participants were excluded for missing data (3 participants from the control group, and 1 from each of the interference groups). An additional 3 participants were excluded for being outliers (2 participants from the related interference group and 1 participant from the unrelated interference group). An outlier was defined as any participant who reported a total number of details more or less than two standard deviations from the mean number of details across all participants. Our final sample consisted of n = 86 younger adult participants (n = 68 women, mean age = 21.22 years, mean years of education = 15.48 years), with n = 30 in the control group (n = 22 women, mean age = 21.67 years, SD = 1.91 years, mean years of education = 16.24 years, SD = 2.06 years), n = 28 in the related interference group (n = 25 women, mean age = 21.16 years, SD = 1.98 years, mean years of education = 15.24 years, SD = 1.89 years), and n = 28 in the unrelated interference group (n = 21 women, mean age = 20.75 years, SD = 1.55 years, years of education = 15.14 years, SD = 1.28 years). There was no significant difference between the groups based on age ($F(2,81) = 1.41$, $p = .25$) or years of education ($F(2,81) = 3.06$, $p = .07$). A chi-squared test was performed to examine the relationship between gender and group, but the relationship between these variables was nonsignificant ($X_2$ (1, 86) = .2.64, $p = .27$).

## Materials

### *Stimuli*

**Videos**. Four silent Mr. Bean videos depicting complex events used in prior work (Sheldon, Gurguryan, Madore, & Schacter, 2019; St-Amand, Sheldon, & Otto, 2017) served as the main stimuli. Each video was 3 minutes and 27 seconds long, depicted between 5 and 9 characters in the scene, and took place in 1 location. The videos were provided with unique, identifying titles (*see Table 1*) which were recorded and presented as audio using a male voice.

**Interference Stimuli**. For each video, a five-paragraph narrative story was developed describing an event that was conceptually related to the general theme of the video (e.g., eating at a restaurant). To create these narratives, we followed guidelines for a standard narrative structure for event descriptions proposed in prior work (Flores, Bailey, Eisenberg, & Zacks, 2017; Speer & Zacks, 2005; Zacks, Tversky, & Iyer, 2001), with each sentence elaborating upon the actions and events in the story. The schematically related content of each paragraph was determined from responses to an online survey addressing event expectations, which was run on Amazon's Mechanical Turk. Sixty-two participants (mean age = 62.67 years, years of education = 15.62 years) completed the survey. They were presented with the general theme of each video and instructed to provide five open-ended responses on events they would expect to occur in the provided scenario (e.g., receiving a menu, ordering food, etc. while dining at a restaurant). We then determined the frequency of each reported event across all participants and incorporated the top 5 most frequently reported events into the narratives. Each narrative was around 3 minutes in length (*see Table 1*) and was audio recorded by a male speaker.

## Procedure

**Overview.** There were two experimental sessions separated by 24 hours (*see Figure 1*). Session 1 began with the participant filling out the consent form and demographic questionnaire. Then, the participant was given instructions for and completed the encoding session, which lasted for 30 minutes. After a 10-minute filled delay, the experimenter provided instructions for the retrieval session. Participants completed the first retrieval session, around 15 minutes in length. After a 24-hour delay, the participant returned to the laboratory and completed the second retrieval session, which was also around 15 minutes in length. Each session is described in detail below.

**Encoding**. This session included four experimental trials. For each trial, participants first heard the title of a randomly selected video and then watched the associated video. Next, they provided ratings on how entertaining they found the video on a scale of 1-5 (*1-not entertaining at all, 5-very entertaining*). Those in the related or unrelated interference groups then listened to a narrative that was schematically related (e.g., “Dining at a Restaurant” video paired with the narrative about dining at a restaurant) or unrelated to the video (e.g., “Dining at a Restaurant” video paired with the narrative about taking an art class), respectively. Participants in the control group were not presented with interfering stimuli and instead waited for an amount of time equivalent to the length of the interfering stimuli associated with the video, around 3 minutes. After this period, participants provided ratings on either narrative entertainment (interference groups) or entertainment during the unfilled delay (control group) on a scale of 1-5 (*1-not entertaining at all, 5-very entertaining*). See *Figure 2* for an overview.

**Break**. During a 10-minute break, participants completed questionnaires that are not part of the presented analyses.

**Retrieval**. Both the first and second retrieval sessions included two experimental trials, each testing memory for a distinct and randomly selected video. That is, no video that was tested in the first retrieval session was also tested in the second retrieval session. As illustrated in *Figure 3*, each trial began with an auditory presentation of the video title for 2 seconds. Next, participants had 5 seconds to rate how well they remembered the content of the video on a scale of 1 to 5 (*1 – no memory for video content, 5 – able to remember everything that happened in the video*). They were instructed that the content of the video referred to what happened in the video, such as events and activities that had occurred. After a 1 second fixation cross, participants had 5 seconds to rate how vividly they could picture the video in their mind (*1 – cannot picture the video, 5 – can vividly picture the video*). They were instructed that vividness referred to how well they could imagine what the video looked like. For each rating, participants entered their response via a keyboard press. After these ratings, participants were instructed to verbally report first the central details of the video and then the peripheral details of the video. They were informed that a central detail constituted the events or actions in the video, and that they should describe what was happening in the video as though speaking to someone who was writing a script about the video. For peripheral details, they were informed that these involved any perceptual element that described the people, objects, and environment of the video, and that they should report their memory as though speaking to someone who had never seen the video. A voice recorder was used to capture participants' separate verbal reports for the central and peripheral details, which were later transcribed.

**Scoring**

Each transcription was scored for the presence of central and peripheral details. Central details were scored with a template created for each video, following the method used by Sekeres et al. (2016). According to the templates, each video was divided into 35 distinct central details which concerned the events and activities surrounding the actions of the main character. For each video, the central details were further coded as schema-congruent, meaning they conveyed an expected event, as determined from the top 10 most frequent responses to the online event expectation survey discussed above, or schema-incongruent, meaning they did not appear in the survey responses and so were unexpected. For example, in the video “Dining at a Restaurant”, the central detail “Mr. Bean received a menu from the waiter” and other central details related to this event would be coded as a schema-congruent detail, because the event “receiving/reading a menu” was one of the top 10 most frequently reported events for that scenario. However, a detail like “Mr. Bean threw his napkin at the lady next to him” would be scored as schema-incongruent, as it did not appear in the responses for that scenario. Using this method, each video was determined to have between 14 and 19 schema-congruent central details. A central detail was thus scored as present if it appeared at any point in the transcript (1) and absent if it was not described within the transcript (0). If present, it was further designated as a schema-congruent or schema-incongruent central detail.

Next, the transcriptions were scored for the number of peripheral details recalled using a modified version of the Autobiographical Interview (Levine, Svoboda, Hay, Winocur, & Moscovitch, 2002). This method involved classifying informational segments that were not central details and then categorizing the segment as an object detail (perceptual information about objects or people), a context detail (relating to the position of objects or people in the environment), or an emotion/reaction detail (relating to the emotions or reactions of people in the video). Each peripheral detail was also classified as embedded if it appeared alongside a central event (e.g., “Mr. Bean received a *large, red menu*”) or unembedded if it was reported independent of any central details (e.g., “The *menu* was *large* and *red*.”).

**Analytic Plan**

To ensure that group differences in how entertaining participants perceived the stimuli to be could not influence our results, a 3 x 2 mixed ANOVA was conducted to investigate the effect of the between-subjects factor of group (3 levels: control, related interference, unrelated interference) and the within-subjects factor of stimulus type (2 levels: video, narrative) on entertainment rating. We additionally conducted two separate 3 x 2 mixed ANOVAs to look at the effect of the between-subjects factor of (3 levels: control, related interference, unrelated interference) and the within-subjects factor of session (2 levels: session 1, session 2), on story content rating and vividness rating respectively, in order to examine how our group and session manipulations effected the subjective experience of remembering.

Our main analyses focused on the recall of central and peripheral details. Separate 3 x 2 x 2 mixed ANOVAs were run on the average number of central and peripheral details with the between-subjects factor of group (3 levels: control, related interference, unrelated interference), the within-subjects factor of session (2 levels: session 1, session 2) and the within-subjects factor of detail type (for central details, 2 levels: schema-congruent, schema-incongruent and for peripheral details, 3 levels: object, context, emotion/reaction).

Finally, to examine the interrelatedness of central and peripheral details and the fact that interference may affect this relationship, two linear mixed effects models were constructed. Model 1 will predict embedded object details, which were recalled incidentally while reporting central details, from fixed factors of session, group, schema-congruent central details, schema-incongruent central details, and the interaction between session, group and each central detail type. Model 2 will predict unembedded object details, which were recalled independently of central details, from fixed factors of session, group, schema-congruent central details, schema-incongruent central details, and the interaction between group and each central detail type.

# Results

## Ratings

A 3 x 2 mixed ANOVA was conducted to investigate the effect of the between-subjects factor of group (3 levels: control, related interference, unrelated interference) and the within-subjects factor of rating type (2 levels: video, post-encoding) on entertainment rating. This analysis found a significant main effect of rating type ($F(1,78) = 744.96$, $p < .0001$; *see Figure 4*), which pairwise comparisons revealed to be driven by significantly higher entertainment ratings for the video than the post-encoding period ($t(78) = 27.29$. $p < .0001$). No significant main effect of group ($F(2,78) = 2.79$, $p = .07$) or interaction between group and rating type ($F(2,78) = .61$, $p = .54$) was identified. This suggests that entertainment ratings did not differ between groups; videos were consistently rated as more entertaining than the post-encoding period, and our interference groups were not more entertained by the interference stimuli than the control group was by waiting.

A 3 x 2 mixed ANOVA conducted to examine the effect of the between-subjects factor of group (3 levels: control, related interference, unrelated interference) and the within-subjects factor of session (2 levels: session 1, session 2) on story content rating revealed a significant main effect of session ($F(1,78) = 28.61$, $p < .0001$; *see Figure 5*). Pairwise comparisons revealed that this was due to significantly higher ratings at session 1 compared to session 2 for all groups ($t(78) = 5.35$, $p < .0001$). No significant main effect of group ($F(2,78) = .11$, $p = .90$) or interaction between group and session ($F(2,78) = .53$, $p = .59$) was identified.

Finally, a 3 x 2 mixed ANOVA conducted to examine the effect of the between-subjects factor of group (3 levels: control, related interference, unrelated interference) and the within-subjects factor of session (2 levels: session 1, session 2) on vividness rating revealed a significant main effect of session ($F(1,78) = 30.25$, $p < .0001$; *see Figure 6*). Pairwise comparisons revealed that this was due to significantly higher ratings at session 1 compared to session 2 for all groups ($t(78) = 5.50$, $p < .0001$). No significant main effect of group($F(2,78) = .84$, $p = .44$) or interaction between group and session ($F(2,78) = .18$, $p = .83$) was identified.

**Central Detail Recall**

The 3 x 2 x 2 mixed ANOVA conducted to examine the effects of the between-subjects factor of group (3 levels: control, related interference, and unrelated interference), the within-subjects factor of session (2 levels: session 1, session 2), and the within-subjects factor of central detail type (2 levels: congruent, incongruent) on the number of central details generated found a significant main effect of group ($F(2,79) = 3.17$, $p = .05$). Pairwise comparisons revealed that this was driven by significantly more central details recalled in the control group than the unrelated interference group ($t(79) = 2.52$, $p = .037$; *see Figure 7*). There was no significant difference between the control group and related interference group ($t(79) = 1.15$, $p = .49$) or the related interference group and the unrelated interference group ($t(79) = 1.36$, $p = .37$).

A main effect of session was also reported ($F(1,79) = 17.15$, $p < .0001$), as was a main effect of central detail type ($F(1,79) = 191.42$, $p < .0001$) and a significant interaction between session and central detail type ($F(1,79) = 6.08$, $p = .02$). Focusing on this interaction effect, pairwise comparisons revealed there were significantly fewer schema-incongruent central details reported at session 2 than session 1 ($t(156) = 4.59$, $p < .0001$; *see Figure 8*). There was no difference between the number of schema-congruent central details at session 1 and session 2 ($t(156) = .91$, $p = . 36$). There were no significant interactions were found between group and session ($F(2,79) = .98$, $p = .38$), group and central detail type ($F(2,79) = .55$, $p = .58$), or group, session, and central detail type ($F(2,79) = .28$, $p = .76$).

**Peripheral Detail Recall**

The 3 x 2 x 3 mixed ANOVA was conducted to examine the effects of the between-subjects factor of group (3 levels: control, related interference, unrelated interference), the within-subjects factor of session (2 levels: session 1, session 2) and the within-subjects factor of peripheral detail type (3 levels: object, context, emotion/reaction) on the number of peripheral details recalled. There was no significant main effect of group ($F(2,79) = 2.02$, $p = .14$) or session ($F(1,79) = 3.53$, $p = .06$), but there was a significant main effect of peripheral detail type

($F(1,79) = 850.77$, $p < .0001$) as well as a significant interaction between group and peripheral detail type ($F(2,79) = 4.53$, $p = .01$). Focusing on the interaction effect, pairwise comparisons revealed that significantly more object details were reported in the control group than in the unrelated interference group ($t(212) = 4.39$, $p < .0001$), and in the related interference group compared to the unrelated interference group ($t(212) = 2.54$, $p = .031$; *see Figure 9*). There was no significant difference between the number of object details in the control group and the related interference group ($t(212) = 1.82$, $p = .16$), or between any of the contrasts for context and emotion/thought details. No significant interactions were found between group and session ($F(2,79) = .01$, $p = .99$), session and peripheral detail type ($F(1,79) = 1.87$, $p = .17$), or group, session, and peripheral detail type ($F(2,79) = .43$, $p = .68$).

**The Relationship Between Central Detail and Peripheral Detail Recall**

As object peripheral details were reported to be most susceptible to interference effects, as noted above, we focused on this category of peripheral details to examine the relation to central details. We also considered how each object peripheral detail was reported by the participant – either as an embedded peripheral detail, incorporated within a statement about a central detail, or an unembedded peripheral detail, which was reported independently of central detail information (*see Scoring section for more information*). Embedded and unembedded peripheral details were analyzed in separate models.

**Model 1**. A linear mixed effects model predicting embedded peripheral details from fixed factors of session, group, schema-congruent central details, schema-incongruent central details, and the interaction between session, group, and each central detail type revealed that both schema-congruent and schema-incongruent central details were significant positive predictors ($\beta = 1.15$, $p < .001$ and $\beta = 1.04$, $p < .001$ respectively). This suggests that the more central details recalled, the more embedded peripheral details recalled alongside them. A significant three-way interaction between session, the related interference group, and schema-incongruent central details was found ($\beta = .90$, $p = .015$). In order to interpret this interaction, we ran two further models, splitting session 1 (Model 1.1) and session 2 (Model 1.2). No other significant predictors or interactions were found (*see Table 2*).

**Model 1.1**. A linear mixed effects model predicting embedded peripheral details at session 1 from fixed factors of group, schema-congruent central details, schema-incongruent central details, and the interaction between group and each central detail type was conducted. This revealed that embedded peripheral details were again positively predicted by both schema-congruent ($\beta = 1.07$, $p < .001$) and schema-incongruent central details ($\beta = 1.05$, $p < .001$). Consistent with the previous model, the more central details remembered at session 1, the more embedded peripheral details recalled. No other significant predictors or interactions were found (*see Table 3*).

**Model 1.2**. A linear mixed effects model predicting embedded peripheral details at session 2 from fixed factors of group, schema-congruent central details, schema-incongruent central details, and the interaction between group and each central detail type was conducted. This revealed that embedded peripheral details were again positively predicted by both schema-congruent ($\beta = 1.46$, $p < .001$) and schema-incongruent central details ($\beta = 0.58$, $p = .002$).

Consistent with the previous models, the more central details remembered at session 2, the more embedded peripheral details recalled. A significant interaction was found between the related interference group and schema-congruent central details ($\beta = -.83$, $p = .0003$) and the unrelated interference group and schema-congruent central details ($\beta = -.96$, $p = .005$). This suggests that participants who recalled more central details in either of the interference groups also recalled fewer embedded peripheral details at session 2 compared to the control group. When interference is present, consolidation may be uncoupling peripheral details from central details. However, an interaction between the related interference group and schema-incongruent central details ($\beta = .60$, $p = .019$) suggests that in the related interference group, participants who recalled more schema-incongruent central details also recalled more embedded peripheral details compared to the control group. Better memory for schema-incongruent central details in the related interference condition may help preserve embedded peripheral details. No other significant predictors or interactions were found (*see Table 4*).

**Model 2**. A linear mixed effects model predicting unembedded peripheral details from fixed factors of session, group, schema-congruent central details, schema-incongruent central details, and the interaction between session, group, and each central detail type revealed no significant predictors or interactions (*see Table 5*). Embedded object details recalled independently from central details are not remembered in the same way as those recalled alongside them; they are not predicted by central details, nor by session or group.

## Discussion

Complex episodic memories require access to different levels of information, including both episode-specific details and prior, schematic knowledge. Evidence suggests that episode-specific central and peripheral details are forgotten at different rates, but no research has been done to assess how the schema congruency of an encoded memory and the schema relatedness of post-encoding interference influences how these details are lost. The present study addressed two gaps in the literature on the forgetting of detailed memories by taking into account that episodic memories are situated within the context of prior knowledge, like schemas, and that interference can be related or unrelated to this prior knowledge. Our main results revealed several novel effects of interfering information. Firstly, fewer central details and fewer objected-related peripheral details were reported after exposure to interference that was unrelated to the schema of the memory as compared to a control group. Secondly, the relationship between central and peripheral details changed after consolidation depending on the schema congruence of the central details and the relatedness of the interfering information. Additionally, we discovered that the 24-hour delay differently affected schema-congruent and schema-incongruent central details, independent of the effects of interference. These findings and their implications are discussed below.

## Interference Effects on Detailed Episodic Memory

The key finding of the present study was an effect of the content of the interfering stimuli on forgetting. The existing literature on interference has identified a profound negative effect of post-encoding interference on memory retention for oral narratives (Della Sala et al., 2005; Dewar et al., 2010), but has not investigated how interference separately affects distinct detail types from those memories or compared the effects of interference that varies in schematic relatedness to the encoded memory. Our findings demonstrate not only that forgetting after post-encoding related interference is comparable to forgetting after an unfilled delay, but importantly that both central and peripheral details are forgotten due to unrelated interference. We focussed on these two detail types based off of previous work suggesting that they are the primary components of episodic memories (Jessica Robin & Moscovitch, 2017; Rumelhart & Ortony, 1977) and that they are forgetten at distinct rates (Furman et al., 2007; Sekeres et al., 2016). Interestingly, of the three kinds of peripheral details (object, context, emotion) we assessed, unrelated interference affected only the object-related peripheral details. In general, participants reported fewer context and emotion details than object-related details, which may contribute to why a difference was found only for object-related details. However, some research has suggested that emotional (Holland & Kensinger, 2010; Kensinger & Corkin, 2003) and spatial information (J. Robin, Wynn, & Moscovitch, 2015; Jessica Robin, Buchsbaum, & Moscovitch, 2018) are more resistant to forgetting. Subsequent work might match the stimuli on all three of these peripheral detail types to ascertain whether this is the case.

In general, these results provide evidence for two, not mutually exclusive, theories focussing on the role of schematic prior knowledge during the post-encoding period. Firstly, one theory suggests that there is memory benefit for schema-congruent associative information during the post-encoding period, which slowly declines over the course of 48 hours (van Kesteren, Rijpkema, Ruiter, & Fernández, 2013). Presenting unrelated schema information during this critical post-encoding window may compete with or block the previously activated schema, preventing the schema congruency effect and causing forgetting. This would explain why the unrelated interference group had steeper rates of forgetting compared to the group with an unfilled delay; the schema congruency effect is not disrupted for the latter group, resulting in better memory performance. A second theory to explain these results is that post-encoding related interference reinforces memory for schema-congruent information by reactivating the associated schema and representations of the encoded event (Van Kesteren et al., 2012). This is likely similar to any rehearsal that may have taken place during the unfilled delay, thus leading to comparable memory for these two groups, but poorer performance in the unrelated interference group. Future work may pit these two explanations against each other in order to elucidate whether they contribute to the effects of interference together or separately.

A second key result of the current study was that interfering information affected forgetting after an extended delay, which included a period of sleep consolidation. Recent work looking at active post-encoding interference identified no disruption of encoded episodic memories after a period of sleep consolidation (Varma et al., 2017). However, Varma et al. (2017) tested memory for word-picture associations followed by either a post-encoding unfilled delay or a 2-back task. No study prior to ours has looked at the consolidation of complex episodic memories after post-encoding exposure to two kinds of naturalistic interference stimuli. We identified similar and distinct memory effects from both kinds of interference after consolidation by assessing the relationship between the central and peripheral details recalled. Prior to consolidation, the recall of both schema-congruent and schema-incongruent central details positively predicted embedded peripheral details, with no effect of either interference group. But after consolidation, this relationship became more nuanced. Firstly, we found that better memory for schema-congruent central details predicted worse memory for embedded peripheral details in both interference groups compared to the control group, with the magnitude of the effect greater in the unrelated interference group. Importantly, this was true only of the embedded peripheral details—no effect of consolidation was found for unembedded peripheral details. Interference, regardless of whether it is related or unrelated, accelerates the loss of perceptual content from episodic memories during consolidation, but only when that perceptual information is recalled naturalistically alongside central detail information.

An explanation for this effect is that post-encoding interference hastens memory schematization. In essence, the schema-congruent episodic memory trace is rapidly integrated into semantic memory structures through consolidation (Morris, 2006); superfluous perceptual information is lost while the higher level, conceptual information is stabilized (Diekelmann & Born, 2010). Such findings align with memory transformation theories such as Trace Transformation Theory and Multiple Trace Theory, both of which implicate episodic processes in memory for rich, perceptual content and episode-specific gist information (Moscovitch, Cabeza, Winocur, & Nadel, 2016; Winocur & Moscovitch, 2011). With consolidation, these episodic memories are transformed to become more schematic, less perceptually detailed, and less hippocampally dependent (Jessica Robin & Moscovitch, 2017). The exact mechanisms through which interference facilitates schematization are not known, but present interesting avenues for future research.

Additionally, the finding that unembedded, or independently recalled, peripheral details were not affected by consolidation suggests that some difference exists between perceptual content recalled alongside central detail information and perceptual content recalled alone.

Although not within the scope of the current study, we propose that this is due to the unexpectedness or novelty of the unembedded peripheral details; as a result, they are more episodic in nature and do not readily undergo schematicization and integration into existing semantic knowledge networks. A recent model looking at how memory performance is influenced by schemas and novelty postulates that elements encountered in a schema-incongruent context (e.g., a toy duck in a bakery) are encoded purely through episodic processes, without recruitment of schematic knowledge. After consolidation, retrieval of the novel object-context pair is mediated purely through episodic activation, rather than through interacting episodic and semantic processes (Van Kesteren et al., 2012), thus giving rise to improved memory for novel items. Unembedded perceptual details, much like novel object-context pairs, are less reliant on the interplay between the episodic and semantic memory systems during retrieval and are thus remembered better. Future work might explicitly manipulate the novelty of peripheral detail information in order to determine whether this is the case.

Secondly, we found that, after consolidation, better memory for schema-incongruent central details in the related interference group positively predicted embedded peripheral details. Again, we interpret this in light of the model proposed by Van Kesteren et al. (2012); central details which were unexpected or novel in the context of the overarching schema and the peripheral information associated with them are encoded and retrieved after consolidation via episodic processes alone. That this was true only of the related interference group and not of the unrelated interference group is likely due to the reactivation of the memory-congruent schema in the related interference group, which may have emphasized the novelty of the unexpected information.

**Time-Dependent Forgetting Effects**

The importance of considering the schema content of not only the interference stimuli, but the encoded memories, is also emphasized by the novel finding that schema-incongruent central details are subject to forgetting over time, regardless of interference exposure. Previously, a study by Sekeres et al. (2016) had investigated how central and peripheral details were forgotten from short, complex video stimuli and determined that central details were resistant to forgetting over time, much like the schema-congruent central details from our study. A reason for the difference in our findings is that we used longer video stimuli containing a greater range of detail types, as might be the case in memories for everyday events. This allowed us to separately assess memory for schema-congruent and -incongruent central details in order to uncover the fact that only congruent central detail information is truly resistant to forgetting over time. We interpret this result as evidence for prior knowledge content housed within the semantic memory system, such as schemas, improving episodic recall (Anderson & Conway, 1993; Tulving, 2002). Indeed, research has indicated that schema information accelerates memory consolidation (Morris, 2006), resulting in better memory for information that is schema congruent (Dudai, 2004).

Another surprising finding from the present study is that peripheral details did not decline over time. This finding also conflicts with Sekeres et al. (2016), where it was determined that reported peripheral details declined rapidly over time. It is possible that the present study, having tested participants after a 10-minute and then a 24-hour delay, did not have a long enough period of time between encoding and retrieval for the effect of time-dependent forgetting on peripheral details to be uncovered. Importantly, our overall findings are consistent with that of Sekeres et al. (2016)—that central and peripheral details are forgotten at different rates. However, it is worth noting that our findings also suggest that central and peripheral details are intertwined, with both the schema congruency of the memory itself and its similarity to information encountered post-encoding playing a role in forgetting over time.

## Implications for Episodic Memory Processing

Our findings also extend our understanding of how the component processes of episodic memory are affected by the schema congruency of encountered events. Complex, extended events like the ones investigated in the present study engage prior knowledge representations during encoding (Renoult & Rugg, 2020) and may strongly recruit semantic processes when the event is congruent with existing schemas (Van Kesteren et al., 2012). Subsequently, schema-congruent details are actively consolidated both immediately post-encoding and over longer periods (Morris, 2006), becoming less susceptible to forgetting (Dudai, 2004). This is supported by our findings that schema-congruent central details were resistant to forgetting over time—due either to stronger encoding, rapid consolidation, or both. Future work may aim to disentangle the effects of stronger encoding from better consolidation, both of which have similar behavioral outcomes.

We also observed that the post-encoding period is unaffected when information related to the schema of the memory is present, as observed by the lack of a difference between our related interference and control groups. The post-encoding period is critical for retrieval of the memory trace, both due to a schema congruency effect which is evident after encoding (van Kesteren et al., 2013) and because, prior to retrieval, the reactivation of the recently learned information occurs during this time (Van Kesteren et al., 2012). However, when a competing schema is activated post-encoding, memory performance is impacted, either through premature termination of the schema congruency effect or a disruption of memory reactivation. As observed in our study, this results in fewer central and peripheral details retrieved in the unrelated interference group compared to the control. Whether the schema congruency effect or the reactivation of the memory trace plays a bigger role in memory performance at retrieval has yet to be contrasted.

Finally, we both confirm and extend upon theories that episodic memories are transformed through over a period of time including the opportunity for sleep consolidation (Squire, Genzel, Wixted, & Morris, 2015; Tompary & Davachi, 2017; Winocur, Moscovitch, & Sekeres, 2007) through our finding that interference acts as an accelerator of memory schematicization. Central details were positively predictive of embedded peripheral details prior to sleep consolidation, but afterward this relationship changed depending on whether the central details were schema-congruent or incongruent. Under conditions of interference, better memory for schema-congruent central details became predictive of fewer peripheral details, suggesting that the memory was becoming devoid of rich, perceptual content and more schematic in nature. After post-encoding interference, the greater the interplay between the episodic and semantic memory systems for the encoded information, the more rapid the process of integrating the trace into the semantic network (Morris, 2006). How and why interfering information might cause this effect presents a direction for further research.

**Conclusions and Limitations**

There are several limitations to the design of the present work. It is important to note that our scoring system only accounted for the schema congruency of the central details in our videos, not of the peripheral details. While each video had a set number of central details, the peripheral details were more unconstrained and so classifying them as schema congruent or incongruent would have to be done on a case by case basis. To avoid this kind of post-hoc decision-making, we chose not to categorize our peripheral details. However, follow-up studies could be designed in which the number of peripheral details is more controlled, and the schema congruency predetermined prior to scoring. This would shed light upon how the schema congruency of perceptual content affects its forgetting. Additionally, our video stimuli and interference stimuli were presented in different modalities; videos were purely visual and interference stimuli were purely auditory. Thus, our findings may reflect a difference in how auditory information interferes with memory for visual information specifically, rather than how interference in general affects memory. Subsequent work might match the sensory modality of the to-be-remembered information and the interfering information to see if similar results are obtained.

There are also two important factors to consider with regards to the participants used in this study. Firstly, our interference stimuli were developed using an online survey where we did not control the age of the respondents. As such, the participants in the survey were older than the participants in the experiment (mean age for survey = 62.67 years; mean age for experiment =

21.22 years), although all participants were drawn from the North American populace. Despite the fact that there are well-established age differences in the use of schemas for memory and other cognitive tasks (Badham & Maylor, 2016), evidence that schema content is significantly different between age groups of similar cultural background is sparse (Blanchard-Fields, 1996). However, future work might more closely match the age of the survey respondents to the age of the participants in the experiment in order to rule out any possible differences. Secondly, participants in the current study were overwhelmingly female (n = 68 women, n = 18 men). Some research has shown that there are differences in memory performance between women and men on verbal memory tasks and visuospatial tasks, which may depend on the time of the menstrual cycle when women are tested (Herlitz & Rehnman, 2014; Rosenberg & Park, 2002). The current study design did not involve any explicitly visuospatial tasks, but participants were asked to verbally report their memories. However, as all participants were randomly sampled from the population, it is likely that any sex differences due to menstrual cycle phase were not systematic and should not significantly affect our results.

The current study investigated how forgetting occurs from complex, episodic memories by taking into account that event memories are situated within the context of prior knowledge and that interference can be similar or distinct from this prior knowledge. We built upon previous work by using complex, naturalistic stimuli and by contrasting two types of interference. We find a role for interference that is unrelated to the schema of the memory in the forgetting of both central, gist-related, and peripheral, perceptual details. In addition, interference may interact with consolidation processes to change the relationship between the elements of a memory—in some cases causing forgetting, and in others enhancing memory. The effect of time-dependent forgetting was also prominent, causing forgetting of unexpected or schema-incongruent details from episodic memories. Together, these results enrich our understanding of how episodic memories interact with prior knowledge and how they change due to different mechanisms of forgetting.

References

Alba, J. W., & Hasher, L. (1983). Is memory schematic? *Psychological Bulletin*, *93*(2), 203–231. Retrieved from http://dx.doi.org/10.1037/0033-2909.93.2.203

Aly, M., & Turk-Browne, N. B. (2016). Attention Stabilizes Representations in the Human Hippocampus. *Cerebral Cortex*, *26*(2), 783–796. https://doi.org/10.1093/cercor/bhv041

Anderson, S. J., & Conway, M. A. (1993). Investigating the structure of autobiographical memories. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *19*(5), 1178–1196. https://doi.org/10.1037/0278-7393.19.5.1178

Badham, S. P., & Maylor, E. A. (2016). Antimnemonic effects of schemas in young and older adults. *Aging, Neuropsychology, and Cognition*, *23*(1), 78–102. https://doi.org/10.1080/13825585.2015.1048774

Barry, D. N., & Maguire, E. A. (2019). Remote Memory and the Hippocampus: A Constructive Critique. *Trends in Cognitive Sciences*, *23*(2), 128–142. https://doi.org/10.1016/j.tics.2018.11.005

Bartlett, F. C. (1932). REMEMBERING: A STUDY IN EXPERIMENTAL AND SOCIAL PSYCHOLOGY. *British Journal of Educational Psychology*, *3*(2), 187–192. https://doi.org/10.1111/j.2044-8279.1933.tb02913.x

Blanchard-Fields, F. (1996). Causal Attributions Across the Adult Life Span: The Influence of Social Schemas, Life Context, and Domain Specificity. *Applied Cognitive Psychology*, *10*(7), 137–146. https://doi.org/10.1002/(sici)1099-0720(199611)10:7<137::aid-acp431>3.0.co;2-z

Bonasia, K., Sekeres, M. J., Gilboa, A., Grady, C. L., Winocur, G., & Moscovitch, M. (2018).

Prior knowledge modulates the neural substrates of encoding and retrieving naturalistic events at short and long delays. *Neurobiology of Learning and Memory*, *153*(February), 26–39. https://doi.org/10.1016/j.nlm.2018.02.017

Chan, D., Fox, N. C., Scahill, R. I., Crum, W. R., Whitwell, J. L., Leschziner, G., … Rossor, M. N. (2001). Patterns of temporal lobe atrophy in semantic dementia and Alzheimer’s disease. *Annals of Neurology*, *49*(4), 433–442. https://doi.org/10.1002/ana.92

Della Sala, S., Cowan, N., Beschin, N., & Perini, M. (2005). Just lying there, remembering: Improving recall of prose in amnesic patients with mild cognitive impairment by minimising interference. *Memory*, *13*(3–4), 435–440. https://doi.org/10.1080/09658210344000387

Dewar, M., Della Salla, S., Beschin, N., & Cowan, N. (2010). Profound retroactive interference in anterograde amnesia: What interferes?, *24*(3), 357–367. https://doi.org/10.1037/a0018207.Profound

Diekelmann, S., & Born, J. (2010, February 4). The memory function of sleep. *Nature Reviews Neuroscience*. Nature Publishing Group. https://doi.org/10.1038/nrn2762

Dolan, R. J., & Fletcher, P. C. (1997). Dissociating prefrontal and hippocampal function in episodic memory encoding. *Nature*, *388*(6642), 582–585. https://doi.org/10.1038/41561

Dudai, Y. (2004). The Neurobiology of Consolidations, Or, How Stable is the Engram? *Annual Review of Psychology*, *55*(1), 51–86. https://doi.org/10.1146/annurev.psych.55.090902.142050

Flores, S., Bailey, H. R., Eisenberg, M. L., & Zacks, J. M. (2017). Event segmentation improves event memory up to one month later. *Journal of Experimental Psychology: Learning Memory and Cognition*, *43*(8), 1183–1202. https://doi.org/10.1037/xlm0000367

Frankland, P. W., Kohler, S., & Josselyn, S. A. (2013). Hippocampal neurogenesis and forgetting. *Trends in Neurosciences*, *36*(9), 497–503. https://doi.org/10.1016/j.tins.2013.05.002

Friston, K. (2005). A theory of cortical responses. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *360*(1456), 815–836. https://doi.org/10.1098/rstb.2005.1622

Furman, O., Dorfman, N., Hasson, U., Davachi, L., & Dudai, Y. (2007). They saw a movie: Long-term memory for an extended audiovisual narrative. *Learning & Memory*, *14*(6), 457–467. https://doi.org/10.1101/lm.550407

Greenberg, D. L., & Verfaellie, M. Interdependence of episodic and semantic memory: Evidence from neuropsychology, 16 Journal of the International Neuropsychological Society § (2010). NIH Public Access. https://doi.org/10.1017/S1355617710000676

Guerin, S. A., Robbins, C. A., Gilmore, A. W., & Schacter, D. L. (2012). Retrieval failure contributes to gist-based false recognition. *Journal of Memory and Language*, *66*(1), 68–78. https://doi.org/10.1016/j.jml.2011.07.002

Haubrich, J., Bernabo, M., Baker, A. G., & Nader, K. (2020). Impairments to Consolidation, Reconsolidation, and Long-Term Memory Maintenance Lead to Memory Erasure. *Annual Review of Neuroscience*, *43*(1). https://doi.org/10.1146/annurev-neuro-091319-024636

Henson, R. N., & Gagnepain, P. (2010). Predictive, interactive multiple memory systems. *Hippocampus*, *20*(11), 1315–1326. https://doi.org/10.1002/hipo.20857

Herlitz, A., & Rehnman, J. (2014). Sex Differences in Episodic Memory. *Current Directions in Psychological Science*, *17*(1), 52–56. https://doi.org/10.1111/j.1467-8721.2008.00547.x

Hodges, J. R., Graham, N., & Patterson, K. (1995). Charting the Progression in Semantic Dementia: Implications for the Organisation of Semantic Memory. *Memory*, *3*(3–4), 463–

495. https://doi.org/10.1080/09658219508253161

Holland, A. C., & Kensinger, E. A. (2010, March). Emotion and autobiographical memory. *Physics of Life Reviews*. https://doi.org/10.1016/j.plrev.2010.01.006

Kan, I. P., Alexander, M. P., & Verfaellie, M. (2009). Contribution of prior semantic knowledge to new episodic learning in amnesia. *Journal of Cognitive Neuroscience*, *21*(5), 938–944. https://doi.org/10.1162/jocn.2009.21066

Kensinger, E. A., & Corkin, S. (2003). Memory enhancement for emotional words: Are emotional words more vividly remembered than neutral words? *Memory and Cognition*, *31*(8), 1169–1180. https://doi.org/10.3758/BF03195800

Keppel, G., & Underwood, B. J. (1962). Proactive inhibition in short-term retention of single items. *Journal of Verbal Learning and Verbal Behavior*, *1*(3), 153–161. https://doi.org/10.1016/S0022-5371(62)80023-1

Koen, J. D., & Rugg, M. D. (2016). Memory Reactivation Predicts Resistance to Retroactive Interference: Evidence from Multivariate Classification and Pattern Similarity Analyses. *Journal of Neuroscience*, *36*(15), 4389–4399. https://doi.org/10.1523/JNEUROSCI.4099-15.2016

Levine, B., Svoboda, E., Hay, J. F., Winocur, G., & Moscovitch, M. (2002). Aging and autobiographical memory: Dissociating episodic from semantic retrieval. *Psychology and Aging*, *17*(4), 677–689. https://doi.org/10.1037/0882-7974.17.4.677

Manns, J. R., Hopkins, R. O., & Squire, L. R. (2003). Semantic memory and the human hippocampus. *Neuron*, *38*(1), 127–133. https://doi.org/10.1016/S0896-6273(03)00146-6

Minarik, T., Berger, B., & Sauseng, P. (2018). The involvement of alpha oscillations in voluntary attention directed towards encoding episodic memories. *NeuroImage*, *166*, 307–

316. https://doi.org/10.1016/j.neuroimage.2017.10.064

Morris, R. G. M. (2006, June 1). Elements of a neurobiological theory of hippocampal function: The role of synaptic plasticity, synaptic tagging and schemas. *European Journal of Neuroscience*. John Wiley & Sons, Ltd. https://doi.org/10.1111/j.1460-9568.2006.04888.x

Moscovitch, M., Cabeza, R., Winocur, G., & Nadel, L. (2016). Episodic Memory and Beyond: The Hippocampus and Neocortex in Transformation. *Annual Review of Psychology*, *67*(1), 105–134. https://doi.org/10.1146/annurev-psych-113011-143733

O'Reilly, R., & Rudy, J. (2001). Conjunctive representations in learning and memory: Principles of cortical and hippocampal function. *Psychological Review*, *108*(2), 311–345. https://doi.org/10.1037/0033-295X

Renoult, L., & Rugg, M. D. (2020). An historical perspective on Endel Tulving's episodic-semantic distinction. *Neuropsychologia*, *139*, 107366. https://doi.org/10.1016/j.neuropsychologia.2020.107366

Richards, B. A., Xia, F., Santoro, A., Husse, J., Woodin, M. A., Josselyn, S. A., & Frankland, P. W. (2014). Patterns across multiple memories are identified over time. *Nature Neuroscience*, *17*(7), 981–986. https://doi.org/10.1038/nn.3736

Robin, J., Wynn, J., & Moscovitch, M. (2015). The spatial scaffold: The effects of spatial context on memory for events. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 42*(2), 308–315. https://doi.org/http://dx.doi.org/10.1037/xlm0000167

Robin, Jessica, Buchsbaum, B. R., & Moscovitch, M. (2018). The Primacy of Spatial Context in the Neural Representation of Events. *The Journal of Neuroscience, 38*(11), 2755–2765. https://doi.org/10.1523/jneurosci.1638-17.2018

Robin, Jessica, & Moscovitch, M. (2017). Details, gist and schema: hippocampal–neocortical interactions underlying recent and remote episodic and spatial memory. *Current Opinion in Behavioral Sciences*. https://doi.org/10.1016/j.cobeha.2017.07.016

Roediger, H., Weinstein, Y., & Agarwal, P. (2010). Forgetting: Preliminary considerations. In S. Salla Della (Ed.), *Forgetting* (pp. 1–22). Psychology Press. https://doi.org/10.1386/ctl.9.1.5

Rosenberg, L., & Park, S. (2002). Verbal and spatial functions across the menstrual cycle in healthy young women. *Psychoneuroendocrinology*, *27*(7), 835–841. https://doi.org/10.1016/S0306-4530(01)00083-X

Rugg, M. D., Otten, L. J., & Henson, R. N. A. (2002). The neural basis of episodic memory: Evidence from functional neuroimaging. In *Philosophical Transactions of the Royal Society B: Biological Sciences* (Vol. 357, pp. 1097–1110). https://doi.org/10.1098/rstb.2002.1102

Rumelhart, D. E., & Ortony, A. (1977). The Representation of Knowledge in Memory 1. In *Schooling and the Acquisition of Knowledge* (pp. 99–135). Routledge. https://doi.org/10.4324/9781315271644-10

Sadeh, T., Ozubko, J. D., Winocur, G., & Moscovitch, M. (2014). How we forget may depend on how we remember. *Trends in Cognitive Sciences*. https://doi.org/10.1016/j.tics.2013.10.008

Sekeres, M. J., Bonasia, K., St-Laurent, M., Pishdadian, S., Winocur, G., Grady, C., & Moscovitch, M. (2016). Recovering and preventing loss of detailed memory: Differential rates of forgetting for detail types in episodic memory. *Learning and Memory*, *23*(2), 72–82. https://doi.org/10.1101/lm.039057.115

Sheldon, S., Gurguryan, L., Madore, K. P., & Schacter, D. L. (2019). Constructing autobiographical events within a spatial or temporal context: a comparison of two targeted episodic induction techniques. *Memory*, 1–13. https://doi.org/10.1080/09658211.2019.1586952

Sosic-Vasic, Z., Hille, K., Kröner, J., Spitzer, M., & Kornmeier, J. (2018). When learning disturbs memory - Temporal profile of retroactive interference of learning on memory formation. *Frontiers in Psychology*, *9*(FEB), 82. https://doi.org/10.3389/fpsyg.2018.00082

Speer, N. K., & Zacks, J. M. (2005). Temporal changes as event boundaries: Processing and memory consequences of narrative time shifts. *Journal of Memory and Language*, *53*(1), 125–140. https://doi.org/10.1016/j.jml.2005.02.009

Squire, L. R., Genzel, L., Wixted, J. T., & Morris, R. G. (2015). Memory consolidation. *Cold Spring Harbor Perspectives in Biology*, *7*(8). https://doi.org/10.1101/cshperspect.a021766

St-Amand, D., Sheldon, S., & Otto, A. R. (2017). Modulating episodic memory alters risk preference during decision-making. *Journal of Cognitive Neuroscience*, *30*(10), 1433–1441. https://doi.org/10.1162/jocn_a_01253

Tompary, A., & Davachi, L. (2017). Consolidation Promotes the Emergence of Representational Overlap in the Hippocampus and Medial Prefrontal Cortex. *Neuron*, *96*(1), 228-241.e5. https://doi.org/10.1016/j.neuron.2017.09.005

Tulving, E. (1984). Relations among components and processes of memory. *Behavioral and Brain Sciences*, *7*(2), 257–268. https://doi.org/10.1017/S0140525X00044617

Tulving, E. (1985). How many memory systems are there? *American Psychologist*, 385–398.

Tulving, E. (2002). Episodic memory: from mind to brain. *Annual Review of Psychology*, *53*(1), 1–25. https://doi.org/10.1146/annurev.psych.53.100901.135114

van Kesteren, M. T. R., Rijpkema, M., Ruiter, D. J., & Fernández, G. (2013). Consolidation Differentially Modulates Schema Effects on Memory for Items and Associations. *PLoS ONE*, *8*(2), e56155. https://doi.org/10.1371/journal.pone.0056155

Van Kesteren, M. T. R., Ruiter, D. J., Fernández, G., & Henson, R. N. (2012). How schema and novelty augment memory formation. *Trends in Neurosciences*. https://doi.org/10.1016/j.tins.2012.02.001

Varma, S., Takashima, A., Krewinkel, S., van Kooten, M., Fu, L., Medendorp, W. P., … Daselaar, S. M. (2017). Non-interfering effects of active post-encoding tasks on episodic memory consolidation in humans. *Frontiers in Behavioral Neuroscience*, *11*, 54. https://doi.org/10.3389/fnbeh.2017.00054

Verfaellie, M. (2000). Semantic learning in amnesia. In *Handbook of Neuropsychology* (pp. 335–354). Retrieved from https://psycnet.apa.org/record/2004-16990-014

Waldhauser, G. T., Braun, V., & Hanslmayr, S. (2016). Episodic memory retrieval functionally relies on very rapid reactivation of sensory information. *Journal of Neuroscience, 36*(1), 251–260. https://doi.org/10.1523/JNEUROSCI.2101-15.2016

Winocur, G., Becker, S., Luu, P., Rosenzweig, S., & Wojtowicz, J. M. (2012). Adult hippocampal neurogenesis and memory interference. *Behavioural Brain Research*, *227*(2), 464–469. https://doi.org/10.1016/j.bbr.2011.05.032

Winocur, G., & Moscovitch, M. (2011). Memory transformation and systems consolidation. *Journal of the International Neuropsychological Society*. https://doi.org/10.1017/S1355617711000683

Winocur, G., Moscovitch, M., & Sekeres, M. (2007). Memory consolidation or transformation: Context manipulation and hippocampal representations of memory. *Nature Neuroscience, 10*(5), 555–557. https://doi.org/10.1038/nn1880

Wixted, J. T. (2004). The Psychology and Neuroscience of Forgetting. *Annual Review of Psychology*, *55*(1), 235–269. https://doi.org/10.1146/annurev.psych.55.090902.141555

Yassa, M. A., & Reagh, Z. M. (2013). Competitive trace theory: A role for the hippocampus in contextual interference during retrieval. *Frontiers in Behavioral Neuroscience*, *7*(JUL), 107. https://doi.org/10.3389/fnbeh.2013.00107

Zacks, J. M., Tversky, B., & Iyer, G. (2001). Perceiving, remembering, and communicating structure in events. *Journal of Experimental Psychology: General*, *130*(1), 29–58. https://doi.org/10.1037/0096-3445.130.1.29

## Tables

*Table 1: Unique titles assigned to each video and a brief excerpt from the corresponding interference stimuli.*

| **Video Title** | **Interference Stimuli Excerpt** |
|---|---|
| "Taking an Art Class" | Terrence arrived for the class he had signed up for at his local community center. He settled down at a desk and he introduced |

| | |
|---|---|
| | himself to the people seated around him. They told him their names and occupations. |
| “Shopping at a Department Store” | Jonah pulled into the parking lot outside of the department store. He planned to pick up some necessities, as he had recently moved. There were only a few other cars parked because it was early in the morning. |
| “Dining at a Restaurant” | Hassan entered the new restaurant just in time for dinner. He wondered what kinds of food were on their menu. The waiter informed him that he would have to wait for five minutes for a table. |
| “Waiting at a Hospital” | Fred entered the clinic ten minutes before his scheduled appointment. He checked in with the receptionist at the front. She instructed him to fill out a number of forms. |

*Table 2: Results of Model 1, a linear mixed effects model predicting embedded peripheral details from fixed factors of session, group, schema-congruent central details, and schema-incongruent central details.*

| | **Embedded Peripheral Details** | | |
|---|---|---|---|
| *Predictors* | *Estimates* | *CI* | *p* |
| Intercept | 1.71 | -2.97 – 6.40 | 0.474 |
| Session 2 | 2.02 | -2.70 – 6.74 | 0.402 |

| | | | |
|---|---|---|---|
| RelatedInterference | 2.66 | -2.58 – 7.90 | 0.320 |
| UnrelatedInterference | -1.07 | -6.64 – 4.50 | 0.707 |
| CongruentCentralDetail | 1.15 | 0.72 – 1.58 | **<0.001** |
| IncongruentCentralDetail | 1.04 | 0.69 – 1.39 | **<0.001** |
| Session 2:RelatedInterference | -2.41 | -9.04 – 4.23 | 0.477 |
| Session 2:UnrelatedInterference | 0.76 | -6.29 – 7.81 | 0.833 |
| Session 2:CongruentCentralDetail | 0.23 | -0.36 – 0.81 | 0.448 |
| RelatedInterference:CongruentCentralDetail | -0.11 | -0.68 – 0.46 | 0.696 |
| UnrelatedInterference:CongruentCentralDetail | -0.02 | -0.69 – 0.65 | 0.959 |
| Session 2:IncongruentCentralDetail | -0.48 | -0.98 – 0.02 | 0.061 |
| RelatedInterference:IncongruentCentralDetail | -0.26 | -0.74 – 0.21 | 0.280 |
| UnrelatedInterference:IncongruentCentralDetail | -0.09 | -0.60 – 0.43 | 0.745 |
| Session 2:RelatedInterference:CongruentCentralDetail | -0.65 | -1.48 – 0.19 | 0.128 |
| Session 2:UnrelatedInterference:CongruentCentralDetail | -0.90 | -1.89 – 0.10 | 0.078 |
| Session 2:RelatedInterference:IncongruentCentralDetail | 0.90 | 0.18 – 1.62 | **0.015** |
| Session 2:UnrelatedInterference:IncongruentCentralDetail | 0.68 | -0.09 – 1.46 | 0.083 |
| **Random Effects** | | | |
| $\sigma^2$ | 19.37 | | |
| $\tau_{00}$ Subject | 3.07 | | |
| $\tau_{00}$ VideoNumber | 8.80 | | |
| ICC | 0.38 | | |
| N Subject | 82 | | |
| N VideoNumber | 4 | | |
| Observations | 328 | | |
| Marginal $R^2$ / Conditional $R^2$ | 0.563 / 0.729 | | |

*Table 3: Results of Model 1.1, a linear mixed effects model predicting embedded peripheral details at session 1 from fixed factors group, schema-congruent central details, and schema-incongruent central details.*

| | **Session 1 Embedded Peripheral Details** | | |
|---|---|---|---|
| *Predictors* | *Estimates* | *CI* | *p* |
| Intercept | 1.23 | -3.83 – 6.28 | 0.634 |
| RelatedInterference | 2.98 | -2.70 – 8.66 | 0.304 |
| UnrelatedInterference | -0.13 | -6.17 – 5.90 | 0.965 |

| | | | |
|---|---|---|---|
| CongruentCentralDetail | 1.07 | 0.58 – 1.57 | **<0.001** |
| IncongruentCentralDetail | 1.15 | 0.75 – 1.55 | **<0.001** |
| RelatedInterference:CongruentCentralDetail | -0.13 | -0.75 – 0.49 | 0.691 |
| UnrelatedInterference:CongruentCentralDetail | -0.11 | -0.84 – 0.62 | 0.770 |
| RelatedInterference:IncongruentCentralDetail | -0.29 | -0.81 – 0.23 | 0.271 |
| UnrelatedInterference:IncongruentCentralDetail | -0.12 | -0.68 – 0.44 | 0.666 |
| **Random Effects** | | | |
| $\sigma^2$ | 22.77 | | |
| $\tau_{00}$ Subject | 3.05 | | |
| $\tau_{00}$ VideoNumber | 10.05 | | |
| ICC | 0.37 | | |
| N Subject | 82 | | |
| N VideoNumber | 4 | | |
| Observations | 164 | | |
| Marginal $R^2$ / Conditional $R^2$ | 0.545 / 0.711 | | |

*Table 4: Results of Model 1.2, a linear mixed effects model predicting embedded peripheral details at session 2 from fixed factors group, schema-congruent central details, and schema-incongruent central details.*

| | **Session 2 Embedded Peripheral Details** | | |
|---|---|---|---|
| *Predictors* | *Estimates* | *CI* | *p* |
| Intercept | 3.10 | -1.25 – 7.44 | 0.162 |
| RelatedInterference | 1.09 | -3.33 – 5.51 | 0.629 |
| UnrelatedInterference | 0.86 | -3.91 – 5.62 | 0.725 |
| CongruentCentralDetail | 1.46 | 1.03 – 1.88 | **<0.001** |

| | | | |
|---|---|---|---|
| IncongruentCentralDetail | 0.58 | 0.21 – 0.94 | **0.002** |
| RelatedInterference:CongruentCentralDetail | -0.83 | -1.38 – -0.29 | **0.003** |
| UnrelatedInterference:CongruentCentralDetail | -0.96 | -1.62 – -0.29 | **0.005** |
| RelatedInterference:IncongruentCentralDetail | 0.60 | 0.10 – 1.10 | **0.019** |
| UnrelatedInterference:IncongruentCentralDetail | 0.49 | -0.06 – 1.03 | 0.078 |
| **Random Effects** | | | |
| $\sigma^2$ | 16.04 | | |
| $\tau_{00}$ Subject | 2.65 | | |
| $\tau_{00}$ VideoNumber | 8.03 | | |
| ICC | 0.40 | | |
| N Subject | 82 | | |
| N VideoNumber | 4 | | |
| Observations | 164 | | |
| Marginal $R^2$ / Conditional $R^2$ | 0.583 / 0.750 | | |

*Table 5: Results of Model 2, a linear mixed effects model predicting embedded peripheral details from fixed factors of session, group, schema-congruent central details, and schema-incongruent central details.*

| | **Unembedded Peripheral Details** | | |
|---|---|---|---|
| *Predictors* | *Estimates* | *CI* | *p* |
| Intercept | 4.86 | -0.39 – 10.10 | 0.070 |
| Session 2 | 4.07 | -1.79 – 9.93 | 0.174 |
| RelatedInterference | -1.16 | -8.17 – 5.86 | 0.747 |
| UnrelatedInterference | -0.37 | -7.84 – 7.10 | 0.923 |
| CongruentCentralDetail | 0.48 | -0.06 – 1.02 | 0.083 |

| | | | |
|---|---|---|---|
| IncongruentCentralDetail | 0.25 | -0.22 – 0.71 | 0.296 |
| Session 2:RelatedInterference | 0.59 | -7.69 – 8.88 | 0.888 |
| Session 2:UnrelatedInterference | 0.37 | -8.37 – 9.12 | 0.934 |
| Session 2:CongruentCentralDetail | -0.59 | -1.35 – 0.17 | 0.127 |
| RelatedInterference:CongruentCentralDetail | 0.01 | -0.72 – 0.74 | 0.979 |
| UnrelatedInterference:CongruentCentralDetail | -0.10 | -0.95 – 0.76 | 0.826 |
| Session 2:IncongruentCentralDetail | 0.05 | -0.60 – 0.70 | 0.876 |
| RelatedInterference:IncongruentCentralDetail | 0.05 | -0.58 – 0.68 | 0.876 |
| UnrelatedInterference:IncongruentCentralDetail | 0.02 | -0.66 – 0.69 | 0.956 |
| Session 2:RelatedInterference:CongruentCentralDetail | 0.49 | -0.59 – 1.57 | 0.371 |
| Session 2:UnrelatedInterference:CongruentCentralDetail | 0.30 | -0.98 – 1.58 | 0.645 |
| Session 2:RelatedInterference:IncongruentCentralDetail | -0.45 | -1.39 – 0.49 | 0.346 |
| Session 2:UnrelatedInterference:IncongruentCentralDetail | -0.21 | -1.20 – 0.78 | 0.678 |
| **Random Effects** | | | |
| $\sigma^2$ | 29.26 | | |
| $\tau_{00}$ Subject | 12.18 | | |
| $\tau_{00}$ VideoNumber | 2.80 | | |
| ICC | 0.34 | | |
| N Subject | 82 | | |
| N VideoNumber | 4 | | |
| Observations | 328 | | |
| Marginal $R^2$ / Conditional $R^2$ | 0.066 / 0.382 | | |

**Figures**

*Figure 1: Experimental overview.*

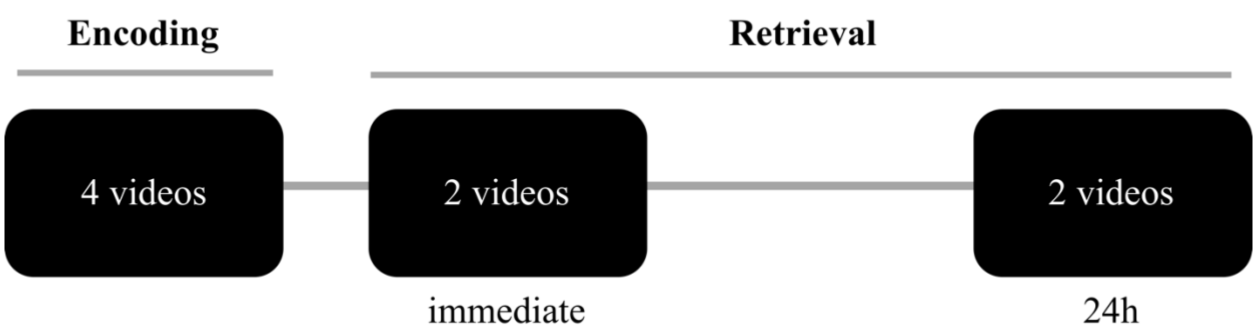


*Figure 2: During the encoding session, participants completed four trials. During each trial, they watched a video and were then presented with either interfering stimuli (related or unrelated) or a waiting period.*

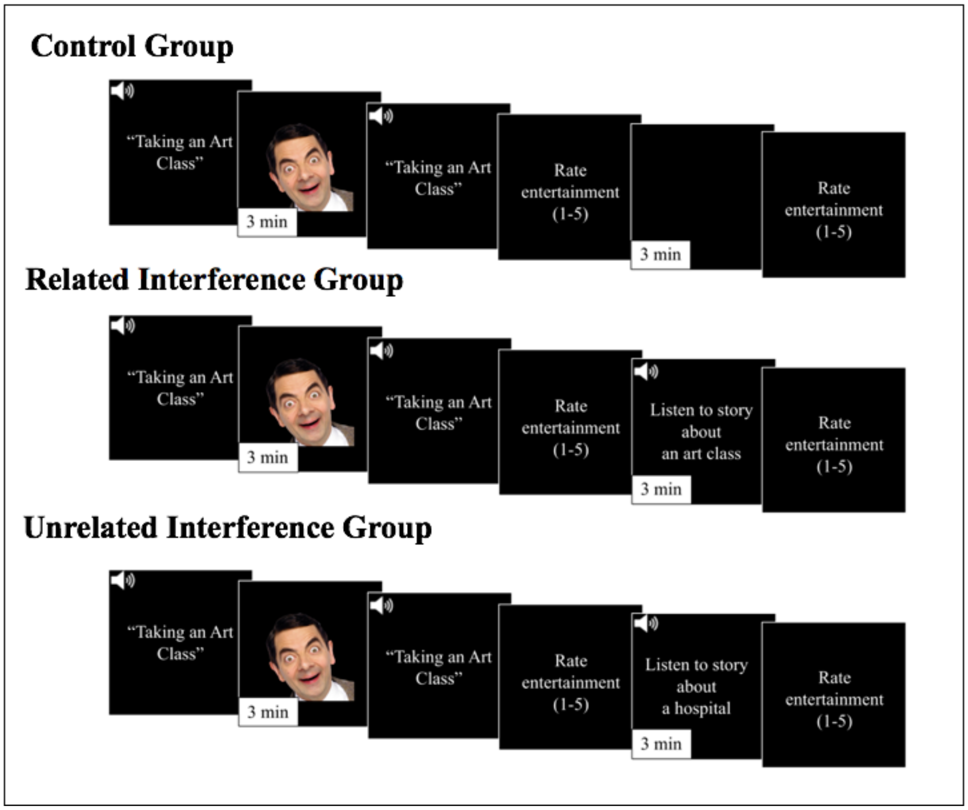



*Figure 3: During retrieval, participants completed ratings and verbally recalled central and peripheral details. They were tested on 2 videos on day one and 2 videos on day two.*

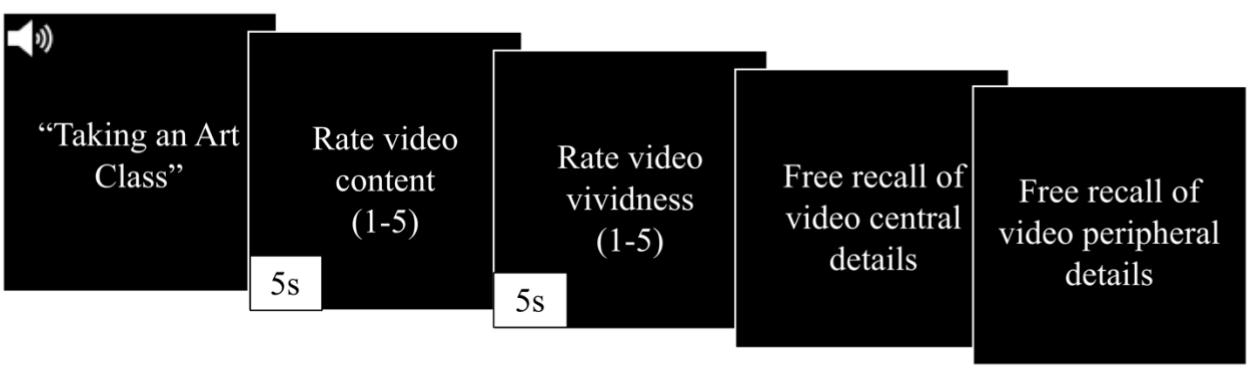



*Figure 4: Average entertainment rating for the post-encoding period and the video, according to group.*

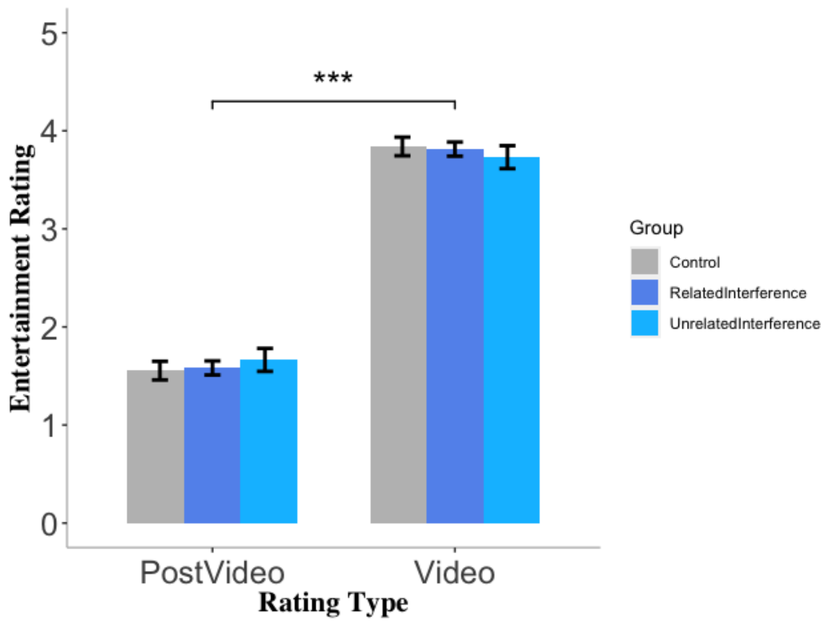



*Figure 5: Average story content rating at session 1 and session 2 according to group.*

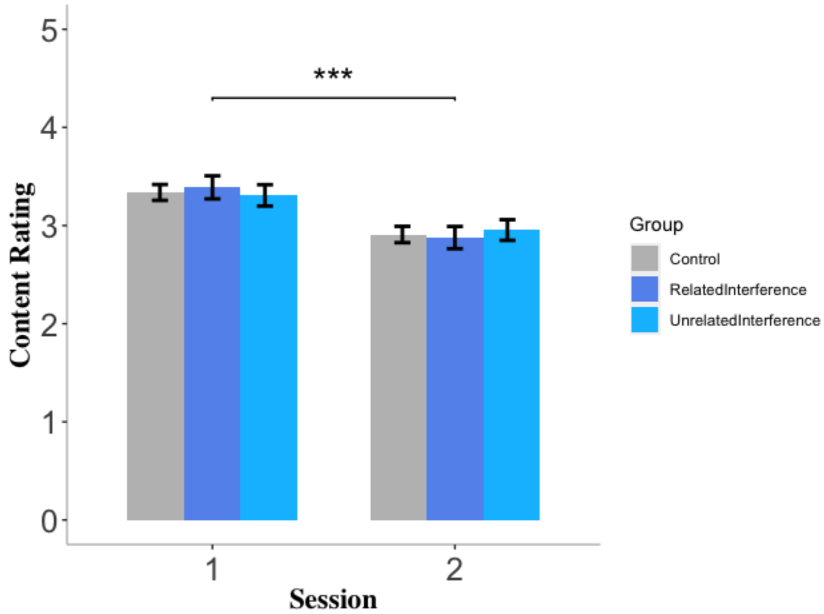



*Figure 6: Average vividness rating at session 1 and session 2 according to group.*

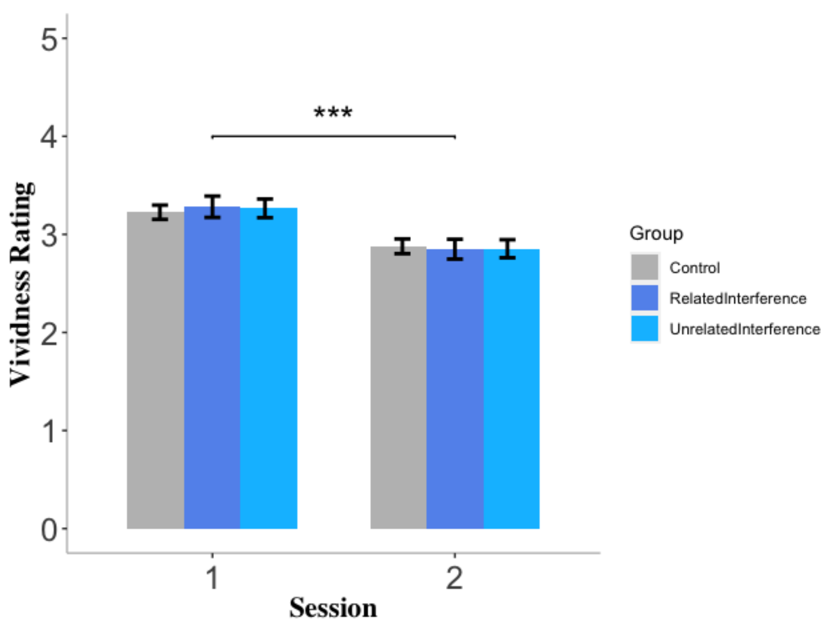



*Figure 7: Average central details by group.*

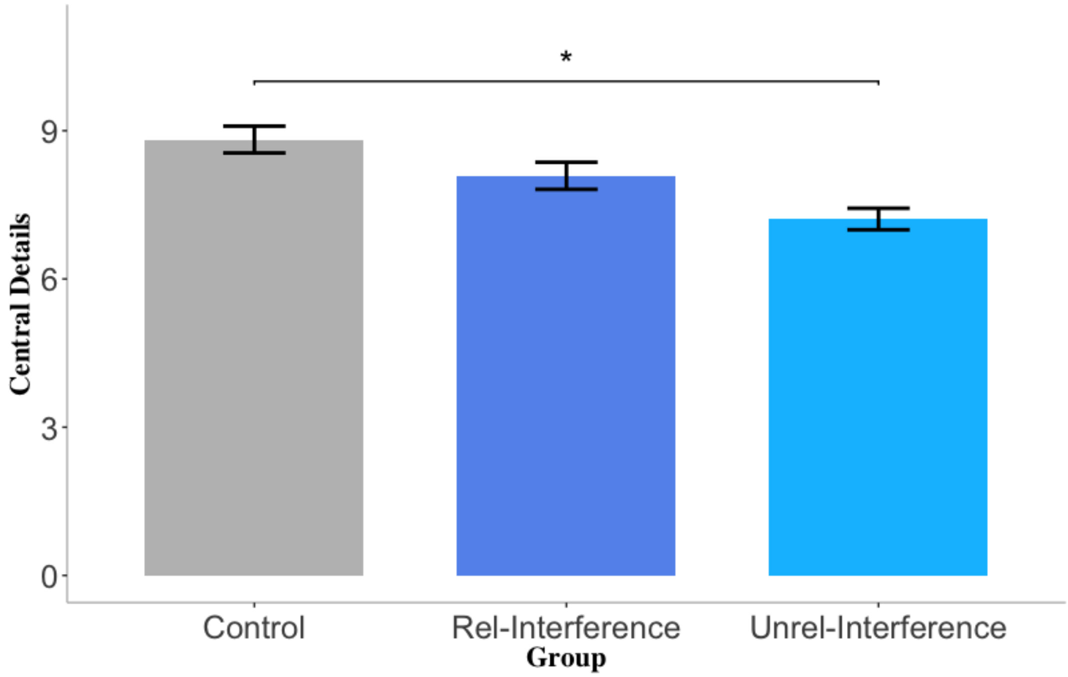



*Figure 8: Average number of central details at session 1 and session 2 according to central detail type.*

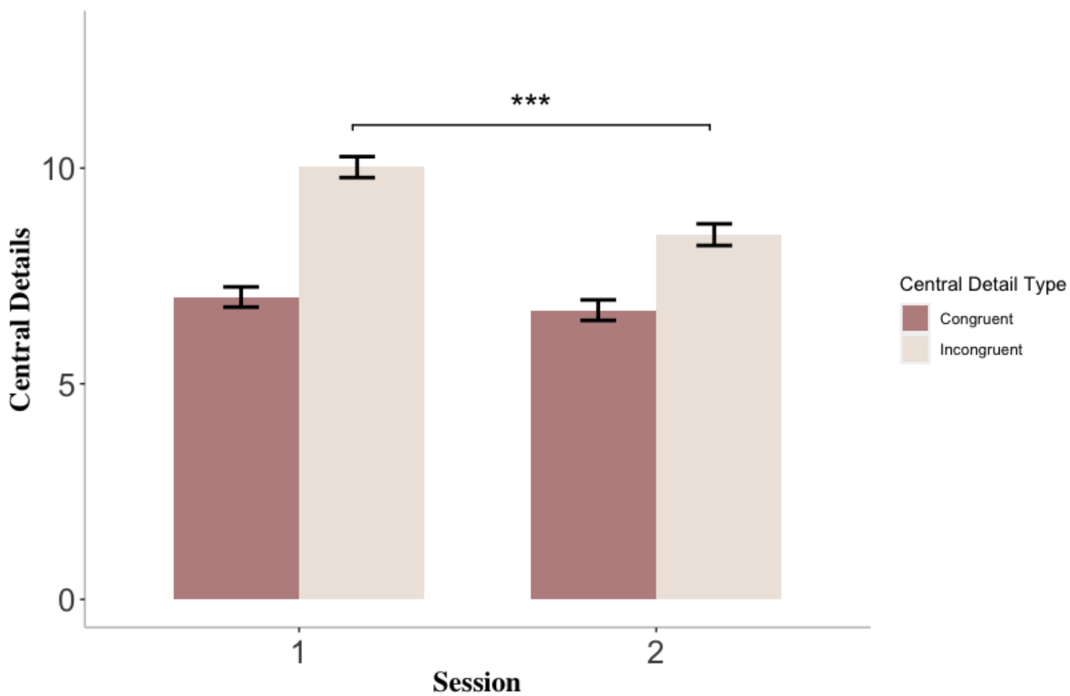
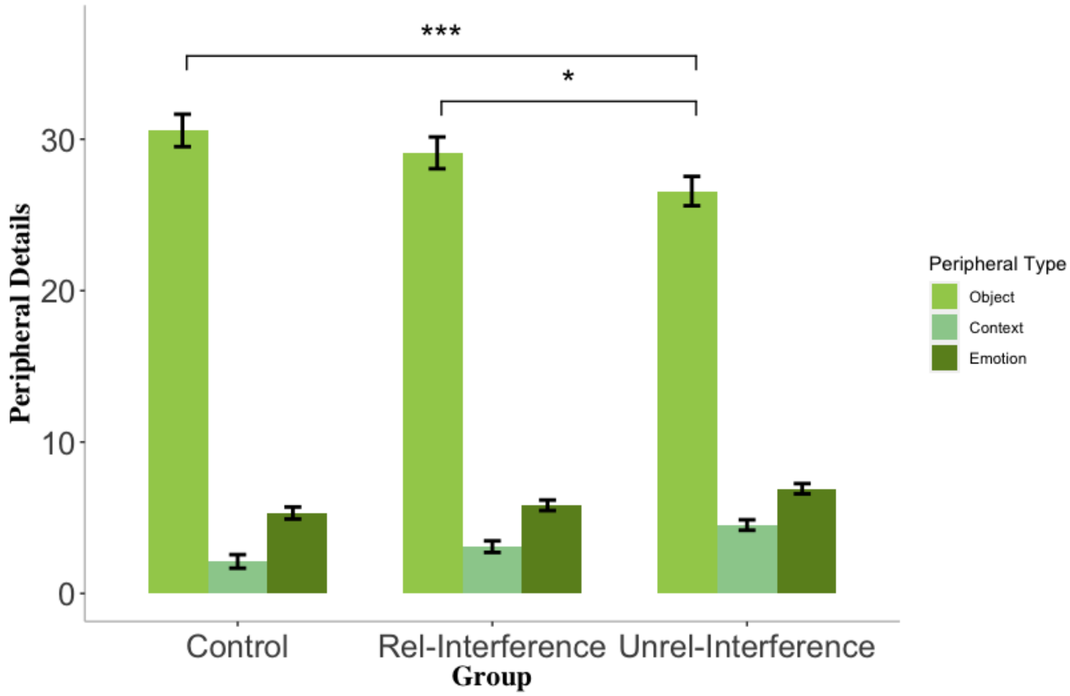



*Figure 9: Average number of peripheral details in each group according to peripheral detail type.*


***
*
30
20
10
0
Peripheral Details
Control
Rel-Interference
Unrel-Interference
Group
Peripheral Type
Object
Context
Emotion