DEPARTMENT of PSYCHOLOGY

Investigating Interference, and Context Presentation in Episodic Memory Through Behavioural and Pupillometry Studies.

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Abstract

This research aims to examine the effects of interference and context presentation during the retrieval of encoded information which was encoded in a dynamic context. To examine this, we conducted two experiments where there was a presentation of information where half of the overall encoded information shared a constituent with information that was encoded in another context. The remaining half of the information was encoded in only one context. We then presented half of the information with context presentation during recall and half without. We then tested participants' recall of this information and used regressions on behavioral and pupillometry results to examine under what circumstances. Behavioural results indicated that there was a higher level of proactive, rather than retroactive interference in both experiments (i.e, performance was lower for information with a shared constituent when that constituent was learned prior to the information being retrieved was encoded). Results from both experiments indicated that when examining all the information, and there was no context presented, retrieval of shared constituent information was reduced compared to non-shared constituent information. This finding reversed when context was presented. When examining the final encoded information, both findings were also found in the first experiment, whilst only the finding relating to no context presentation was found in the second experiment. In both experiments when examining first encoded information none of these results were found. In the first experiment, when examining overall data, pupillometry results indicated there was increased pupil dilation when a) retrieving second half encoded information, and b) when retrieving information with no shared constituent when context was presented. When examining first encoded information only the finding relating to context presentation was found. These findings were not found when examining the final encoded information, or data form experiment 2. We discuss these results in relation to two underlying processes.

Keywords: Pupillometry, Interference, Episodic memory, Context presentation.

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Episodic memory refers to the memory of a conscious event, recall of which involves recalling a personal experience containing information on what happened, where it happened, and when it happened (Tulving, 1985). Early research suggested that some episodic memories may be intercorrelated with other episodic memories, which may affect the retrieval of a specific episodic memory. For instance, Bergström (1890) found that previously encoded memory related to a newly encoded episodic memory may result in that new episodic memory being slower encoded than unrelated episodic memory (retroactive interference). Similarly, Muller and Pilzecker (1900) found that information presented after the encoding of episodic memory can interfere with that episodic memory (proactive interference). Thus, early research regarding episodic memory indicates that it is not independent of other episodic memory.

This early research by Bergström (1890), and Muller and Pilzeckers (1890), in addition to studies by McGeoch (1932) and Whitely (1927) may have given rise to the Interference theory (McGeoch, 1932). This theory claims that similar memories compete with each other leading to memory interference resulting in memories not being recalled (McGeoch, 1932). The interference theory conceptualizes two categories of interference that may arise from episodic memory. The first category of interference, retroactive interference, arises from old memories affecting the recall of new memories which share similarities to the old memory (Wickens et al., 1963). Previously, this type of interference was thought to be the main source of interference and subsequently the main cause of forgetting (Underwood, 1957). However, recent research has indicated that the main source of interference may arise from the second category of interference, proactive interference (Wixted, 2004). Proactive interference arises from the interference of new memories impacting the retrieval

of older memories (Baddeley and Dale, 1966). Therefore, episodic memory is not solitary, and per the interference theory forgetting is a result of interference that may arise from both older and newer memories interfering with the retrieval of each.

The interference theory can still be seen to be relevant at present. For instance, Cox et al. (2021) claim that the main challenge of episodic memory research is understanding the effects of retroactive and proactive interference on memory. Two competing theories on long-term episodic memory, the multiple trace theory, and the systems consolidation theory may explain retroactive and proactive interference (Yassa & Reagh, 2013). Therefore, the interference theory can still be seen to be of relevance to episodic memory research.

The first theory Systems consolidation theory, postulates that interference is a result of memory stability (Dudai, 2004). Memory becomes stable over time and can be influenced by new stimuli before it is stable (Muller & Pilzecker, 1900, as cited in Dundai, 2004), a claim known in the first century, but attributed to Muller and Pilzecker's episodic memory research (Dudai, 2004). Muller and Pilzeckers's research found that recall was improved over time, but if presented with new stimuli after encoding previous stimuli recall was impaired (Muller & Pilzecker, 1900, as cited in Dundai, 2004). Proactive interference, per the systems consolidation theory, arises from stable encoded information overriding the ability to consolidate new memory (Dudai, 2004). Whereas retroactive interference, per the systems consolidation theory, arises from the encoding of a new memory interrupting the consolidation of a previous one (Alves, and Bueno, 2017). However, according to Yonelinas (2019), the systems consolidation theory emphasizes the role of retroactive interference over proactive interference. Therefore, systems consolidation theory explains both retroactive and proactive interference but places more emphasis on retroactive interference.

This process per the systems consolidation theory mainly involves two brain areas. The first area is the hippocampus, which first organizes the memory within the second area (Dudai, 2004).

The second area is the neocortex, where memory first exists, and over time it consolidates the memory and becomes independent of the hippocampus (Dudai, 2004). Neurobiological support for the Systems consolidation theory, and memory stability over time, comes from medial temporal lobe lesions. Patients with MTL lesions exhibit retrograde amnesia i.e, loss of recent memories and reduced loss of earlier memories (Scoville &Milner, 1957). Thus, medial temporal lobe lesions provide evidence for memory becoming consolidated within the neocortex across time and the independence of stable memory from the neocortex.

However, the systems consolidation theory interpretation of consolidation has been criticized. Nadel and Moscovitch provide another interpretation, in which they claim that the medial temporal lobe is always needed to represent episodic memory. Evidence of this has been provided by neuroimaging studies which show equal activation of the hippocampus during retrieval of recent and remote episodic memory (Conway et al., 1999; Ryan et al., 2000; Gilboa et al., 2004; for review see Maguire, 2000; Moscovitch et al., 2005, Moscovitch et al., 2006). Thus, there is evidence that the MTL is always involved in the recall of episodic memory.

The second competing theory which explains retroactive and proactive interference, the Multiple trace theory, conforms to the view that the medial temporal lobe is always activated during retrieval of episodic memory. The medial temporal lobe binds the activated neurons into a trace, with each encoded memory a unique combination of traces, although some of these traces may conform to an overarching framework (Nadel, et al., 2000). Retroactive and proactive interference per this theory arises from the recall phase where activation of multiple traces results in competition between traces (Nadel et al., 2000). Medial temporal lobe lesions per this theory affect memory in relation to the extent and location of damage as memory traces are distributed throughout the medial temporal lobe (Moscovitch and Nadel, 1995). Thus, rather than affect encoding, the multiple trace theory sees interference as a result of recall.

Interference may arise from multiple sources. Per the contextual binding theory of episodic memory forgetting is a result of interference, which may arise from multiple sources, but the main source is contextual similarities between memories (Yonelinas et al., 2019). This theory conforms to the multiple traces theory interpretation that the hippocampus is always involved in episodic memory and that hippocampal-based remote memories are more contextually rich compared to neocortex-based remote memories (Wiltgen et al., 2010). For instance, this theory claims that the Hippocampus binds together item-related and context-related information, and episodic memory depends upon the Hippocampus (Yonelinas et al., 2019). However, similar to the systems consolidation theory, this theory claims that similar context is more likely to lead to interference when the context is presented close in time between each memory (Yonelinas., 2019). Thus, context may be a source of interference between episodic memory.

Contextual similarities as a source of interference have also been exhibited in behavioral research. For instance, research conducted by Kim et al. (2019) found that reactivation of a previous memory, during encoding within a new context, results in worse memory performance for the initial context. Moreover, research conducted by Bramão et al. (2022) found that interference may be caused by the reactivation of context associated with competitor memories. Thus, context can be seen as a source of interference within episodic memory.

However, proactive interference has not always been found in research. For instance, research that examined retrieval practice has found support for increased correct retrieval the more participants are tested on previously encoded information (Roediger & Karpicke, 2006). Retrieval practice protecting from proactive interference has been found across test types (McDaniel et al., 2012: Pan et al., 2015), retention intervals (McDaniel et al., 2009), with and without feedback (McDaniel et al., 2015), ages (Carpenter et al., 2016), and memory ability (Agarwal et al., 2017). Therefore, retrieval practice may protect against the effect of proactive interference.

Similarly, retroactive interference has not always been found in research. During a new learning event previous memories can become reactivated (Norman & O'Reilly., 2003). This reactivation has occasionally been found to result in the strengthening of the original memory (Tambinie & Davachi, 2019). Research has found that the reactivation of old memory can result in the diminishment of retroactive interference (Kuhl et al., 2010). Moreover, further research has indicated that the reactivation of attributes of an old memory shared across multiple memories may reduce retroactive interference (Koen & Rugg, 2016). Therefore, the reactivation of old memories, which should be related to retroactive interference, is not always related to retroactive interference.

However, different research coming to different conclusions about the presence of interference may be a result of the research methods used within that research. For instance, Cox et al. (2021) proposed that research that promotes the associations between new and old memories which share a constituent results in the reduction of interference by promotion of separation between those memories (Cox et al., 2021). To examine this claim, they performed three behavioral experiments, in which participants learned word pairs across two days (Cox et al., 2021). Results of which indicated that contextual similarity during encoding promotes memory integration and recall of both word pairs, whereas variable context in encoding results in enhanced new, and reduced old, word-pair recall (Cox et al., 2021). However, they found that these results were reversed when the context was presented during retrieval (Cox et al., 2021). Therefore, the study methodology may explain differences in results concerning the interference theory.

Research that has found support for the occurrence of interference has related it to measurable pupillary responses. For instance, Kucewicz et al. (2018) found an increase in pupil dilation when word pairs are recalled with an increase in dilation positively related to interference. However, per Kucewicz et al. (2018) their research did not present cues during recall.

Moreover, this research did not present contextual information during recall (Kuxewicz et al., 2018), which per the contextual binding theory of memory may affect the amount of interference present (Yonelinas et al., 2019). Thus, research has linked interference with increased pupil dilation, although this research was focused on free recall with no contextual information presented.

Pupil dilation in relation to recall has been shown to vary across the recall phase. In research by Johansson et al. (2020) most often pupil dilation was found to peak during the early phase of recall, and they claim that this peak was found to be related to the cognitive control necessary to deal with interference. The pupil was also found to peak at the end of the retrieval phase, and they claim that this was related to overall task engagement (Johansson et al., 2020). Thus, pupil dilation may vary across the retrieval phase.

Explanations have been proposed to explain why pupil dilation may be related to interference, and how cognitive control may be measured through pupil dilation. For instance, the dilation of the pupil is related to the autonomous nervous system activity (Steinhauer et al., 2004) which Wang and Munoz (2015) claim is controlled by the superior colliculus. Joshi et al. (2016), and Lewandowska et al. (2019) claim pupil dilation is also related to the locus coeruleus norepinephrine (LC-NE) system. Research by Grueschow et al. (2020) has found that cognitive control is related to the level of functional coupling between the LC-NE and the dorsomedial prefrontal cortex. Moreover, this research also shows that the pupil was significantly more dilated during difficult tasks compared to easy tasks (Grueschow et al., 2020). Thus, pupil dilation may be considered a measure of cognitive control as it indicates the coupling between the LC-NE and the dorsomedial prefrontal cortex.

However, pupil dilation may also measure things other than cognitive control. For instance, research by Zhao et al. (2019) indicates that pupil dilation is positively related to task attention. Moreover, pupil dilation has also been positively related to arousal (Wang et al., 2018). Similarly,

pupil dilation has also been found after making an error (Maier et al., 2019). Pupil dilation has also been found to be a measure of memory strength, with increased dilation being related to increased retrieval difficulty (Oliveira et al., 2021). Finally, pupil dilation has also been related to light, with increased luminance resulting in increased pupil dilation (Xhang et al., 2022). Therefore, pupil dilation may be a measure of cognitive control, but it also measures attention, arousal, errors, memory strength, retrieval difficulty, and luminance.

Therefore, using pupillometry, as a marker of cognitive control, we aim to examine whether context presentation (the presentation of an image, corresponding to a dynamic visual scene in encoding) can reduce the interference of competing information. To do this we will carry out two experiments.

Hypotheses in this experiment were,

1. when information is presented with no context presentation during retrieval information which shares a constituent will be harder to retrieve compared to information with no shared constituent, as there will be increased interference during retrieval of shared constituent information. This will be observable through,
    a) increased retrieval performance
    b) decreased maximum pupil dilation during successful retrieval.
2. during retrieval, if the encoding context associated with the specific information being retrieved is presented (a reminder of the encoding event) recall for information which shares a constituent will be easier. This will be observable through,
    a) increased retrieval performance,
    b) decreased maximum pupil dilation during successful retrieval.

3. Information which was encoded at the end of encoding will be easier to recall, as there will be less interference. This will be observable through,
    1. increased retrieval performance,
    2. decreased maximum pupil dilation during successful retrieval .

Experiment 1

This experiment considers how information which is encoded with other information that shares a constituent will affect retrieval performance. Moreover, this research also considers how the presentation of an image, from encoding, during retrieval of one of the encoded information with a shared constituent will affect retrieval. In addition, pupil dilation will be considered, which will be able to highlight the affect of competing constituents during successful retrieval.

Method

Participants.

The recruitment for this experiment took part in June and July 2022. Recruitment was through Lund University's social media accounts, Lund community Facebook groups, and word of mouth. All participants self-selected and were compensated 100SEK for their participation. Inclusion criteria were proficiency in English exceeding CEFR B2, the ability to read words on a screen, and aged 18 or older. Overall, 20 people volunteered for this study, of which 8 provided usable data. Their ages ranged from 18 to 36 with a mean age of 24.12 (SD = 2.8). 3 were male, and 5 were female. For a breakdown of age of participants who provided non-useable data see Appendix A

All participants were first given informed consent sheets, and signed a document stating that they were informed about the study and agreed to take part. At the end of the study participants were

once again informed about what the study was researching and thanked for their time. As our study did not collect biological or sensitive information, there was no physical intervention, the study did not seek to cause harm or mental distress the study conformed to national research ethics (Ethical review of research involving humans, 2003), and university research ethical guidelines. Moreover, prior to taking part in the study, participants were informed about the procedure of these experiments. As the study conformed to national research ethics, an ethical review was not needed.

Design.

The research design of these experiments was a 3x2 within-subject experiment. Independent variables within these experiments were Interference (proactive or retroactive), Competition (competitive or non-competitive), and Context presentation (present or absent), which all had two conditions. Participants underwent each condition 96 times, although each condition was also presented with one other condition for each of the other two independent variables. Interference's two conditions were, B and C. B corresponded to word pairs that were presented during the first half of the encoding phase, and as such may influence the recall of C, whereas C corresponded to word pairs presented in the second half of the encoding phase, and as such may influence the retrieval of B. Competition's two conditions were DE and A. DE was defined as word pairs with no other word pair sharing the same first word (non-competitive condition). A was defined as a word-pair in which the first word was shared with another word pair (competitive condition). Context's conditions were presented and non-presented. Presented corresponded to an image, taken from the movie used in the encoding trial, being present within the retrieval phase. Whereas, Non-presented corresponded to a grey screen background during the recall phase. Recall accuracy was the dependent variable, and had two conditions, retrieved, and not retrieved. Retrieved corresponded to a correct recall of the second letter of the word-pairs second word, whereas Not retrieved corresponded to either an incorrect response or no response.

Materials.

96 five-letter nouns and 192 four-letter nouns not beginning with Q were selected from the Merriam-Webster online dictionary (Merriam-Webster, n.d) and used in these experiments. Five letter nouns beginning with the same initial letter and with no obvious association with each other were paired into groups of three, resulting in 32 triplets. Two of these triplets were assigned to DE and 1 was assigned to A. 48 quadruplets were made for four-letter nouns, but contrastingly these did not share the same initial letter. The assignment of word to condition was counterbalanced across participants.

Two first-person perspective movies were used in the experiment 1) walking in a forest, and 2) driving in New York City. These movies were sourced from Bramão et al. (2022), are perceptually and semantically different from each other, and each has an overall length of 7 minutes (Bramão et al., 2022).

The presentation of this experiment occurred on an 52.7 x 29.6 cm computer monitor running PsychoPy, version 2022.1.3. The timing within Psychopy was linked to the pupillometry recording device Tobii Pro Spectrum, and pupil data was measured at a frequency of 600Hz.

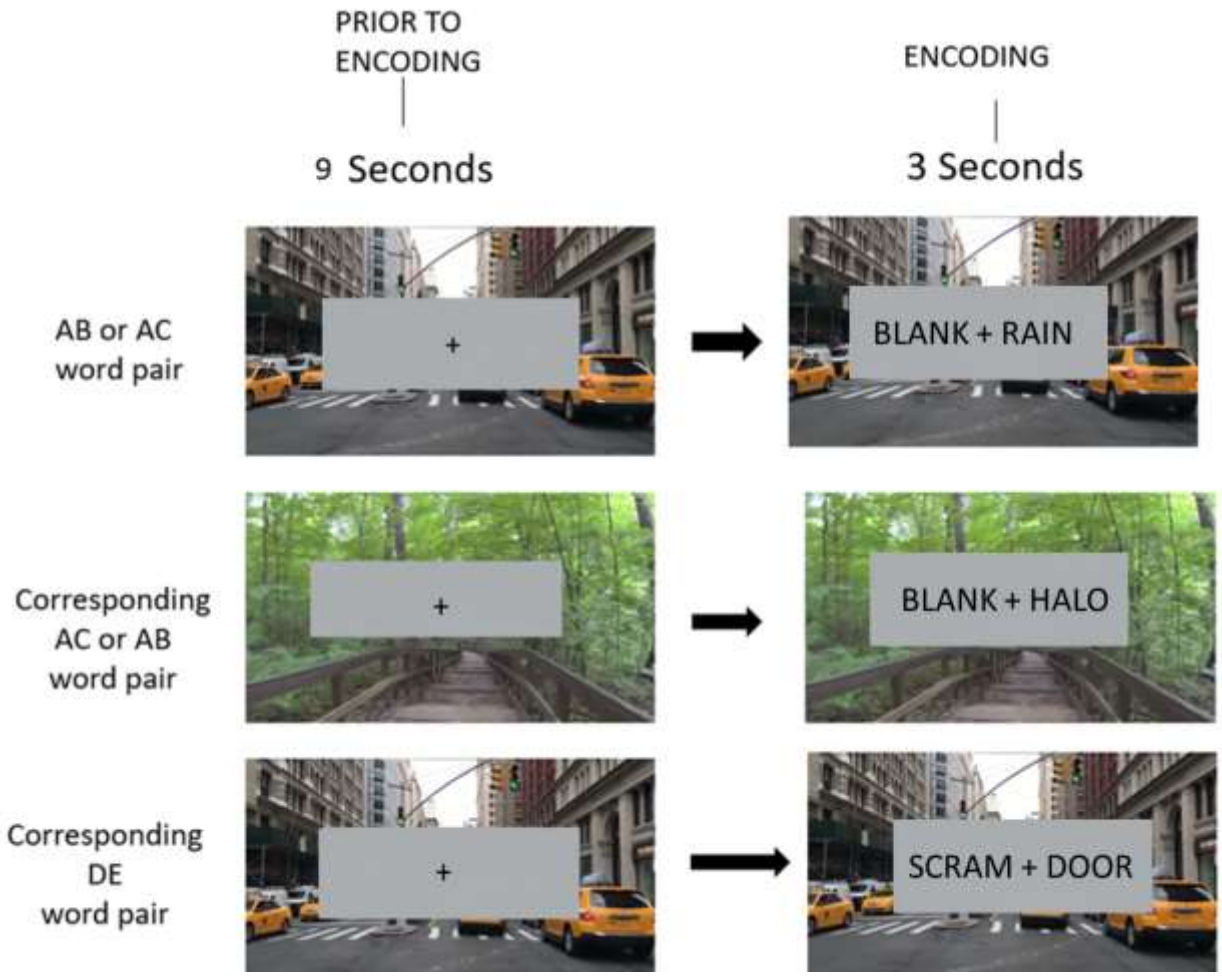
Procedure.

Participants were first given informed consent sheets, which they read over and signed. They were instructed that instructions would be presented before starting the study. They then underwent calibration of the eye tracker with the guidance of the experimenter. Once participants had completed this they read over the instructions and pressed the spacebar to begin the practice block. This practice block comprised an encoding phase, where each participant viewed a fixation cross followed by a word pair, this repeated 6 times. This was followed by a retrieval phase where the first word was presented for 2 seconds and then the first letter of the second word was presented for 5

seconds. Participants pressed the spacebar once the first letter of the second letter was presented if they knew the second word, input the second letter in the next screen, and rated their confidence in that answer in the next screen.

The experimental phase comprised 6 blocks, each block was presented in the same overall manner. In each block there were 2 parts, the encoding phase, and the retrieval phase. The encoding phase comprised 2 parts, part B and part C. All experiments began with part B, followed by part C. Each part had a specific movie, counterbalanced across trials and participants, assigned to it. Participants were first presented for 9 seconds with a fixation cross that overlay a movie segment. Secondly, a novel cue associate, a five-letter word from the triplet, and a four-letter word from the quadruplet was displayed for 3 seconds. This is illustrated in Figure 1. This was repeated 8 times, with a random order of A or DE presentation, half of these word-pairs corresponded to A, and the other half of the word pairs corresponded to DE. After this section participants were presented with the second encoding part, part C. The second encoding part followed the same order of word-pair presentation and timings, with either the same five-letter word presented corresponding to A, or a different five-letter word corresponding to DE, although the paired four-letter word always differed.

Figure 1.
Encoding phase

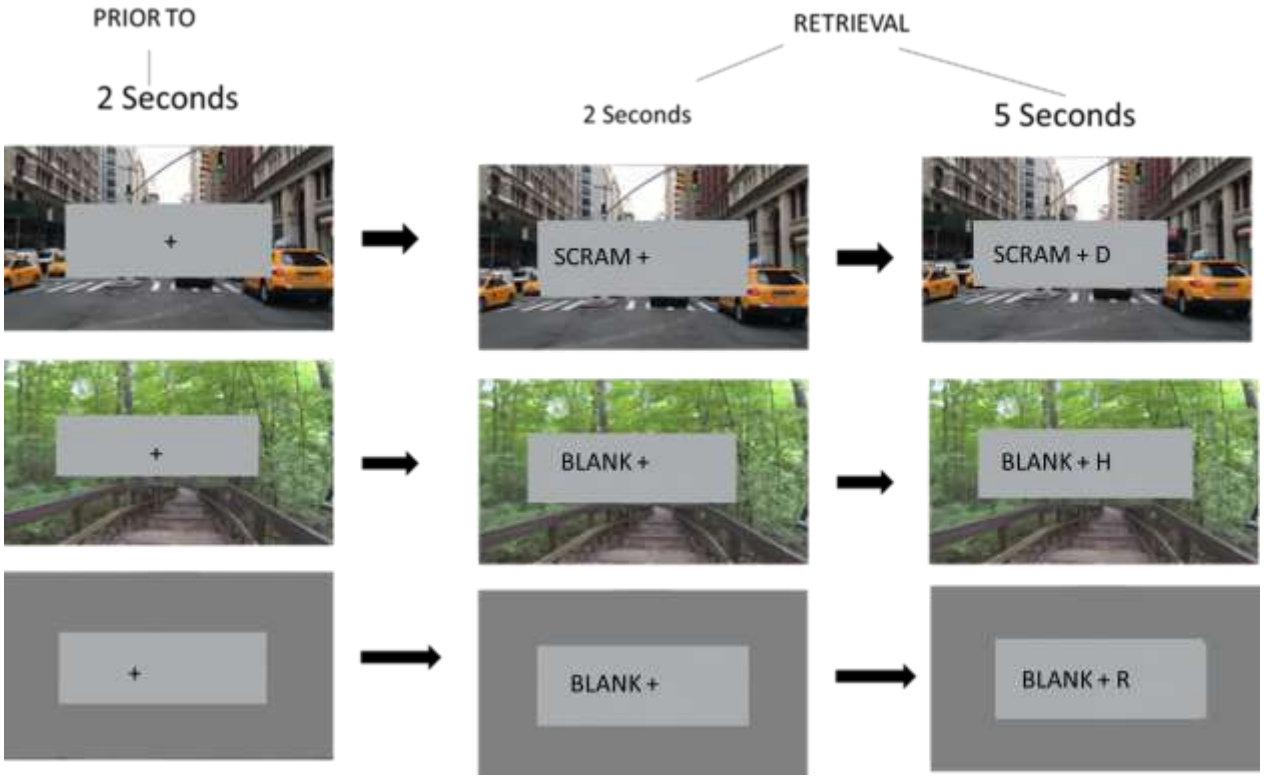


The encoding phase was followed by a distractor task. This task consisted of repeatedly subtracting a given number, ranging from 3 to 7, from a 3-digit number. These numbers varied throughout the trials.

In the retrieval phase participants' memory for all word pairs was tested within a block. This began by the presentation of either a blank screen or a screen with an image (corresponding to whether context was presented or not in the retrieval trial) for 2 seconds. After which a screen with either a grey background or an image from the encoding phase was presented with the first word from a word pair for 2 seconds followed by the presentation of the first letter of the second word (the probe) for 5 seconds, as illustrated in Figure 2. Participants pressed the spacebar if they knew

the second letter of the second word once the first letter of the second word was presented, to input this letter in the following screen and to input their confidence in the next screen.

Figure 2
Retrieval phase



Note: The presentation of word pair type (AB/AC/DE) and Context presentation (Blank/City/Forest was counterbalanced.

Scoring

Scoring was separated into two parts, behavioral, and pupillometry scoring. However, before the analysis of the data we removed participants with a recall accuracy below 25%. Participant behavioral scoring was done through the use of Excel, R, and the psychopy output. The Excel function =EXACT was used to remove duplicates of rows within a psychopy output generated from each participant. Within this output there were rows for participant number, encoding context (Forest or City), recall trial (1-16), recall accuracy (0 = incorrect/no response 1 = correct), response

time, retrieval half (1 = first half, or 2 = second half), block number (1-6), and what word pair, condition (B or C), and interference (A or DE) was being tested. Then each psychopy output was bound together, resulting in a data table. We imported this into R, using the readxl package. We then coded the independent variables, Competition, Interference, and Context presentation. This coding corresponded to Competition B to -1 and C to 1, Competition DE to 0 and A to 1, and Context presentation to 1, and No presentation to 0.

Participants' pupillometry scoring was carried out through Excel and R. Eyetracking data and event eye tracking output was given by the Tobii eye-tracker. The event eye tracking output showed when the first word was shown, the end of the second word presentation, the start of fixation, and the end of fixation. This was used to create two columns, one row for start and stop. Using the data frames for each participant we input another column to this Excel sheet which contained the concatenated value of whether the context was reinstated (B for not reinstated and C for reinstated), their recall accuracy (1 - correct or blank for no response), what competition (A - shared word-pair, or DE for non-shared word-pairs) and interference (B or C) the trial was. Moreover, we also input another column to show which block and retrieval number the trial was. We then obtained the timepoint in which the last 200ms of each fixation event began and replaced the specific fixation start value with this.

We then imported the Tobii eye-tracking data into R, added a column from the Tobii eye-tracking event output to indicate what was happening at the time, and used the pupillometryR package to preprocess this data. We began by regressing each pupil against each other for some measure of smoothing and created another column which was the mean of each pupil. We then removed recall trials with missing data over 75% and performed median filtering. We then performed linear interpretation across blinks. To baseline the data, we used the column created from the Excel sheet and subset the data into events. We divided each recall event by the means of the last

200ms of each corresponding fixation event and changed each time so that each recall event started at 0.

To obtain maximum pupil values during retrieval we subset each retrieval phase into a specific condition, we created an interaction between the event, participant, and condition. We then checked the maximum value of these interactions which returned the maximum value of each interaction.

Results

Behavioural

We conducted three mixed effect regressions to examine Interference, Competition, and Context presentation on recall, the results of which can be seen in Table 1. The first mixed effect regression model investigated whether Interference, Context presentation, Competition, and the interaction between Context presentation and Competition were significant predictors of retrieval success. In this model, we controlled for the random effects of participant, block number, and encoding context. Results indicated that Competition (OR = .69, (CI: .52, .91) p = .008), Interference (OR = .87, (CI: .79, .96) p = .007), and the interaction between Context presentation and Competition (OR = 1.61, (CI: 1.09, 2.37) p = .008), were significant predictors of correct recall. See Appendix B for a visual representation. Indicating that a) there was increased interference when the context was not presented, b) when context was presented interference was reduced, and c) word pairs learned in the first half were most likely to be recalled.

To examine whether these effects differed during retrieval depending upon encoding half we subset the data into subset B (word pairs corresponding to interference B condition), and subset C (word-pairs corresponding to interference C condition). We then reran the previous model but used subset B. Therefore, Context presentation, Competition, and their interaction were our fixed effects,

participant, block number, and encoding context were our random effects, and response accuracy was our dependent variable. Results indicated that Competition (OR = .75, (CI: .49, 1.13), p = .165), Context (OR = .97, (CI: .64, 1.47), p = .875), and Competition*Context (OR = 1.47, (CI: .82, 2.64), p = .199), were not significant predictors of correct retrieval. See Appendix C for a visual representation. Indicating that retrieval of the word pair is not related to interference and/or whether the context was presented or not.

We also reran the first model but only used data from subset C. Therefore, Context presentation, Competition, and their interaction were our fixed effects, participant, block number, and encoding context were our random effects, and response accuracy was our dependent variable. . Results indicated that Context (OR = .76, (CI: .51, 1.12), p = .161) and Competition*Context (OR = 1.52, (CI: .87, 2.66), p = .137) were not significant predictors of correct recall. However, Competition was a significant predictor of correct recall (CI = .65, (CI: .44, .97), p = .033). See Appendix D for a visual representation. Indicating that retroactive interference is increased when the context is not presented.

Table 1.
Results of mixed effect regressions

	Overall			**Subset B**					**Subset C**
Predictors	*Odds Ratios*	*CI*	*P*	*Odds Ratios*	*CI*	*P*	*Odds Ratios*	*C1*	*P*
Intercept	1.01	.70-2.02	.978	.87	.40-1.92	.732	.87	.56-1.36	.554
Competition	.69	.52-.87	**.008**	.75	.49-1.13	.165	.65	.44 - .97	**.033**
Context Presentation	.82	.62-1.09	.151	.97	.64-1.47	.875	.76	.51-1.12	.161
Interference	.87	.79-.96	**.007**						
Comp*Cont	1.61	1.09-2.37	**.016**	1.47	.82-2.64	.199	1.52	.87-2.66	.137
Random Effects									
	3.29			3.29			3.29		
Participant	.16			.57			.21		
Block	.00			.23			.05		
Encoding Context	.01			.07			.00		
ICC	.05			.21			.07		

Observations	1728	864	864
Marginal R^2	.011	.004	.007
Conditional R^2	.062	.214	.081

Pupillometry

We ran three mixed effects regressions to examine whether Competition, Interference, Context presentation, and the interaction between Interference and Context presentation were predictors of maximum pupil dilation values in successfully retrieved trials, results of which can be seen in Table 2. The first of these included Interference, Context presentation, Competition, and the interaction between Context presentation and Competition as fixed effects, participant as random effect, and maximum pupil dilation in successfully retrieved trials as the dependent variables. Results indicated that Context presentation (OR = .02, (CI: .00, .03), p = .031), and Interference (OR = .87, .01, (CI: .00, .01), p = .020), were significant predictors of maximum pupil dilation in successfully retrieved trials. See Appendix E for a visual representation of these results. Indicating that there was larger maximum pupil dilation when a) successfully retrieving non-shared word pairs when the context was presented, and b) retrieving second half.
encoded word pairs.

In our second mixed effect regression we examined whether there were specific effects of context presentation, interference, and the interaction between interference and context presentation at predicting maximum pupil dilation in when successfully retrieving competition B word pairs. Therefore, Context presentation, Competition, and their interaction were our fixed effects, participant was our random effect, and response accuracy was our dependent variable. Results indicated that only Context presentation (OR = .03 (CI: .00, .05), p = .031), was significant in predicting maximum pupil dilation. Refer to Appendix F for a visual result. Indicating that maximum pupil values are larger when successfully retrieving non-shared word pairs.

In our third model, we examined whether there were specific effects of Competition, Context presentation, and Interference in maximum pupil dilation in successfully retrieved second half encoded word pairs. In this model, we included Competition, Interference, and their interaction as fixed effects, participant as a random effect, and maximum pupil dilation as the dependent variable. Results of which indicated that none of these predictors were a significant predictor of maximum pupil dilation when retrieving second half encoded word pairs. Visual results are provided in Appendix G. Indicating that maximum pupil dilation when retrieving second half encoded word pairs is not affected by Interference, or Context presentation.

Table 2.
Results of mixed effect regressions

					Subset B				**Subset C**
Predictors	*Odds Ratios*	*CI*	*P*	*Odds Ratios*	*CI*	*P*	*Odds Ratios*	*C1*	*P*
Intercept	1.14	1.11-1.16	**<.001**	1.13	1.10-1.15	**<.001**	1.14	1.12-1.17	**<.001**
Competition	.01	-.00-.03	.131	.01	-.01-.03	.352	.02	-.01-.04	.199
Context Presentation	.02	.00-.03	**.031**	.03	.00-.05	**.031**	.01	-.01-.04	.250
Interference	.01	.00-.01	**.020**						
Comp*Cont	-.02	-.05-.00	.063	-.02	-.05-.01	.206	-.03	-.06-.01	.145
Random Effects									
σ^2	.00			.00			.00		
Participant	.00			.00			.00		
ICC	.36			.36			.36		
Observations	1533			809			724		
Marginal R^2	.002			.002			.006		
Conditional R^2	.360			.362			.363		

Discussion

In contrast to hypothesis 1a, that encoded information from the end of encoding would be easier to recall, the behavioural results of this experiment suggest that participants were most likely to recall word pairs learned in the first half of the encoding phase. This claim may be considered to contrast with the systems consolidation theory of memory, and the contextual binding theory of memory. Per Dudai (2004), the systems consolidation theory claims that retroactive interference is

the main cause of interference, as reactivation of memories leads to consolidation of the new information over the old information. If our results were to conform to this claim, we would have expected lower recall for word pairs learned in the first half compared to the second. Moreover, per Yonelinas (2019), the contextual binding theory of memory claims that both retroactive and proactive interference should occur during retrieval. If this was to have occurred, we would have expected Competition to have been a predictor of retrieval success in both subset C (proactive interference) and subset B (retroactive interference). However, this experiment contrasts with the systems consolidation theory and the contextual binding theory, in that both theories are theories regarding long-term memory (Dudai, 2004), whereas we tested participants after they had encoded the information. Consequently, our results, which indicated that information encoded during the beginning of the experiment was most likely to be recalled, may not have conformed to these theories as they did not examine long term memories.

Moreover, although hypothesis 2a, that competitive information would be less likely to be recalled when the context was not presented, was supported in the overall model and the model which used Interference C word pairs, results of this experiment indicated that there was no difference in amount of recalled information when examining interference B competitive word pairs. However, as our results suggested that there was an effect when examining interference C word pairs, our research can be considered to conform to previous interference research which examined episodic memory tested immediately after encoding. For instance, research by Bramao et al. (2022), has indicated that when word pairs are encoded in a real-life-like context and when retrieval involves no context presentation proactive but not retroactive interference may occur. Consequently, our results suggest that proactive interference occurred, and retroactive interference did not, which is in line with previous research that used a life like visual context. .

An explanation for why there was an increased level of proactive interference, compared to proactive interference, may be that the first word in AB word pairs was associated with a strong association between the first and second word in AB word pairs. If there was a strong association between first and second words, in AB word pairs, we would expect reactivation of AB word pairs when we asked participants to encode AC word pairs. This may occur as the first word in AC word pairs may have functioned as a retrieval cue. Van den Hoven and Eggen (2014) defined retrieval cues as information which are a facilitator for memory recall. As the specific first word was only previously present in the AB word pair it can be considered a strong retrieval cue for that specific AB word pair (Bramão & Johansson, 2017). This claim is supported by the systems consolidation theory, which claims that encoding new memory may lead to the reactivation of similar previous memories (Dudai, 2004). Moreover, previous research has shown that during a new learning event, previous memories which become reactivated may result in strengthening of those reactivated memories (Tambinie & Davachi, 2019). Thus, the association between first and second words in AB word pairs may have functioned as a retrieval cue during AC encoding, which may have resulted in the strengthening of memory for AB word pairs.

Moreover, the pupillometry results which indicate that there was increased pupil dilation during successful recall when there was context presentation and participants successfully recalled DE word pairs encoded in the first half of the encoding phase, and that did not show this for word pairs encoded in the second, can be seen as further support for a strong association between first and second words in AB word pairs. Previous research has indicated that similarity between neural patterns of associated memory leads to reduced accuracy (Treves & Rolls, 1992). Research has indicated that pattern separation results in decorrelating similar memories, resulting in improved memory performance (McClelland et al., 1995). Similarly, other research has indicated that there is greater retrieval of same event memory compared to similar non-same event memory (Zotow et al.,

2020). Moreover, rodent studies have indicated that the hippocampus binds same context encoded information together and binds different context information separately (McKenzie et al., 2014). Therefore, if reactivation of AB word pairs occurred whilst encoding AC word pairs, we may have seen an increased decorrelation between AB and AC word pairs as participants may have noticed differences between the two encoding contexts, supporting pattern separation. Contrastingly, another way to interpret this, is that if AB word pairs were reactivated during encoding of AC word pairs, they may have been associated with that encoding context, resulting in decreased memory performance for AB word pairs when context was presented. However, our behavioural results do not support this interpretation. Therefore, reactivation of AB word pairs, whilst encoding AC word pairs may have supported pattern separation. In addition, these pupillometry results can be seen as providing mixed support for hypothesis 3b, which claimed that context presentation would improve the recall of competitive word pairs.

Furthermore, the pupillometry results, which indicated that there was increased pupil dilation during retrieval of non-competitive word pairs learned in the first encoding half may support context functioning as a retrieval cue. Van den Hoven and Eggen (2014) defined retrieval cues as information which is a facilitator for memory recall. As the specific context was presented during encoding of all the words in the first encoding phase, context presentation may have functioned as a retrieval cue for all of the word-pairs learned in the first encoding half (Bramão & Johansson, 2017). In contrast, as the first word was only present in one of the encoded word pairs the first word would have functioned as a retrieval cue for one word-pair (Bramão & Johansson, 2017). Therefore, decreased pupil dilation, during retrieval of non-competitive word pairs may have resulted from increased discriminatory power between the first word compared to context presentation when the first word was not shared in first half encoded word-pairs. Similarly, behavioral results indicated that when the context was presented, and the word-pair was shared, recall of word pairs learned in the

second encoding half was improved, which supports hypothesis 3a. Therefore, our pupillometry and behavioral results support context being a retrieval cue, but this may have different affects depending upon whether the first word was shared or not.

However, the low number of participants who provided usable data in this study may affect the reliability and validity of these results. Overall, 8 participants provided usable data in this study, and thus our analysis was based upon 8 participants. Research by Krzywinski and Altman (2013) has indicated that low sample size may not reliably indicate overall population estimations. Moreover, research by Halsey et al. (2015) has indicated that p-values from research with low sample sizes reflect greater variability in reproducible p-values. Consequently, the reliability and validity of the findings in this research may only reflect outcomes for this specific studies population.

Moreover, the low number of participants providing usable data can be seen as a limitation of our study. Research has indicated that low sample sizes may inaccurately represent the population value, with increasing sample sizes more accurately indicating the population value (Andrade, 2020). Additionally, our results provide no explanation for why only 40% of participants provided usable data. Although, an explanation for this may have been the participants' motivation, and differences in working memory. Research by Murty and Dickerson (2016) has indicated that the mesolimbic dopamine system, which underlies motivation, interacts with the medial temporal lobe in order to support episodic memory. They claim that low motivation reduces episodic memory (Murty & Dickerson, 2016). Similarly, research by Ball et al. (2018) has indicated that there are differences between individuals' episodic memory abilities. Therefore, a limitation in our research is that we cannot claim whether the low completion rate present in our research is a result of participants level of motivation or their episodic memory ability.

However, this experiment only looked at interference and how that interference is affected by context presentation during only one of the potential sources of information. For instance,

previous research has indicated that retroactive and proactive interference may occur (Underwood, 1957, Baddeley and Dale, 1966). Therefore, the results of context presentation in this study may have been influenced by what word pairs were associated with context presentation. For instance, a participant may have recalled AB word pairs regardless of whether context presentation occurred. However, as only half of the word pairs were presented with context our results may have been confounded by participants recall aligning with what we had presented with context, and not necessarily context presentation itself.

Experiment 2

This experiment considers how Interference and Context presentation affect retrieval performance, and pupil dilation in successfully retrieved trials when visual context from encoding is presented during retrieval. In contrast to the first experiment, this experiment is interested in how context presentation in information that shares constituents affects behavioural outcomes, and pupil dilation. Within this experiment, context was presented for half of the encoded information. For information that is non-competitive, this involves a counterbalanced selection of information which included context presentation. For information that shared constituent parts this involved context presentation in overlapping information (i.e, if information from B included context presentation the corresponding information from C also included context presentation).

Method

Participants.

Recruitment for this experiment took place during the month of September 2022. Overall, 32 people took part in this study. However, only 18 participants provided usable data. Those who

provided useable data had a mean age of 23.83 (SD = 3.23), of which 8 were male and 10 were female. For a breakdown of participants who provided non-useable data see Appendix H.

Design.

The design of this experiment followed the same design as described in experiment 1.

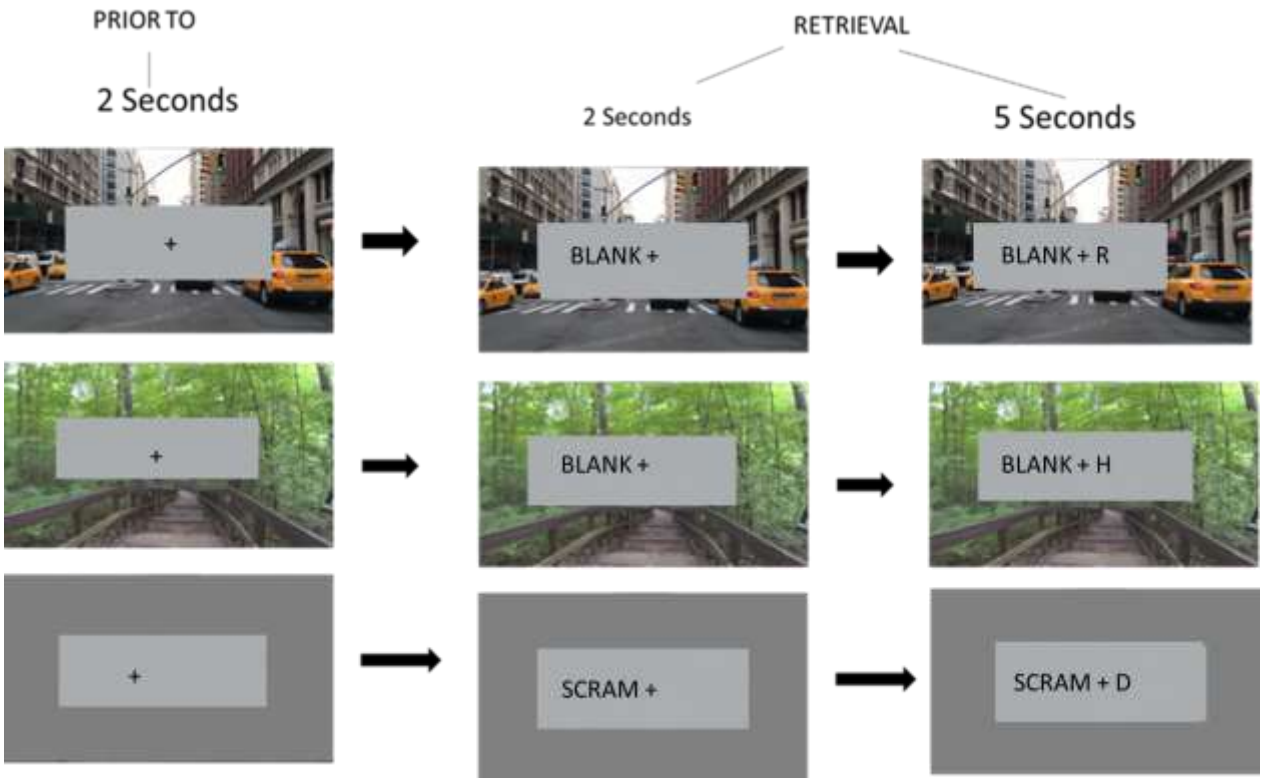
Materials.

This experiment used the same presentation apparatus, word lists, and movies as those specified in experiment 1. However, the movies were presented for 108 seconds.

Procedure.

Participants followed the same general procedure described in experiment 1. However, the experimental phase was repeated 12 times, with participants encoding 4 word pairs in each encoding half. Differences within each repeat of the experimental phase arose within the retrieval phase. Four retrieval phases began with the random presentation of the first two A and DE word pairs from part B and the last two A and DE word pairs from part C. Four retrieval phases began with the random presentation of the last two A and DE word pairs from part C. The remaining four retrieval phases had a random distribution of word pairs, with the caveat that no corresponding word pair was presented in the same retrieval half. These retrieval phases differed in context presentation. Of the four corresponding retrieval blocks, two had context presentation for a random selection of overlapping AB/AC/DE word pairs, whereas the other retrieval block had the opposite, i.e, context presentation for the word pairs with no context presentation in the first block. Figure 3 provides an example.

Figure 3.
Retrieval phase



Scoring.

Scoring in this experiment followed the description in experiment 1.

Results.

Behavioural

We conducted three mixed-effect regressions to examine the effect of Interference, Competition, and Context presentation on retrieval. The results of which can be seen in Table 3. Our first model investigated whether Interference, Context presentation, Competition, and the interaction between Context presentation and Competition were significant predictors of retrieval success. In this model we controlled for the random effects of participant, block number, and encoding context. Result indicated that Competition (OR = .61, (CI: .50, .75) p = <.001), Interference (OR = .86, (CI: .80, .92) p = <.001), Context (OR = .75, (CI: .61, .91) p = .005), and the interaction between

Context presentation and Competition (OR = 1.49, (CI: 1.13, 1.98) p = .005),.were significant predictors of correct recall. A visual demonstration is provided in Appendix I, Indicating that when a) when context was not presented word pairs that shared their first word were less likely to be recalled, b) when context was presented word-pairs which did not share their first word were less likely to be recalled, c) when context was presented and word pairs shared their first word, recall was more likely and c) word-pairs learned in the first half were most likely to be recalled.

We subset the data into subset B (word pairs learned in the first encoding half) and subset C (word-pairs learned in the second encoding half). We then reran the previous model but used data from subset B. Therefore, Context presentation, Competition, and their interaction were our fixed effects, participant, block number, and encoding context were our random effects, and response accuracy was our dependent variable. Results, as shown in Appendix J, indicated that none of the independent variables were significant predictors of correct retrieval. Indicating that retrieval of first half encoded word pairs is not affected by context presentation or whether the first word is shared or not.

We also reran the first model but used data from subset C. Although results indicated that including the random effects of block number and encoding context resulted in an overfit model. Therefore, our final model included the fixed effects of Context presentation, Competition, and their interaction, participant was the random effect, and response accuracy was our dependent variable. Results, as illustrated in Appendix K, indicated that Competition (OR = .49, (CI: .37, .65), p = <.001), Context (OR = .61, (CI: .46, .80), p = <.001) and Competition*Context (OR = 2.00, (CI: 1.35, 2.96), p = .001) were significant predictors of correct recall. Indicating that when a) context was not presented word pairs that shared their first word were less likely to be recalled, b) context was presented word-pairs which did not share their first word were less likely to be recalled and c) context was presented and word pairs shared their first word, recall was more likely.

Table 3.
Results of mixed effect regressions

	Overall Model			**Subset B**			**Subset C**		
Predictors	*Odds Ratios*	*CI*	*P*	*Odds Ratios*	*CI*	*P*	*Odds Ratios*	*C1*	*P*
Intercept	1.43	.97-2.10	.069	1.39	.81-2.39	.235	1.42	1.08-1.86	**.012**
Competition	.61	.50-.75	**<.001**	.78	.59-1.04	.090	.49	.37-.67	**<.001**
Context	.75	.61-.91	**.005**	.94	.70-1.25	.651	.61	.46-.80	**<.001**
Presentation									
Interference	.86	.80-.92	**<.001**						
Comp*Cont	1.49	1.13-1.98	**.005**	1.10	.73-1.64	.660	2.00	1.35-2.96	**.001**
Random Effects									
σ^2	3.29			3.29			3.29		
Participant	.19			.23			.16		
Block	.07			.10					
Encoding Context	.03			.09					
ICC	.08			.11			.05		
Observations	3456			1728			1728		
Marginal R^2	.016			.003			.007		
Conditional R^2	.095			.116			.081		

PUPILLOMETRY

We ran three mixed effects regressions to examine whether Competition, Interference, Context presentation, and the interaction between Interference and Context presentation were predictors of maximum pupil dilation values in successfully retrieved trials. The results of which can be seen in Table 4. The first of these included Interference, Context presentation, Competition, and the interaction between Context presentation and Competition as fixed effects, participant as random effect, and maximum pupil dilation in successfully retrieved trials as the dependent variables. Results, as demonstrated in Appendix L, indicated that none of these were significant predictors of maximum pupil dilation in successfully retrieved trials. Indicating that maximum pupil dilation was not related to context presentation, interference, or competition.

In our second mixed effect regression we examined whether there were specific effects of context presentation, interference, and the interaction between interference and context presentation at predicting maximum pupil dilation when successfully retrieving competition B word pairs. Therefore, Context presentation, Competition, and their interaction were our fixed effects, participant was our random effect, and response accuracy was our dependent variable. Results, as shown in Appendix M, indicated that none of these were significant at predicting maximum pupil dilation. Indicating that in competition B word pair retrieval maximum pupil dilation is not related to context presentation, or interference.

In our third model we examined whether there were specific effects of Context presentation, Interference, and the interaction between Context presentation and Interference in maximum pupil dilation in successfully retrieved second half encoded word pairs. Thus, in this model we included Competition, Interference, and their interaction as fixed effects, participant as a random effect and maximum pupil dilation during successful retrieval of second half encoded word pairs as the dependent variable. Results of which, as demonstrated in Appendix N, indicated that none of these predictors were a significant predictor of maximum pupil dilation when retrieving second half encoded word pairs. Indicating that maximum pupil dilation when retrieving second half encoded word pairs is not affected by Interference, or Context presentation.

Table 4.
Results of mixed effect regressions

	Overall			**Subset B**					**Subset C**
Predictors	*Odds Ratios*	*CI*	*P*	*Odds Ratios*	*CI*	*P*	*Odds Ratios*	*C1*	*P*
Intercept	1.13	1-11-1.16	**<.001**	1.14	1.11-1.16	**<.001**	1.13	1.10-1.15	**<.001**
Competition	.01	-.00-.02	.065	.00	-.01-.02	.440	.01	-.00-.03	.061
Context Presentation	.00	-.01-.01	.877	.00	-.01-.02	.565	-.00	-.02-.80	.711
Interference	-.00	-.01-.01	.675						
Comp*Cont	-.01	-.02-.00	231	-.01	-.03-.00	.131	-.00	-.02-.02	.863
Random Effects									

σ^2	.00	.00	.00
Participant	.00	.00	.00
ICC	.36	.36	.36
Observations	1533	809	724
Marginal R^2	.002	.002	.006
Conditional R^2	.360	.362	.363

DISCUSSION

Across both of the experiments, results indicated that, in contrast to our Results indicated that when retrieving word pairs that did not share a constituent with another word pair retrieval was reduced. However, when examining word pairs that shared a constituent with another word pair, results indicated that there was an improvement in performance. Thus, our results support hypothesis 3a. This result may indicate that context presentation and the first word functioned as retrieval cues. Previous research has indicated that the presentation of information that results in the reactivation of previously encoded information can reactivate non-needed information (Bramão & Johansson, 2017). This research has indicated that this reactivation is a result of such information being non-distinctive enough, resulting in the activation of non-necessary information (Bramão & Johansson, 2017). However, this experiment employed a method whereby during encoding a context was presented with all the word pairs, whereas the first word in the word pair was only presented in one (competitive), or two (competitive) word pairs. As such, context and the first word may have induced retrieval of all word pairs associated with it. Consequently, the first word in non-competitive word pairs would have specifically reactivated a single word pair it can be considered highly distinguishing. Contrastingly, the context presentation may not have been as distinctive and resulted in poorer performance for non-competitive word pairs, whilst the interaction between context presentation and first word may have benefited competitive word pairs.

However, the finding that context presentation supported the retrieval of competitive word pairs and challenged the retrieval of non-competitive word pairs may have been influenced by the

level of interference present when retrieving the word pair. For instance, in the analysis which used only Interference B data, there was no effect of context presentation on the number of word pairs recalled, which contrasted with hypothesis 1a. This may have occurred as there was no indication from the results that retroactive interference occurred. Research has indicated that retroactive interference may occur when retrieving older information when this retrieval is hindered by similar newly encoded information (Wickens et al., 1963). Therefore, as there was no significant difference between retrieving competitive and non-completive word pairs our results indicate that retrieval was not hindered by similar newly encoded word pairs. In contrast, the results which used Interference B word pairs indicated that there was a significant reduction in the amount of recalled competitive word pairs compared to non-competitive word pairs when the context was not presented. Moreover, in Interference C word pair recall there was evidence that proactive interference occurred. Research has indicated that proactive interference is when older encoded information affects the ability to recall newly encoded information (Baddeley & Dale, 1966). Consequently, context presentation may only benefit the retrieval of word pairs when interference between word pairs occurs.

However, our pupillometry results, in contrast to hypotheses 2b and 3b, indicated that there was not an effect of context presentation on maximum pupil dilation in successfully retrieved trials. Moreover, the results also indicated that there was no effect of competition on maximum pupil dilation, in contrast to hypothesis 1b. An explanation for these results may come from the blocking account of retrieval-induced forgetting. The blocking account claims that selective retrieval induces forgetting of non-retrieved items (Roediger & Neely, 1982), Consequently, as there was no evidence that there was a difference in maximum pupil dilation due to either context presentation or interference blocking of competing information may have occurred. .

General Discussion

Research has indicated that encoded information competes against each other during retrieval, resulting in reduced recall of word pairs (McGeoch, 1932). Sources of interference arise from proactive interference, when newly encoded information interferes with the recall of newly encoded information (Baddeley and Dale, 1966), and retroactive interference, when previously learned information interferes with the recall of newly encoded information (Wickens et al., 1963). As both experiments indicated that participants were most likely to recall information from the first encoded half, this may be seen as a higher level of interference within the recall of second half encoded information. Thus, proactive interference may have been higher in both experiments, which does not conform with the first hypothesis in both experiments. Further support for the higher presence of proactive interference in both experiments comes from the regressions which examined word pairs encoded in different encoding halves separately. In the regression which used first half encoded word pairs, there was no effect relating to recall rate, of interference when the context was not presented. In contrast, in the regression which used word pairs from the second encoding half results indicated that participants were less likely to recall competitive word pairs when context was not presented. Therefore, these results provide mixed support for hypothesis 1a and 2a. and provide evidence that there was a higher level of proactive interference in both studies.

Moreover, both experiments can be seen as providing similar support for the effect of context presentation on memory. Behavioural results in both experiments indicated that context presentation benefitted the retrieval of competitive word pairs,, which supports hypothesis 3a. These results may support context presentation supporting pattern separation. Research has indicated that presentation of an overlapping cue will result in all associated stored representations becoming reactivated, through a process of pattern completion (Norman & Reilly, 2003). This has been claimed as the hippocampus relying upon pattern separation, whereby overlapping encoded memories from separate events are made more distinct, and where presentation of an overlapping

cue is not distinct enough to distinguish between overlapping encoded memories (McClelland et al., 1995). Neuroimaging support for this claim came from research which examined similar spatial environments, which found distinct hippocampal pattern representations between similar environments (Stokes et al., 2013). Therefore, context presentation may have supported pattern separation in both of these studies.

However, behavioural results diverge on how context presentation affects the retrieval of noncompetitive word pairs. Results from the first experiment indicated that there was no effect of context presentation on rate of recall of non-competitive word pairs, which does not support hypothesis 4a. In contrast, the second experiment indicated that when context is presented recall of non.competive word pairs is reduced, which supports hypothesis 4a. This may have occurred as the presentation would have been a retrieval cue for all words encoded in a given context, whereas the first word would have been a singular retrieval cue. For instance,, memory for information learned in the same event has been shown to be correlated, with retrieval of some information resulting in retrieval of elements from the same event (Horner et al., 2015). Therefore, memory performance for non-competitive information may be decreased when context is presented.

Moreover, the pupillometry results found in both of these experiments diverge. For instance, in experiment 1, results indicated that there was increased maximum pupil dilation when recalling information learned in the second encoding half, and non-competitive word pairs when context was not presented overall performance. However, the increased maximum pupil dilation when recalling non-competitive word pairs when context was not presented was only found in subset B. In contrast, in experiment 2, there was no difference in any comparisons regarding maximum pupil dilation. These diverging findings may indicate that there was a different function which resulted in participants not recalling word pairs. Research has indicated that retrieval of some items may induce forgetting, or blocking, of other items, which is known as retrieval-induced forgetting (Bäuml &

Kliegl, 2017). Two theories suggest why this may happen, the blocking account claims that selective retrieval induces forgetting of non-retrieved items (Roediger & Neely, 1982), whereas the inhibition account claims that non-recalled information interferes with recalled information (Anderson, 2003). Consequently, as there was difference in maximum pupil dilation depending upon condition, this may be seen as support for the inhibition theory, as condition should have been associated with different levels of competing information. In contrast, as experiment 2 indicates that there was no difference in maximum pupil dilation in relation to condition, this may be seen as support for the blocking theory. Therefore, two different functions may have been associated with participants not recalling word pairs in these experiments.

However, these findings may have been a result of the methodology used in these studies. During these studies, prior to participants recalling a word pair they were presented with a fixation cross and either a blank background or an image of the encoding context followed by the presentation of the first word. Previous research has shown that retrieval cues which are able to separate between multiple competing sources of information are better than those which do not (Bramão & Johansson, 2017). Thus, the presentation of the context image prior to the first word may have resulted in the activation of all word-pairs associated with the context, in comparison the presentation of the word pair would have only resulted in the reactivation of word-pairs associated with that word. Moreover, research has also indicated that competitor context is reinstated during retrieval (Bramão et al., 2022). Therefore, the presence of the encoding context prior to the first word of the word pair may have resulted in the activation of all word-pairs associated with that context which may have confounded the results. However, if this was the case, we would expect increased interference in context presented retrieval of word pairs. Our pupillometry results provide evidence that this was not the case. Our results indicate that when comparing context presented and no context presentation retrieval there was no difference between maximum pupil dilation value.

Therefore, our methodology may have confounded the results, but this claim is challenged by our pupillometry results.

Moreover, the pupillometry results may have arisen from the analysis employed in our studies. Previous research has employed time course analysis which has been found to be an indicator of mental functions across time (McGarrigle et al., 2017). However, as we used maximum pupil dilation, we were only able to access mental functions at one specific time point (Franzen et al., 2022). Moreover, pupil dilation has also been related to decision making, whereby making a decision results in increased pupil dilation (De Gee et al., 2013). Furthermore, our plots of pupil dilation across time revealed differences in pupil dilation across time and conditions, indicating that there may be findings present within time course analysis not found within this study. Consequently, the challenges to theories found by these studies may have been reflective of participants deciding to do something rather than reflective of mental processes of memory.

A further limitation of our study may have been that we did not assess participants' mental context during the retrieval of word pairs. During retrieval, per the contextual binding theory (Yonelinas, 2019), the mental context overlaps between retrieval and encoding supports the retrieval of memory. However, we used images to represent context which may not have referred to participants' mental contexts, and as we did not ask participants to encode word pairs with images this may not have resulted in visual image mental context overlap (Bramão et al., 2022). Consequently, a limitation in our study may have been that we did not reference participants' mental context when retrieving the word pair, which would have further examined the claims made by the contextual binding theory.

Moreover, the spatial context in which this research took place may have been a limitation of this research, Per Yonelinas (2019), the spatial context in which encoding took place is a source of interference, whereby similar spatial contexts reactivate information learned in those spatial contexts.

Therefore, as participants encoded all information in the same room it took place in the same spatial context. Consequently, a limitation in our research can be considered the same spatial context across the encoding phase.

Moreover, the word-pairs used in our study may have been another limitation in our study. Research by Brysbaert, et al. (2013), has indicated that word pairs have a range from concrete word pairs (referring to a perceptible entity) to abstract word pairs (referring to a non-perceptible entity). As we constructed the word-pair lists to have no relation between first word and second word, the overall word pairs may be highly abstract. Research by Davis et al. (2021), has indicated that when encoding abstract word-pairs and the context is arbitrary the retrieval of the context is reduced compared to encoding concrete word-pairs. Moreover, as we did not promote associations between word-pairs and context, this may have resulted in no link between the word-pair and the context (Bramão et al., 2022). Consequently, our findings that context had no effect on retrieval may have resulted by using abstract word pairs and placing no emphasis on the link between context and word-pairs.

Furthermore, a further limitation of our results is the potential generalizability of the findings. Previous research has found that clinical conditions (Minassian et al., 2004), and medication use (li et al., 2013) may influence the dilation of the pupil. However, we did not ask participants any questions in regard to their medication use or clinical conditions. Therefore, we are unable to state whether the findings found within these studies were a result of clinical conditions or meditation use, which may affect the generalizability of these findings.

Therefore, we suggest that future research should examine whether the concreteness of the word pairs may have affected the results in this study. Moreover, further research should also examine other sources of context reinstatement in relation to memory performance. For instance, as the contextual binding theory claims that both mental and spatial context may affect the recall of

memory, future research could perform correlational analysis between fixation points prior to encoding and retrieving word-pairs. Similarly, further research could utilize a between participant design wherein one set of participants undergoes the same research methodology of this study, and another set learned the same words in the same room but encodes another set in a different spatial context. Furthermore, future research should ask participants about any clinical conditions they have or whether they are currently on any medications. We believe that our results may not have been affected by any other participant characteristics, materials, or context. However, future research should examine them as they may uncover such effects as this allows for our understanding to be refined.

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