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Pupil Dilation is Not Associated with Memory for Prior Remembering

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PUPIL DILATION IS NOT ASSOCIATED WITH MEMORY FOR PRIOR REMEMBERING

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This is to certify that the thesis prepared by Sana Z. Aftab entitled: "Pupil Dilation is Not Associated with Memory for Prior Remembering" has been approved by her committee as satisfactory completion of an honors thesis as partial fulfillment for the degree of Bachelor of Science.

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Abstract

This experiment was conducted to assess the relationship between pupil dilation and memory for prior remembering. Prior remembering is the judgment of whether a memory was previously remembered. Previous studies have suggested that pupil dilation can change in response to emotional stimuli as well as "old" versus "new" stimuli in recognition memory tests. The present experiment had participants view emotional and neutral context image-word pairs before they completed two separate cued-recall tests. Critically, some image-word pairs changed between tests. During the second cued-recall test, participants were also asked to make a judgment about whether they previously retrieved a given word on the first test. It was found that pupil dilation was significantly greater for incorrectly remembered words compared to correctly remembered words during the first cued-recall test. No other hypotheses were supported, and pupil dilation did not differ whether participants were correct or incorrect about their judgment of prior remembering. Differences between the analyses that were run and stimuli presented in comparison with previous studies could have led to the null findings. These results suggested that a relationship may not exist between pupil dilation and memory for prior remembering.

Pupil Dilation and Memory for Prior Remembering

Pupillary responses are one type of measure utilized in modern research. Pupil responses are controlled by the sympathetic nervous system, as part of the autonomic nervous system that is involved with arousal, wakefulness, and the fight-or-flight response (Mathôt, 2018). Most people often think of pupillary movement as a response to emotional content, specifically in the sense of pupil dilation. Previous studies have indicated that pupil dilation can be linked to not only emotion, but memory as well (Bradley & Lang, 2015; Heaver & Hutton, 2011; Onoda et al., 2009; Võ et al., 2008). One aspect of memory that has not yet been explored with respect to pupil dilation is prior remembering. Prior remembering is the judgment of whether a memory was previously remembered. It could be beneficial to determine whether pupil dilation can be indicative of prior remembering.

Pupil dilation is often thought to be tied to emotion. In one study, Kinner et al. (2017) had participants view negative and neutral images and/or practice emotional regulation strategies in response to viewed negative images. The emotional regulation strategies were separated into three conditions. In the Decrease condition, participants were instructed to reimagine the images in a positive light and/or with a positive ending. In the Increase condition, participants were instructed to dwell on the emotions of the negative images to intensify the emotions. Finally, in the Distract condition, participants were given a math problem for them to decide whether the solution given was correct. As a neutral baseline, participants also underwent a View condition in which they viewed neutral images without any emotional regulation. They found that pupil size increased with participants' emotional arousal to the negative images compared to the neutral images. Furthermore, they found a generalized increase in pupil dilation during the regulation of negative emotions despite the participants' efforts to increase, decrease, or distract themselves from the emotional scenes. This study supports a link between pupil dilation and emotion, in the sense that emotional arousal may lead to increased pupil dilation. In another study, Bradley and Lang (2015) had participants free-view emotionally arousing and neutral images before completing a recognition task to determine whether they had seen the images before. They found that pupil diameter was significantly larger when participants viewed emotional images compared to neutral ones (Bradley & Lang, 2015). These findings also support the link between pupil dilation and emotion by suggesting emotional arousal can lead increased pupil size in comparison to neutral images.

The study conducted by Bradley and Lang (2015) not only suggested a link between pupil dilation and emotion, but a link between pupil dilation and memory as well. Alongside their previous finding of pupil dilation increases towards emotional images, they also found increased pupil dilation for correctly recognized old images versus images never seen before. With this finding, they replicated what was dubbed the pupil old/new effect. The pupil old/new effect was first reported in a study conducted by Võ et al. (2008), in which they had participants undergo a recognition task while having their eye movements tracked. Participants were instructed to memorize a series of words before being tested on another series of words in the test phase. During the test phase, participants were to quickly indicate whether a word had been presented before in the previous phase. They found the presence of the pupil old/new effect, which was demonstrated by elevated pupil responses when correctly classifying old words compared to new words. These findings from both Bradley and Lang (2015) and Võ et al. (2008) suggest a significant link between pupil dilation and memory, in which pupil dilation increases when remembering old stimuli in comparison to new stimuli.

Other replications of the pupil old/new effect have since been reported in different studies. One such replication was done by Heaver and Hutton (2011). In their study, participants were asked to imagine that they had been involved in a car accident and were in recovery before completing three blocks of testing, including a learning phase and a recognition phase. During the learning phase, participants were asked to study a list of words before being tested on those words in the recognition phase to determine whether they had previously seen the words (Heaver & Hutton, 2011). They also implemented specific conditions that separated participants into three groups. In the “standard instructions” condition, participants were asked to perform as accurately as they could during the recognition phases. In the “malingering” condition, participants were asked to act to feign memory impairment and perform accordingly in the recognition phases (i.e., to occasionally “forget” things they had previously seen). Finally, in the “single response” condition, participants were asked to respond with “new” during the recognition phases, regardless of whether or not they saw the word previously. Across all conditions, they found that pupil dilation was significantly increased when viewing old items compared to new items. Similarly, to the pupil old/new effect, these results suggest an implicit memory process in which participants do not need to explicitly remember something in order for pupil dilation to occur. Instead, these results suggest that participants need only to have had previous exposure to stimuli (similarly to “old” stimuli) for increased pupil dilation.

The previously mentioned studies found support for links between pupil dilation and emotion, and pupil dilation and memory. However, a link between emotion and memory is suggested as well. Võ et al. (2008) established the presence of the pupil old/new effect in which pupil size can change depending on memory for old versus new stimuli. This effect, however, was not their only finding. When they tested participants’ memory for words with a recognition task, they manipulated the type of words in regards to their emotionality. They presented words of varied emotionality while not explicitly instructing participants to guide their attention to said emotionality of the words. With this, they found that the previously established pupil old/new effect was attenuated by the emotion of the presented words, in the sense that the effect was significantly reduced for emotional words compared to neutral words. While pupil dilation has been indicated to show changes in memory, this suggests that emotion allows for an indirect link to memory as well. When applying an emotional context to emotional stimuli, pupil dilation can be reduced regardless of having correctly remembered a word. Vo et al. (2008) attributed this effect of emotionality on memory performance to the idea that more processing is needed to correctly reject new words, of which would require a higher cognitive load.

While the previously mentioned studies conducted research using emotion and recognition tasks, another study conducted by Onoda et al. (2009) utilizing functional Magnetic Resonance Imaging (fMRI) supported the effect of emotionality on memory performance with regards to brain activation. Participants were instructed specifically to learn 24 word-pairs in which one half of the pairs were negative in emotional content while the other half were neutral in content. After encoding the word pairs, the participants underwent a retrieval phase in which they were presented with one word from the pairs and two other words below it. They were instructed to press a button (left or right) to indicate which of the two words were paired with the first presented word. During the experimental phase of the study, participants also had their brains scanned via fMRI that was synchronized to the onset of each trial (Onoda et al., 2009). With regards to the neutral word-pairs, they found that the hippocampus showed “robust activation” during the encoding and retrieval trials. In contrast, the middle temporal gyrus—of which serves to aid semantic memory processing—showed activation during the encoding and retrieval trials for the negative word-pairs. Hippocampal activity was also seen to be lower and memory performance for the negative word-pairs was poorer compared to the neutral word-pairs (Onoda et al., 2009). These findings thus demonstrate a biological basis for associative memory in the sense that memory for word-pairs can be seen with activity in specific regions in the brain. Altogether, these studies show that pupil dilation has been found to be greater for emotional stimuli and “old” stimuli under separate conditions, but potentially due to a higher cognitive load needed, trying to remember old stimuli that is emotional in context can lead to decreased or attenuated pupil dilation.

Most prior research has focused on the relationship between recognition memory and pupil dilation. In the present study, I aimed to extend what we know about pupil dilation and memory to the process of memory for prior remembering. Memory for prior remembering can be defined as the experience of previously recalling a memory. An example of prior remembering is when you are telling a friend a story and you are deciding whether or not you previously told the story to them. In clinical settings, patients reporting intrusive memories and/or traumatic experiences are inherently using memory for prior remembering. Schooler (2001) initially investigated the idea of prior remembering as a way to explain why individuals would forget previous instances of remembering abuse. In his study, Schooler (2001) conducted case-study analyses to determine how perception of prior abuse in victims influenced the remembering of forgotten memories as well as an analysis of their awareness of the remembering experience. The case studies included seven individuals that had previous experiences with sexual abuse, six of which were confident about having no knowledge of remembering the abuse beforehand, while the remaining one remained uncertain. All of the cases experienced “discovering” memories. All of the individuals’ experiences of discovered memory were characterized by feelings of suddenness, followed by an immediate unpacking, and an emotional rush. Given these experiences, Schooler (2001) found that when the individuals recalled experiences of abuse, they were reported to either have feeling like they had discovered the existence of the memory itself or remembered the memory under a different perspective/lens of meaning. Essentially, the individuals felt that the emotional rush of remembering memories of abuse was so prominent that they believed they would have remembered doing it before, but had in fact entirely forgotten previous recollections of the memories. Schooler (2001) proposed the phenomenon be termed the “Forgot-it-all-along” (FIA) effect.

Arnold and Lindsay (2002) wanted to further investigate the ideas of Schooler (2001) in a controlled laboratory setting. They conducted research in which they further studied the FIA effect by using verbal material (i.e., homographic word pairs; “*hand – palm*”). With the example word pair of “*hand – palm*”, “palm” would be considered the target word, while “hand” would be considered the cue word. Cue words were meant to establish the meaning, or context, of the target words, and in turn, establishing a semantic context. The basic format of all experiments conducted within the study included a study phase, first cued-recall test (Test 1), and second cued-recall test (Test 2).

In the study phase, participants studied a list of homographic target words paired with a disambiguating cue word. In Test 1, participants were tested on most, but not all the target words. During this test, half of the target words were cued with the original studied cue words, while the other half were other cue words to establish a different context. Using the “*hand – palm*” word pair as an example, if the target word “palm” was paired with “hand” in the study phase, during the first cued recall test, “palm” could be presented with the same cue word “hand”, or with another cue word like “tree”. Pairing “palm” with “hand” would reestablish the original studied context, while pairing “palm” with “tree” would establish a different context than what was originally studied. After this first cued-recall test, participants completed Test 2. This test differed from Test 1 in that participants were tested on all of the target words with their original studied cue word. During Test 2, participants were also instructed to determine whether or not they had previously recalled each item during Test 1 (Arnold & Lindsay, 2002). This design allowed them to measure memory for prior remembering when the context stayed the same versus when it changed between Tests 1 and 2.

Experiments 1, 2, and 4 were designed to test the FIA effect by the manipulation of the context and meaning of the words for the studied homographs. Experiment 3 was designed to test the FIA effect by manipulation of the context, but not meaning of the studied words (Arnold & Lindsey, 2002). It was found that participants more often forgot previous instances of remembering a studied target word when there were changes in semantic context versus when context stayed the same (Arnold & Lindsay, 2002). This finding supports the existence of the FIA effect previously described by Schooler (2001) and that it results from changes in how people experience memory retrieval.

Given the relationship between pupil dilation, emotion, and memory, presented by the previous studies (Bradley & Lang, 2015; Heaver & Hutton, 2011; Võ et al., 2008), it could be informative to use pupil dilation as a measure to better understand whether a relationship also exists between pupil dilation and memory for prior remembering. Thus, I aimed to replicate the study conducted by Arnold and Lindsay, with the extension of whether pupil dilation may be associated with prior remembering by assessing individuals’ memory recall with negative and neutral image-word pairs. First, I predict that there will be greater pupil dilation for emotional context image-word pairs than neutral context image-word pairs. Next, I predict that there will be greater pupil dilation for correctly remembered words than incorrectly remembered words. Next, I predict that there will be greater pupil dilation for correct memory for prior remembering judgments than incorrect memory for prior remembering judgments. Lastly, I predict that emotion will attenuate the effects of memory difference in pupil dilation between remembered and forgotten words, and furthermore, will be attenuated for negative context words relative to neutral words.

Methods

Participants

Participants (*N* = 44) were recruited through the SONA online participant management system. Participants consisted of undergraduate students in General Psychology classes at University of Mary Washington. Other participant demographic information was lost due to experimenter error. Participants were assumed to have normal or corrected-to-normal vision. Participants received one credit towards their class as compensation for participating in this study.

Apparatus

To track eye movements and changes in pupil size, the Gazepoint GP3 SD Eye-Tracker was used. It has a sampling rate of 60Hz, meaning the eye-tracker samples sixty images per second of an individual's eyes and pupils to track its movements and changes in size. The eye-tracker utilizes infrared light to image and track the pupil, while the scanner uses reflected light to calculate the specific point to which participants are looking.

Materials

***Personality Assessment Inventory (PAI-ANX, PAI-DEP; Morey 1991)*[1]**

Participants first completed the Personality Assessment Inventory (PAI)-Anxiety subscale (Morey, 1991), followed by the Depression subscale. The Anxiety subscale has 21 questions measuring participants' levels of anxiety on a 4-point scale ranging from "False, Not at all true" to "Very True." The Depression subscale has 27 questions measuring participants' levels of depression on a 4-point scale ranging from "False, Not at all true" to "Very True." The PAI has been shown to have high reliability (Morey, 1991) and discriminant and construct validity (Boyle & Lennon, 1994). The validity for each subscale was calculated for the present study and both showed good internal reliability, with a Cronbach's alpha of .92 for the Anxiety subscale, and .89 for the Depression subscale.

***White Bear Suppression Inventory (WBSI; Wegner & Zanakos, 1994*)[2]**

Participants also completed the White Bear Suppression Inventory (WBSI). The WBSI has 15 questions measuring a person's tendency to engage in thought suppression on a 5-point Likert scale ranging from "Strongly Disagree" to "Strongly Agree." The WBSI shows good internal reliability with a Cronbach's alpha of .87-.89 across multiple samples (Wegner & Zanakos, 1994). In the present study, I observed a high level of internal reliability with Cronbach's alpha of .89.

Stimuli

The images used as context images in the present study were sourced from the International Affective Picture System (IAPS, Lang et al., 2001), Geneva Affective Picture Database (GAPED, Dan-Glauser & Scherer, 2011), and Nencki Affective Picture System

[1] The present study was conducted as an extension to a PSYC 492 behavioral study. Due to this, the PAI was completed by participants, but was not included in any analyses in the present study.
[2] The present study was conducted as an extension to a PSYC 492 behavioral study. Due to this, the WBSI was completed by participants, but was not included in any analyses in the present study.

(NAPS, Marchewka et al., 2014). The present study categorized images under “neutral” in context and “emotional” in context. Emotional images were found to be more emotional in nature than neutral images. Examples of emotional images include dismembered limbs and dead animals. All context images were counterbalanced for emotionality across phases of the experiment in the sense that half of the image-word pairs were presented as emotional in context and the other half were presented as neutral in context. Every word appeared in each context the same number of times across all phase of the experiment.

Procedure

After signing in on a sign-in sheet and completing the informed consent form, participants were directed to complete two questionnaires (PAI-ANX, PAI-DEP, and WBSI) on the computer. After completing the questionnaires, participants’ positioning were adjusted to optimize the eye-tracker tracking their eyes. On average, participants were sat 68.58cm from the monitor screen. participants’ pupils were calibrated to the Gazepoint eye tracker to record eye movements and changes in pupil size. Participants were instructed that a series of 9 circles would be presented on the screen and that they should focus on each one as it appears. After calibration, the data collection portion of the experiment began, during which eye movements and pupil changes were recorded. The remainder of the experiment was automated by E-Prime 3.0 software.

The first phase of the experiment was a study phase. During the study phase, participants saw 102 image-word pairs (For complete list of target words, see Appendix B). All image sizes were standardized to be 14.61cm in length horizontally and 8.26cm in length vertically. The words on average were sized 3.81cm in length horizontally. The images subtended 12.16˚ by

6.89˚ of visual angle. The words subtended 3.18˚ of visual angle. The first and last three image-word pairs were buffers across participants and were not tested. Half of the words were initially studied in each of the possible contexts. Participants were instructed to remember the words and to attend to the images associated with the words. Participants had four seconds to encode each image-word pair. The second phase of the experiment was the first cued-recall test (Test 1). During this first cued-recall test, participants saw 64 image-word pairs. Half of the presented words were paired with emotional context pictures, while the other half were paired with neutral context pictures. The assignment of pairs to Emotionality condition was counterbalanced across the experiment. For this experiment, the pictures are considered the memory cues and the words are considered targets. During Test 1, picture-cues were either the picture originally encoded with the word, or a picture related to the word that was not previously seen. As an example, the word "cherry" could be presented in the study phase. During the study phase, "cherry" could be paired with a picture of red-orange cherries that served as a neutral context. During a trial in Test 1, the picture paired with "cherry" could be the same picture from the study phase if it were a same-context trial, or the image could have changed. In this case, the changed context would be emotional in nature, with the presentation of a cut-open cherry with a maggot inside (See Figure A2, Appendix A). One-third of the words were tested with the same image, one-third were tested with a different image, and one-third were not tested. The assignment of target words to these conditions was counterbalanced across versions of the experiment. The target located below the picture was presented as the first and last letters of a target word separated by underscores in place of each other letter. For example, the target word "cherry" was represented by the cue "c _ _ _ _ y." Participants were instructed to say the word out loud and that their response to the cue should be something they saw during the study phase. The researcher then gave verbal confirmation on whether or not the participant said the correct word. The researcher also input whether the response was “correct” or “incorrect” on the keyboard by pressing 1 or 2 on the number pad, respectively. After receiving feedback, participants were instructed on the computer to rate how each picture made them feel. They rated the valence of the picture on a 5-point Likert-type scale ranging from “Unhappy” to “Happy.” Then, rated the arousal they felt seeing the picture on a 5-point Likert-type scale ranging from “Calm” to “Excited.”

After the first cued-recall test, participants completed a 5-minute distractor task in which they filled out a word-search. Ten seconds before the distractor task ended, participants received a notice on the computer screen that read “Get Ready” to prepare them for the next part of the experiment. The third phase of the experiment was a second cued-recall test (Test 2). Here, participants saw 96 image-word pairs. All the image-word pairs were the same as during the study phase. This means that half of the words were tested in the same context between Test 1 and Test 2 (same-context targets) and half of the words were tested in different contexts between Test 1 and Test 2 (changed-context targets). Participants were again instructed to verbally respond to the cue with a word they remembered from the study phase and received verbal feedback from the researcher. Participants were then asked whether or not they remembered retrieving the word during the first test and were instructed to respond by pressing the “y” key for yes, and “n” key for no. After making these responses, participants were again instructed to rate each picture on both 5-point Likert scales for valence and arousal.

At the end of the experiment, participants were asked to press the ‘x’ key on the keyboard to stop the E-Prime data collection, while the researcher manually stopped the collection of eye-tracking data. Participants were then given a debriefing form and a set of comics for amusement to mitigate any emotional distress that may have occurred during the experiment. Finally, the participants were thanked for their time, handed a pink slip as a paper receipt of their credit, and granted credit through SONA.

Results

Pupil dilation analyses were run based on participants' memory performance across the experiment which can be found in Table 1. It should be noted that no data was recorded when participants blinked their eyes. Given emotional images were rated to be more arousing than neutral images, neutral image-word pairs were assumed as "baseline".

To explore the effects of cued-recall accuracy and emotionality on pupil dilation during Test 1, a 2 (Accuracy: correct and incorrect) x 2 (Emotionality: emotional and neutral) within-subjects ANOVA was performed on average pupil dilation (in millimeters) during Test 1. When conducted, Mauchly's Test of Sphericity was inconclusive, and a Greenhouse-Geisser correction was applied to all effects. A significant main effect of accuracy was found, $F(1, 36) = 6.64$, $p = 0.01$, $\eta^2 = 0.16$. Participants had significantly larger pupil dilation when cued recall was incorrect (M = 4.16) than when it was correct (M = 4.06). Both the main effect of emotionality ($F[1, 36] = 3.05$, $p = 0.09$, $\eta^2 = 0.08$) and interaction effect of emotionality and accuracy ($F[1, 36] = 2.70$, $p = 0.11$, $\eta^2 = 0.07$) were not found to be significant. Pupil dilation for emotional words did not differ from pupil dilation for neutral words. Pupil dilation also did not differ among correct or incorrectly remembered emotional and neutral words.

Table 1.

Averaged Accuracy for Emotionality and Context across Tests and MPR

Test 1		
	Neutral	Emotional
Same	.95 (.01)	.94 (.01)
Changed	.84 (.02)	.93 (.01)

Test 2		
	Neutral	Emotional
Same	.97 (.01)	.96 (.01)
Changed	.97 (.01)	.96 (.01)
MPR		
	Neutral	Emotional
Same	.93 (.01)	.93 (.02)
Changed	.73 (.04)	.73 (.04)

Note. The table above reflects averaged accuracy scores across emotionality and context conditions for Test 1, Test 2, and Memory for Prior Remembering judgments. Numbers reflect mean accuracy as a proportion of correct responses with standard error of the mean in parentheses.

To explore the effects of cued-recall accuracy and emotionality on pupil dilation during Test 2, a 2 (Accuracy: correct and incorrect) x 2 (Emotionality: emotional and neutral) within-subjects ANOVA was performed on average pupil dilation during Test 2. When conducted, Mauchly's Test of Sphericity was inconclusive, and a Greenhouse-Geisser correction was applied to all effects. The main effect of accuracy was not found to be significant, $F(1, 43) = 0.82$, $p = 0.37$, $\eta^2 = 0.02$. Pupil dilation for correctly remembered words did not differ from pupil dilation for incorrectly remembered words. The main effect of emotionality was also not found to be significant, $F(1, 43) = 2.50$, $p = 0.12$, $\eta^2 = 0.05$. Pupil dilation for emotional words did not differ from pupil dilation for neutral words. The interaction effect of emotionality and accuracy was not found to be significant, $F(1, 43) = 0.17$, $p = 0.68$, $\eta^2 = 0.004$. Pupil dilation did not differ among correct or incorrectly remembered emotional and neutral words.

To explore the relationship between pupil dilation and memory for prior remembering (MPR), a 2 (Accuracy: correct and incorrect) x 2 (Emotionality: emotional and neutral) x 2 (Context on Test 1: same and changed) within-subjects ANOVA was performed on average pupil dilation during Test 2. When conducted, Mauchly's Test of Sphericity was inconclusive, therefore a Greenhouse-Geisser correction was applied to all effects. The main effect of accuracy was not found to be significant, $F(1, 14) = 0.58$, $p = 0.46$, $\eta^2 = 0.04$. Pupil dilation for correct judgments of MPR did not differ from pupil dilation for incorrect judgments of MPR. The main effect of emotionality was also not found to be significant, $F(1, 14) = 0.58$, $p = 0.46$, $\eta^2 = 0.04$. Pupil dilation for emotional words did not differ from pupil dilation for neutral words. The main effect of Context on Test 1 was not found to be significant, $F(1, 14) = 0.22$, $p = 0.65$, $\eta^2 = 0.02$. Pupil dilation did not differ between changed-context targets and same-context targets. The interaction effect of emotionality and accuracy was not found to be significant, $F(1, 14) = 0.32$, $p = 0.58$, $\eta^2 = 0.02$. Pupil dilation did not differ among correct or incorrect judgments of MPR for emotional and neutral words. The interaction effect of accuracy and Context on Test 1 was not found to be significant, $F(1, 14) = 0.84$, $p = 0.37$, $\eta^2 = 0.06$. Pupil dilation did not differ among correct or incorrect judgments of MPR for changed-context and same-context words. The interaction effect of emotionality and context on Test 1 was not found to be significant, $F(1, 14) = 0.03$, $p = 0.86$, $\eta^2 = 0.002$. Pupil dilation did not differ among emotional and neutral same-context words and changed-context words. The interaction effect of emotionality, accuracy, and context was not found to be significant, $F(1, 14) = 0.22$, $p = 0.65$, $\eta^2 = 0.02$.

Discussion

In the present study, I aimed to assess the relationship between pupil dilation and memory for prior remembering. I first predicted that there would be greater pupil dilation for emotional image-word pairs versus neutral image-word pairs. This hypothesis was not supported by the data. Next, I predicted greater pupil dilation for correctly remembered words than incorrectly remembered words. While there was a difference between correctly and incorrectly remembered words during Test 1, the direction was opposite of this prediction. Next, I predicted greater pupil dilation for correct memory for prior remembering judgments than for incorrect memory for prior remembering judgments. This hypothesis was not supported by the data. Lastly, I predicted that the addition of emotion would reduce the effect of memory performance in pupil dilation with correctly remembered and incorrectly remembered words, while also being reduced for negative context words relative to neutral words. There was no significant interaction between emotion and accuracy on pupil dilation, failing to support that hypothesis.

First, I found there to be no difference in pupil dilation between emotional and neutral image-word pairs. This finding is in contrast to previous literature (Kinner et al., 2017; Bradley & Lang, 2015), in which pupil dilation was often greater for emotional stimuli versus neutral stimuli. This could be due to conflicts with the analyses conducted, specifically in the sense that they did not account for time. Many studies (e.g., Bradley & Lang, 2015) conducted on pupil dilation often utilized some form of time-bin analysis, in which they looked at pupil dilation at specific millisecond – second time bins over the course of a single trial. With the current study, we analyzed pupil dilations by averaging dilation across both eyes for a single trial. Any difference between emotional and neutral stimuli could thus have been missed if they differed in time course instead of across a given trial. In another study by Bradley and Lang (2008), they found pupil dilation to be tie to physiological arousal, in that they found pupil changes covaried with skin conductance. Essentially, both pupil dilation and skin conductance were greatest when individuals viewed emotional pictures versus neutral. In the present study, participants gave their valence and arousal ratings towards the context images. Analyses conducted on the valence and arousal ratings were included as part of a PSYC 492 behavioral study, of which found that arousal ratings did not differ. There being no difference in arousal ratings across context images could help explain why no pupil dilation was observed for emotional stimuli in the present study.

Second, I predicted that there would be greater pupil dilation for remembered words than forgotten words. While I could not find support for the direction of this prediction, there was a significant finding during Test 1. It was found that there was greater pupil dilation for incorrectly remembered words in comparison to correctly remembered words during Test 1. This finding contrasted with previous literature (Bradley & Lang, 2015; Heaver & Hutton, 2011; Võ et al., 2008) that highlighted the pupil old/new effect, in which pupil dilation was greater for old versus new stimuli. This could be due to the type of memory test used. The current study was designed to test participants using cued-recall tests. This design was different from previously mentioned studies (Bradley & Lang, 2015; Heaver & Hutton, 2011; Võ et al., 2008) that utilized recognition tasks when analyzing the effects of pupil dilation. In the present study, participants were given a study phase, and then a cued-recall phase, indicating that participants only tried to recall words they had seen before. This would mean that over the course of the experiment, there were no "new" stimuli that were presented as would be found in a recognition test. While the context of the words changed throughout the experiment, the words were always "old". The pupil old/new effect, as previously described, highlights the presence of "old" stimuli being tested against "new" stimuli that have never been seen before. With this, one could argue that because of the consistent use of "old" stimuli across the course of the experiment, pupil dilation effects on memory may not apply to cued-recall the same way as recognition.

Lastly, I predicted that the addition of emotion would reduce the effects of memory performance on pupil dilation, further reducing the difference in pupil dilation for emotional and neutral context words. There was no support found for pupil dilation differing across emotionality, accuracy, and memory for prior remembering. This finding could be due to the nature of repeated presentations of stimuli. In their study, Bradley and Lang (2015) analyzed the effects of scene repetitions on pupil diameter. They found that scene repetition had varying effects on pupil dilation depending on the nature of the scenes. For example, they used erotic and violent scenes as part of their experiment. They found that there was no effect on pupil diameter when violent scenes were repeated, while they found modulated effects on pupil diameter in response to the erotic scenes. They also repeated scenes that displayed everyday events, essentially using these scenes as a neutral condition (Bradley & Lang, 2015). They found no effects on pupil diameter even with the repetition of everyday scenes. This could be tied to the current study in the sense that initial exposure to a stimulus could produce the greatest variation in pupil dilation for neutral and emotional pictures. With the current study, only the cued-recall tests were analyzed instead of the study phase in which initial exposure to the stimuli occurred. Thus, the lack of interaction could have resulted from multiple exposures, affecting emotional and neutral pictures the same way. Another avenue for potential analyses could also lie in memory for prior remembering judgments part of the experiment in Test 2. As previously mentioned, pupil dilation was only analyzed during the cued-recall portion of the tests. It is possible we could have seen variation in pupil dilation when participants were actively making the judgment for memory for prior remembering, possibly allowing optimization for accurately reflecting the pupil old/new effect in that way.

Given these effects of analyses, test type, and repetition of scenes, this provides an explanation for not finding a relationship between pupil dilation and memory for prior remembering. Memory for prior remembering involves the use of repeated stimuli and would also not be considered a test of recognition memory. Given the relationship between context and memory for prior remembering (Arnold & Lindsay, 2002), it is known that judgments are not based on recognition alone.

For the benefit of future research, certain aspects of the experiment could be improved. For example, analyses could be run using time-bins, instead of averages for pupil dilation as done in the present study. Utilizing time-bins could aid in analyzing pupil dilations more closely across the span of a single, given trial, thus potentially allowing for more variation to be seen. Future research could also utilize recognition tests, of which are in line with other research conducted on pupil dilation. The use of recognition teste would allow a clear distinction between "old" stimuli and "new" stimuli, of which would thus highlight the pupil old/new effect. It could also be beneficial to utilize block trials, in which trials would be separated into distinct emotional versus neutral blocks. The use of blocked trials could help in the sense that stimuli would then not be mixed together, thus potentially leading to inconsistent variations in pupil dilation. Finally, given previous research has suggested that pupil dilation is tied to physiological factors, it could be beneficial to add skin conductance and luminance analyses. Within the present study, there may have been differences with regards to luminance between emotional and neutral pictures that could have contributed to washing out any pupil effects (Cherng et al., 2020). Further research using cued-recall paradigms could demonstrate that the relationship between pupil dilation and memory performance is due to the type of test being used.

References

Arnold, M. M., & Lindsay, D. S. (2002). Remembering remembering. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *28*(3), 521.

Boyle, G. J., & Lennon, T. J. (1994). Examination of the reliability and validity of the Personality Assessment Inventory. *Journal of Psychopathology and Behavior Assessment*, *16*(3), 173-188.

Bradley, M. M., & Lang, P. J. (2015). Memory, emotion, and pupil diameter: Repetition of natural scenes. *Psychophysiology*, *52*(9), 1186-1193.

Bradley, M. M., Miccoli, L., Escrig, M. A., & Lang, P. J. (2008). The pupil as a measure of emotional arousal and autonomic activation. *Psychophysiology*, *45*(4), 602-607.

Cherng, Y.-H., Baird, T., Chen, J.-T., & Wang, C.-A. (2020). Background luminance effects on pupil size are associated with emotion and saccade preparation. *Scientific Reports, 10,* Article 15718. https://doi.org/10.1038/s41598-020-72954-z

Dan-Glauser, E. S., & Scherer, K. R. (2011). The Geneva affective picture database (GAPED): a new 730-picture database focusing on valence and normative significance. *Behavior Research Methods, 43,* 468-477. https://doi.org/10.3758/s13428-011-0064-1

Heaver, B., & Hutton, S. B. (2011). Keeping an eye on the truth? pupil size changes associated with recognition memory. *Memory*, *19*(4), 398–405.

Kinner, V. L., Kuchinke, L., Dierolf, A. M., Merz, C. J., Otto, T., & Wolf, O. T. (2017). What our eyes tell us about feelings: Tracking pupillary responses during emotion regulation processes. Psychophysiology, 54(4), 508–518. https://doi.org/10.1111/psyp.12816

Marchewka, A. Zurawski, L., Jednorog, K., & Grabowska, A. (2014). The Nencki Affective Picture System (NAPS): introduction to a novel, standardized, wide-range, high-quality, realistic picture database. *Behavior Research Methods, 46,* 596-610. doi: 10.3758/s13428-013-0379-1

Mathôt S. (2018). Pupillometry: Psychology, Physiology, and Function. *Journal of cognition*, *1*(1), 16. https://doi.org/10.5334/joc.18

Morey, L. C. (1991). The Personality Assessment Inventory: Professional manual. Odessa, FL: Personality Assessment Resources.

Onoda, K., Okamoto, Y., & Yamawaki, S. (2009). Neural correlates of associative memory: The effects of negative emotion. Neuroscience Research, 64(1), 50–55. https://doi.org/10.1016/j.neures.2009.01.008

Schooler, J. (2001). *Discovering memories in the light of meta-awareness*. Journal of Aggression, Maltreatment & Trauma, 4(2).

Võ, M. L. H., Jacobs, A. M., Kuchinke, L., Hofmann, M., Conrad, M., Schacht, A., & Hutzler, F. (2008). The coupling of emotion and cognition in the eye: Introducing the pupil old/new effect. *Psychophysiology*, *45*(1), 130-140.

Wegner, D. M., & Zanakos, S. (1994). Chronic thought suppression. *Journal of personality*, *62*(4), 615-640.

Appendix A

Context Images

Below are two sets of examples of emotional and neutral context images. These images may be emotionally distressing in nature.

Figure A1. The above image is the "neutral" context image used for the target word "cherry".

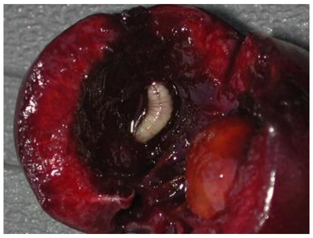

Figure A2. The above image is the "emotional" context image used for the target word "cherry".

Figure A3. The above image is the "neutral" context image used for the target word "astronaut".

Figure A4. The above image is the "emotional" context image used for the target word "astronaut".

Appendix B

Target Word List

Below is the complete list of 102 target words used throughout the experiment. In the study phase, participants saw all target words paired with context images, with the first and last three pairs being buffers (e.g., crocodile, dam, karate, tattoo, butterfly, and violin) that were not tested. Each word had two associated images (i.e., one neutral and one emotional).

Astronaut
Baby
Barn
Bathroom
Belt
Bicycle
Biker
Bird
Boat
Book
Boots
Bottle
Boxing
Boy
Bridge
Building
Carrots
Carry
Cat
Chain
Chair
Cherry
Chess
Chicken
Church
City
Clouds
Cow
Deck
Deer
Dessert
Dog
Doll
Dolphin
Duck
Elderly
Eyes
Face
Fence
Field
Fire
Firefighter
Fish
Flowers
Foot
Frog
Hammer
Hand
Helmet
Horse
Hospital
Jar
Kangaroo
Keyboard
Kitchen
Lake
Leaves
Loaf
Man
Mansion
Mask
Moose
Mouth
Mushroom
Needle
Pan
Pizza
Plane
Plate
Pumpkin
Rabbit
Race
Row
Sand
Seal
Search
Shadow
Shark
Sheep
Skeleton
Sleep
Snow
Soccer
Soldier
Stairs
Suitcase
Tiger
Towel
Train
Tree
Turtle
Vehicle
Watch
Water
Window
Woman