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Attend to Compete or Compete to Attend: The Possible Role of Attention in Processing Competing Stimuli Within Visual Working Memory

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OPEN DATA

Some stimuli (e.g., objects, scenes, faces) are consistently remembered better than others across individuals, due to variations in memorability (the stimulus-intrinsic property that determines ease-of-encoding into visual long-term memory). Within visual working memory (VWM), memorable stimuli enjoy a dual benefit: they are stored more efficiently (observers can store more memorable than forgettable stimuli) and are more competitive (when memorable and forgettable stimuli need to "compete" for limited VWM resources, the memorable stimuli are more likely to "win" access to those resources). Given the link between attention and VWM, we examined attention as a candidate for the source of the competitive benefit. In experiment 1, we investigated if observers selectively attend to memorable stimuli when encoded along with forgettable during a VWM task. Using a letter report probe task that enabled us to index where attention was allocated during encoding, we found that attention was drawn to memorable faces, but not via automatic attentional capture. In experiment 2, we determined the time course of attention allocation in relation to the emergence of the competitive benefit by manipulating the encoding duration of memorable and forgettable stimuli. The competitive benefit did not emerge until *after* there were differences in attention allocation, ruling out the possibility that the difference in attention allocation was caused by the competitive benefit within VWM. We speculate that the competitive benefit is a result of attentional differences between memorable and forgettable stimuli. Importantly, we find that attention *can* interact with stimulus memorability.

Keywords: memorability, visual working memory, attention, spatial attention

Supplemental materials: https://doi.org/10.1037/xlm0001490.supp

Humans have a remarkable ability to remember large numbers of images in visual long-term memory (VLTM), including scenes, faces, and objects in high detail, often after only a single eposure (Brady et al., 2008; Standing, 1973). Memory is frequently studied using a subject-centric approach, examining differences in the efficacy of and the quality of memory encoding, storage, and retrieval processes. However, a subject-centric approach only captures a portion of the variability in memory performance because it ignores stimulus-intrinsic factors that can influence memory (Bainbridge, 2022). Not all images are remembered equally well, and some images are more likely to be remembered than others (Fukuda & Woodman, 2015; Sundby et al., 2019; Tozios & Fukuda, 2019). Interestingly, what stimuli people tend to remember or forget is highly consistent across different observers (e.g., Bainbridge et al., 2013, 2017;

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The data are available at https://osf.io/7jpvf/
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Bainbridge, 2020; Goetschalckx et al., 2018; Isola et al., 2011, 2014; Kolisnyk et al., 2023; Ongchoco et al., 2023; Saito et al., 2023), despite differences in the type and quality of VLTM encoding processes any one individual may experience (i.e., the subject-centric differences). These consistencies in VLTM encoding success and failure demonstrate the existence of a stimulus-intrinsic property that renders an image as memorable or forgettable. As a result of this property, some stimuli are inherently more memorable (i.e., have a higher probability of being recognized on a memory test after encoding) than other stimuli. Memorability has also been found across a broad range of stimulus types, including faces (Bainbridge, 2020; Bainbridge et al., 2013, 2017; Gillies et al., 2023; Ye et al., 2024), objects (Gillies et al., 2023; Green et al., 2023; Kolisnyk et al., 2023; Torres et al., 2024), scenes (Isola et al., 2011, 2014), dance sequences (Ongchoco et al., 2023), and paintings (Davis & Bainbridge, 2022). By utilizing multiple frameworks, we can better predict and understand fluctuations in (or ways to improve) memory performance.

Memorability Cannot Be Fully Explained by a Set of Perceptual Attributes

What makes a stimulus memorable or forgettable? When controlling for low-level features such as color or spatial frequency, or high-level properties such as emotional content, scene content, stimulus category, and attractiveness (for face stimuli), differences in memorability continue to persist (Bainbridge, 2020; Bainbridge et al., 2017; Isola et al., 2014; Kramer et al., 2023). For face stimuli, a combination of social and personality characteristics (e.g., attractiveness, trustworthiness) of the face explain only around 25% of the variance in memory performance (Bainbridge et al., 2017), leaving a large majority of variance unexplained. Memorability is also separable from other phenomena known to influence memory, such as bottom-up attentional capture. In visual search tasks, memorable stimuli do not "pop out" more than forgettable stimuli (Bainbridge, 2020). In sum, memorability is not fully captured by the salience of the stimulus. If memorability is not a purely perceptual property of an image, then when might it emerge during the memory encoding process?

When Does the Stimulus Memorability Benefit Emerge?

Recently, we examined at what stage of VLTM encoding memory representations of memorable stimuli become distinguishable from their forgettable counterparts (Gillies et al., 2023). As VLTM encoding is gated by the capacity limited visual working memory (VWM) system (R. C. Atkinson & Shiffrin, 1968; Cotton & Ricker, 2021; Forsberg et al., 2021; Fukuda & Vogel, 2019), we tested the hypothesis that the memorability benefit emerges during VWM. The memorability benefit can best be described as the *outcome* of stimulus memorability. The memorability scores (likelihood of an item being recognized on a VLTM task) of the items are known, and we are examining how this property influences performance on a VWM task.

To test this, participants encoded groups of face or object stimuli that were known to be highly memorable or forgettable in VLTM (Bainbridge et al., 2017; Kolisnyk et al., 2023) in a VWM recognition task. We found that, within VWM, memorable stimuli receive a dual benefit. First, they are maintained more efficiently in VWM than forgettable stimuli and require fewer VWM resources to be represented (we have called this the "efficiency benefit"). More specifically, participants could recognize more memorable than forgettable stimuli on a VWM task. Second, memorable stimuli were more "competitive" than forgettable ones. When memorable and forgettable stimuli need to be encoded together for a VWM task, the memorable stimuli are more likely to "win" access to the limited VWM resources (we have called this the "competitive benefit"). Within VWM, both the efficiency and competitive benefit contribute to the overall "stimulus memorability benefit." This competitive benefit within VWM is the focus of our current article.

What Is the Origin of the Competitive Benefit Within VWM?

The primary interest of the current research is on the origin of this competitive benefit. Stimuli are rarely presented in isolation in everyday life, and because of this, understanding how combinations of different stimuli influence cognitive processes within our capacity-limited mental workspace is theoretically meaningful.

One possible candidate for the origin of the competitive benefit is attention. Previous research has demonstrated that items that are attended to in a VWM task are more likely to be recognized later on (Desimone & Duncan, 1995; Emrich et al., 2017; Sperling, 1960). For example, when trying to remember an array of letter stimuli, cueing attention toward some of those stimuli improves performance on those items (Sperling, 1960). Conversely, items that are not attended to suffer costs: unattended items are remembered more poorly than items that were attended, and also compared to when attention was not directed toward a particular stimulus (Carrasco, 2011).

Is attention a possible candidate for the origin of the competitive benefit? More specifically, do memorable stimuli attract attention, thereby increasing memory performance? If attention is drawn towards the memorable stimuli, when may this occur? Is it immediate, due to bottom-up attentional mechanisms (e.g., due to perceptual differences between memorable and forgettable stimuli)? Or would attention be drawn toward memorable stimuli later on during encoding?

There is some evidence to suggest that memorable stimuli do not automatically capture attention (Bainbridge, 2020). Bainbridge (2020) investigated if memorability was due to bottom-up processes such as attentional capture by using a visual search paradigm. Participants viewed arrays of memorable and forgettable face stimuli and searched for a target. If memorable faces capture attention, reaction times should be faster when the target face is memorable, or the search may be slowed if memorable distractors are present. Though memorable targets were found more quickly, memorable stimuli did not "pop out" more so than forgettable stimuli (reaction time increased with set size regardless of the target's memorability). Broadly, these results suggest that while memorable stimuli may capture attention, they do not cause automatic "pop-out" capture.

Experiment 1: Is Attention Preferentially Allocated to Memorable Stimuli?

The primary goals of Experiment 1 are to determine (a) if attention is biased towards memorable stimuli when encoded alongside forgettable stimuli and (b) the point in time during VWM encoding when this attentional bias occurs. For the VWM task, observers encoded six faces for 2,000 ms (the duration used in Gillies et al., 2023), and we manipulated the memorability and degree of competition amongst the stimuli. To examine competition between memorable and forgettable stimuli, on some trials, participants viewed three memorable and three forgettable stimuli (mixed condition). Six stimuli are supra-VWM capacity (Gillies et al., 2023; Jackson & Raymond, 2008; Luck & Vogel, 1997), such that the stimuli will need to compete with one another for access to the limited resource pool. As we needed to ensure participants attempted to encode the faces, the VWM task occurred in 77% of trials.

To examine attention allocation during encoding, we intermixed a letter probe task (capture-probe paradigm), adapted from Gaspelin et al. (2015), in the remaining 23% of the trials. Broadly, this task provides information about the allocation of processing resources at multiple locations in a stimulus array (Gaspelin et al., 2015; Lien et al., 2022; Talcott et al., 2022). In Gaspelin et al. (2015), observers searched for a target shape while ignoring color singleton distractors. On a subset of trials, the search array appeared, and after 200 ms, letters then appeared on top of the shapes in the search array for 100 ms. Subsequently, participants were asked to report all the letters they remembered seeing in the preceding display (free recall). We used a similar version of this letter probe task for the present study. Importantly, this probe task allowed us to gather detailed information about where attention was allocated at the moment the letter probes were presented.

Specifically, in our adopted version of the letter probe task, letter probes were briefly presented in the same locations as the face stimuli, and participants reported all the letter(s) they recalled seeing. As we wanted to see how attention allocation may change over the entire encoding duration of 2,000 ms, we split the full encoding duration into four time points (150, 450, 900, and 1,500 ms). As we were interested in differences in attention allocation between memorable and forgettable faces, the probe trials only ever followed the mixed condition. On the probe task trials, three memorable and three forgettable faces were shown at those durations, and the letters were presented after. This probe task enabled us to determine where attention was allocated at these different time points (Gaspelin et al., 2015; Lien et al., 2022; Talcott et al., 2022). As stated earlier, the probe task occurred on 23% of the total trials.

If attention is preferentially drawn to the memorable faces, then participants should recall more probe letters that were in the same location as the memorable faces (“memorable probes”) than probe letters that were in the same location as the forgettable faces (“forgettable probes”). If attention is immediately drawn to memorable stimuli (e.g., via automatic capture of attention), this difference would occur at shorter face stimuli durations. If attention is drawn towards the memorable stimuli later during encoding, this difference would occur at longer face durations (i.e., after 150 ms). As there is some evidence that memorable stimuli are no more likely to capture attention than forgettable stimuli (Bainbridge, 2020), we predicted the latter pattern of results.

Method

Participants

Participants were recruited using Prolific (2021). Prolific is an on-demand self-service data collection platform. Each participant provided electronic consent to the protocol approved by the Research Ethics Board of the University of Toronto prior to participation and received monetary compensation for their participation (7.50 pounds/hr). All participants reported fluency in English, normal or corrected-to-normal vision, no color blindness, no history of head injury, no history of mental illness/condition, and no cognitive impairment/dementia.

A total of 166 participants were recruited, and 10 were excluded (see Participant Exclusion Criteria section for details), leaving a final sample size of 156. A priori power analyses were conducted using G*Power3 (Faul et al., 2007) to test the difference between two dependent groups (pure memorable, mixed memorable) using a paired-sample *t*-test, a small effect size (Cohen’s $d = .20$), and an α value of .05. This power analysis was based on finding a larger area under the receiver operating characteristics (ROC) curve (AUC) in the pure memorable compared to the mixed memorable condition (see “Procedure” for a description of our experimental conditions, and “Analysis” for a description of our dependent measures), and thus, we used a one-tailed test. The results showed that a total sample size of 156 was needed to achieve a power of .80 (see also Gillies et al., 2023). For all results, we report the more conservative two-tailed test, but our results are in line with our predictions.

The mean age of the final sample was 30.55 years ($SD = 5.87$), with 57 females and 98 males (one participant declined to disclose their sex). One-hundred forty-three were right-handed, 11 were left-handed, and two were ambidextrous. Fifty-six wore glasses, 20 wore contacts, and the rest wore neither.

Participant Exclusion Criteria

Participants were excluded based on performance. We excluded participants who performed at or below chance on the pure memorable condition (i.e., an AUC of less than .5). The average AUC for the pure memorable condition was .76 (without exclusions). This led to the removal of nine participants.

One additional participant was removed due to their performance on the probe task. On 18 probe trials, they recalled more letters than were on the previous screen (between 7 and 11 letters), suggesting they were not engaged with the task according to the instructions.

We also repeated the below analyses with all 166 subjects (data and analysis available on the Open Science Framework at https://osf.io/7jpvf; Gillies et al., 2025) and found an identical pattern of results.

Apparatus

All data were collected online. Participants were directed from Prolific to Qualtrics (2020) where they read and digitally signed a consent form and answered additional demographics questions. After submitting the consent form, they were redirected to Pavlovia (Peirce et al., 2019). The experiment was coded on Psychopy3 (Peirce et al., 2019). Only desktop or laptop computers were permitted. Participants were asked to do the experiment in a distraction-free environment and sit about arm’s length from the screen, with their computers plugged in and the brightness set to maximum. Participants were asked to maintain fixation on a central cross throughout the experiment. The main purpose of the fixation cross was to ensure participants were looking in the right direction before the onset of the stimuli. Participants could move their eyes during the task, consistent with Gillies et al. (2023) and other VWM studies of stimulus memorability (Green et al., 2023; Torres et al., 2024; Ye et al., 2024).

Stimuli

Face stimuli were taken from Bainbridge et al. (2013). Each face in the image database is associated with a memorability score, defined as the mean difference in the hit rate and false alarm rate. In this context, a "hit" is the probability of saying "old" when the test stimulus was seen previously (old). A "false alarm" is the probability of saying "old" when being shown a test stimulus that was not seen previously (new). We selected the top 110 most memorable faces and the top 110 most forgettable faces from the database. The memorable faces had an average memorability score of .71 (range = .64–.88). The forgettable faces had an average memorability score of .14 (range = −.02 to .18). The scores were calculated based on performance on a VLTM task (Bainbridge et al., 2013).

Faces were presented in the middle of a white square scaled to .12 times the screen's height. Stimuli were shown in six of the eight total possible locations on an invisible circle. The diameter of the circle was .70 times the screen's height, and the eight locations were equidistant apart. Face stimuli were not repeated until the entire list of 110 faces had been exhausted. No face repeated between consecutive trials.

Procedure

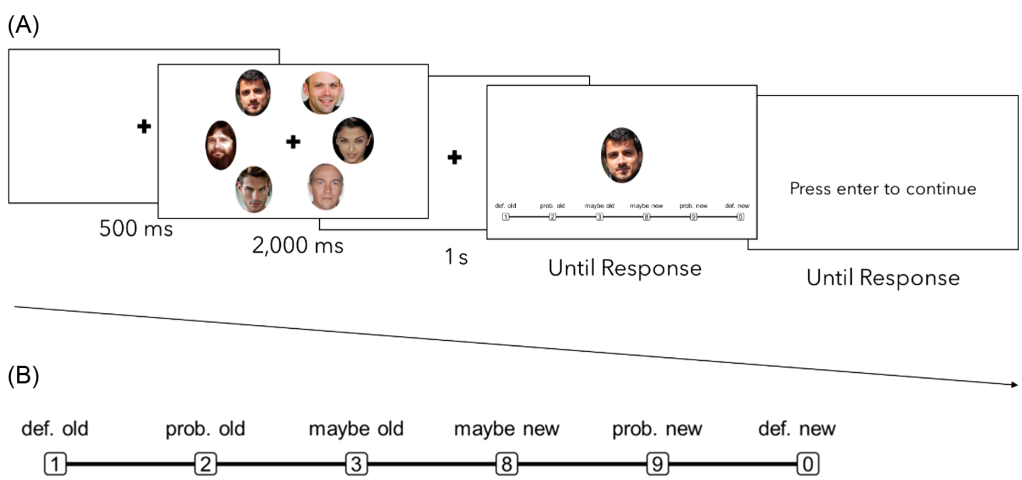
In experiment 1, participants performed both a VWM task and a probe task. There were 208 total trials (160 VWM task trials and 48 probe task trials).

Each trial began with a 500-ms black fixation cross in the center of the screen (.05 times the screen's height), which remained until the response screen appeared. Participants were then shown six face stimuli.

VWM Task. The VWM task occurred on 77% of total trials (see Figure 1). For the VWM task, the faces remained on screen for 2,000 ms. Participants were instructed to remember as many of the faces as they could. Following the faces was a 1,000 ms retention interval, during which only the fixation cross was visible. After the retention interval, one test face was presented in the middle of the screen, and a 6-point scale in the black font was presented below the face. Participants used their keyboards to select one of the six options (1 = *definitely old*, 2 = *probably old*, 3 = *maybe old*, 8 = *maybe new*, 9 = *probably new*, 0 = *definitely new*) to indicate whether the test face was in the preceding array (old) or not (new) and how confident they were in their memory. Responses were not speeded. Participants were then instructed to press the "enter" key to begin the next trial.

Following a mixed display (three memorable and three forgettable faces), the test stimulus had a 50% chance of being old and a 50% chance of being memorable or forgettable. Following a pure display where all the stimuli were memorable, the face had a 50% chance of being old and was always a memorable face. Following a pure display where all the stimuli were forgettable, the face had a 50% chance of being old and was always a forgettable face.

Figure 1
Trial Sequence for the VWM Task



Note. (A) An example of the VWM task procedure. Participants saw six face stimuli in the middle of the screen. The faces could be entirely memorable or forgettable (pure condition), or consist of three memorable and three forgettable faces (mixed condition). Participants were then shown a test face and were asked to indicate if they had seen that face before (old) or not (new) and how confident they were. Face images are from "The Intrinsic Memorability of Face Photographs," by W. A. Bainbridge, P. Isola, and A. Oliva, 2013, *Journal of Experimental Psychology: General, 142*(4), p. 1326 (https://doi.org/10.1037/a0033872). Copyright 2013 by the American Psychological Association. (B) An enlarged schematic of the rating scale participants used to indicate their memory confidence. Def = definitely; prob = probably; VWM = Visual Working Memory. See the online article for the color version of this figure.

In Experiment 1, participants performed 40 trials each of the pure memorable condition, the pure forgettable condition, the mixed memorable condition (three memorable and three forgettable faces were in the array and their memory for a memorable face was tested), and the mixed forgettable condition (three memorable and three forgettable faces were in the array and their memory for a forgettable face was tested). There were 160 total VWM task trials.

Probe Task. The probe task occurred on 23% of total trials (48 of 208 total trials; see Figure 2). For the probe task, the faces remained on screen for 150, 450, 900, or 1,500 ms (12 trials per condition). There were always three memorable and three forgettable faces. Immediately following the faces six red letters (.1 times the screen's height) appeared in the same location as the faces for 100 ms. Letters were randomly selected from the 26 letters of the alphabet (with no replacement) on each trial. Following the letters was a 1,000-ms retention interval, during which only the fixation cross was visible. Note that the retention interval was always 1 s, regardless of the duration of the faces. Next, the response screen appeared, and participants used their keyboards to type out the letters they remembered seeing. Responses were not speeded. Participants were then instructed to press the "enter" key to begin the next trial. There were 48 total probe trials.

The VWM task and probe task trials occurred in an random order for a total of 208 trials.

Analysis

An error in the experiment code resulted in duplicate faces being shown on some trials (i.e., two of the same faces could be displayed during encoding, instead of all unique faces). We removed the trials where this occurred prior to analysis. In total, 52 trials (five probe and 47 VWM task trials) of 32,448 trials were removed.

VWM Task. To quantify memory performance, we used the area under the ROC curve (AUC; Stanislaw & Todorov, 1999). The ROC curve is drawn by plotting the cumulative hit rate (the proportion of trials where the participant correctly responded "old" when the stimulus was old) on the *y*-axis against the cumulative false alarm rate (the proportion of trials where the participant said "old" when the stimulus was new) from the highest confidence "old" responses ("definitely old") to the highest confidence "new" responses ("definitely new").

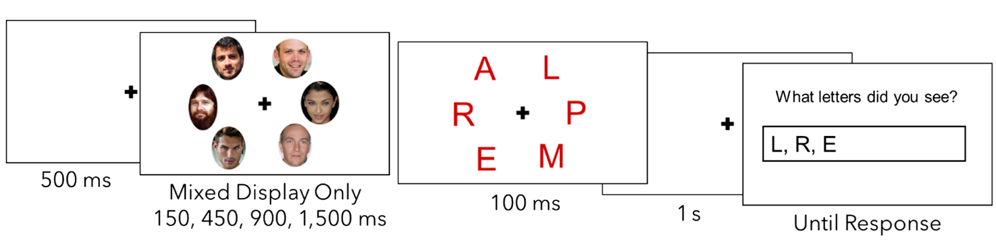
The AUC is equal to one when participants recognized all the encoded information with the highest possible confidence ("definitely old") and rejected all new information with the highest possible confidence ("definitely new"). If participants are unable to discriminate between new and old information, the AUC will be equal to .50. To examine memory performance on the VWM task, we conducted a repeated measures analysis of variance (ANOVA) examining the effects of memorability (memorable, forgettable) and array type (pure, mixed) on AUC. The ANOVA was followed by two planned comparison paired-sample *t*-tests (two-tailed) to examine the difference between the pure memorable and mixed memorable conditions, and the pure forgettable and mixed forgettable conditions.

We also reported the Bayes factor (BF) for each comparison. Specifically, we report BF_{10} for significant results, and values greater than three can be interpreted as substantial evidence in favor of the alternative hypothesis (Wagenmakers et al., 2011). For nonsignificant results, we report BF_{01}, and values greater than three can be interpreted as substantial evidence in favor of the null hypothesis (Jeffreys, 1961; Wagenmakers et al., 2011). Bayesian analyses were conducted using Jeffreys's Amazing Statistics Program, and we used the default priors (Cauchy (0, .707); Wagenmakers et al., 2017).

Probe Task. First, we examined how participants responded across the different stimulus onset asynchronies. More specifically, we wanted to ensure that at short stimulus durations (i.e., at 150 ms) there was no forward-masking (e.g., the perceptual phenomenon where images appearing before the target can interfere with detecting it) from the faces interfering with the letter probe task (e.g., Enns & Di Lollo, 2000; Spencer & Shuntich, 1970). To do this, we examined how the total number of probes correctly recalled changed with the duration of the face stimuli using a one-way ANOVA.

For the probe task, we calculated the average proportion of probes recalled that were presented in the same location as a memorable face and in the same location as a forgettable face for each of the different possible face durations. To determine if and when spatial attention is more likely to be on the memorable faces, we performed four planned comparison paired-sample *t*-tests between the proportion of probes recalled that were in the location of a memorable

Figure 2
Trial Sequence for the Probe Task



Note. An example of the probe task procedure. Participants saw six faces (three memorable and three forgettable, mixed display only) at varying durations (150, 450, 900, or 1,500 ms). The faces were followed by six letters in red font. The letters were presented in the same location as the faces. Letters were present for 100 ms, followed by a 1 s retention interval. After, participants were prompted to type the letters they remembered seeing using their keyboard. Face images are from "The Intrinsic Memorability of Face Photographs," by W. A. Bainbridge, P. Isola, and A. Oliva, 2013, *Journal of Experimental Psychology: General, 142*(4), p. 1326 (https://doi.org/10.1037/a0033872). Copyright 2013 by the American Psychological Association. See the online article for the color version of this figure.

face versus a forgettable face. We also report the corresponding Bayes Factor for each comparison.

Results and Discussion

VWM Task

A 2 (array type: pure, mixed) × 2 (stimulus memorability: memorable, forgettable) repeated measures ANOVA revealed a significant main effect of stimulus memorability, $F(1, 155) = 284.12$, $p < .001$, *partial* $\eta^2 = .65$ (see Figure 3). The memorable stimuli were associated with higher AUCs than forgettable stimuli (i.e., memorable stimuli were more efficiently stored than forgettable). The main effect of array type was not significant, $F(1, 155) = 0.18$, $p = .67$, *partial* $\eta^2 = .001$. There was a significant interaction between array type and stimulus memorability, $F(1, 155) = 48.77$, $p < .001$, *partial* $\eta^2 = .24$.

Planned comparisons revealed that memorable faces had a higher AUC when they were encoded with forgettable faces (mixed condition) compared to when all the faces were memorable (pure condition), $t(155) = 5.96$, $p < .001$, Cohen's $d = .48$, 95% confidence interval (CI) [.31, .64], $BF_{10} = 618{,}084.51$. In addition, forgettable faces were associated with a lower AUC when they were encoded with memorable faces (mixed condition) compared to when they were encoded with all forgettable faces (pure condition), $t(155) = 4.41$, $p < .001$, Cohen's $d = .35$, 95% CI [.19, .51], $BF_{10} = 733.79$. This replicated what was shown in Gillies et al. (2023) where memorable faces are (a) stored more efficiently than forgettable faces, and (b) are also more competitive at drawing VWM resources than forgettable faces.

Probe Task

Overall Accuracy. Given that we observed differences in the total number of probes recalled across the different face durations, we conducted an exploratory one-way ANOVA (stimulus duration: 150, 450, 900, 1,500 ms) to confirm this observation. There was a main effect of stimulus duration on the number of probes correctly recalled, $F(3, 465) = 13.78$, $p < .001$, *partial* $\eta^2 = .082$ (see Figure 4). This was further explored with post hoc analyses.[1] There was no difference in the number of probes accurately recalled between 150 and 450 ms, $t(155) = 0.18$, $p_{\text{bonf}} = 1$, Cohen's $d = .008$. However, people recalled more probes when the faces were on the screen for 450 ms compared to 900 ms, $t(155) = 2.69$, $p_{\text{bonf}} = .045$, Cohen's $d = .13$, and also when the faces were on the screen for 900 ms compared to 1,500 ms, $t(155) = 2.70$, $p_{\text{bonf}} = .04$, Cohen's $d = .13$.

We did not find any evidence of forward masking as participants did not recall fewer letters at shorter stimulus durations. This is not surprising, as our shortest stimulus onset asynchrony was 150 ms, which is outside the narrow time window where forward masking normally occurs (Spencer & Shuntich, 1970).

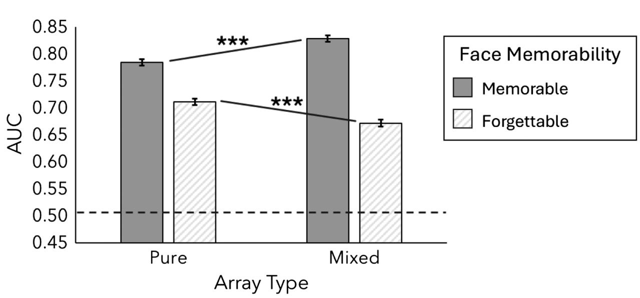
We interpret the number of probes recalled decreasing with increasing durations of the face stimuli to be related to the expectations of a participant during a single trial. From the perspective of the participant, on a single trial the likelihood of any trial being a probe trial decreases the longer the faces are on the screen. At the beginning of a trial, there is an approximate 20% chance of it being a probe trial. However, after 150 ms have passed, there is only a 15% chance of a probe trial, then 10% after 450 ms, and only 5% after 900 ms. These results are in line with research on hazard functions, where participants dynamically adjust expectations of an event occurring over the duration of a trial (de Jong et al, 2024; Moon et al., 2019). Broadly, target detection becomes impaired as the stimulus onset asynchrony between some cue (in this case the faces) and the probe (the letters) increases.

Differences in Attention Allocation. To examine differences in the allocation of attention on the probe task, we compared the proportion of probes recalled at the memorable and forgettable face locations for each face stimulus duration. There was no difference in the proportion of probes recalled at the memorable and forgettable face locations at 150 ms, $t(155) = 0.28$, $p = .780$, Cohen's $d = .02$, 95% CI [−.14, .18], $BF_{01} = 10.78$ (see Figure 5). At 450 ms, people recalled more probe letters at the memorable face locations than the forgettable face locations, $t(155) = 2.56$, $p = .011$, Cohen's $d = .21$, 95% CI [.05, .36], $BF_{10} = 2.11$. The same was true for 900 ms, $t(155) = 3.14$, $p = .002$, Cohen's $d = .25$, 95% CI [.09, .41], $BF_{10} = 9.85$, and 1,500 ms, $t(155) = 2.39$, $p = .018$, Cohen's $d = .19$, 95% CI [.03, .35], $BF_{10} = 1.41$.

Overall, we found that attention was not immediately drawn towards the memorable faces, as there was no difference in attention allocation at 150 ms (despite this being the condition where participants correctly recalled the most probe letters). This is in line with previous literature that found no evidence of automatic attentional capture by memorable stimuli (Bainbridge, 2020). Rather, we found that attention was drawn towards the memorable faces later on in viewing. By at least 450 ms, spatial attention was more likely to be on the memorable faces, as participants recalled significantly more memorable probes than forgettable ones. This effect persisted over time, as attention was still more likely to be on the memorable faces at 900 and 1,500 ms. This result is interesting, as previous work has not found that attention interacts with or contributes to stimulus memorability (Bainbridge, 2020). It is also possible that, despite the equal

Figure 3

VWM Task Results for Experiment 1

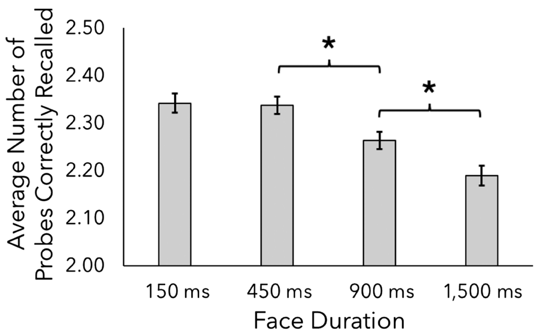


Note. AUC was higher for memorable stimuli than forgettable stimuli (efficiency benefit). There was a significant interaction between memorability and array type in VWM. AUC for memorable stimuli was higher when the memorable stimuli were encoded with forgettable stimuli compared to when all the stimuli were memorable, and AUC was lower for forgettable stimuli encoded along with memorable stimuli compared to when all the stimuli were forgettable (competitive benefit). The dotted line represents the guess rate. Error bars represent Morey's within-subject standard error of the mean (Morey, 2008). VWM = Visual Working Memory; AUC = area under the curve.
*** $p < .001$.

[1] The uncorrected p values for the analysis are as follows: 150 versus 450 ms, $p = .85$; 450 versus 900 ms, $p = .004$; 900 versus 1,500 ms, $p = .006$.

Figure 4

Overall Accuracy for the Probe Task in Experiment 1



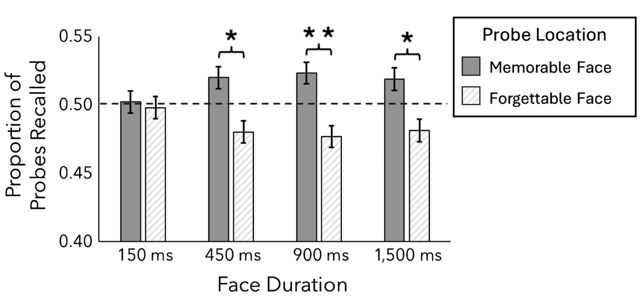
Note. The average number of correctly recalled probes decreased as the duration of the face stimuli increased. This showed that the faces were not interfering with the letter task via forwards-masking at short stimulus durations. Error bars represent Morey's SEM (Morey, 2008). p_{bonf} = Bonferoni correct p value; SEM = standard error of the mean.
* $p_{\text{bonf}} < .05$.

initial allocation of attention across the memorable and forgettable stimuli, attention is more likely to dwell longer on memorable stimuli than forgettable. This is in agreement with our finding that attention was more likely to be on the memorable stimuli from 450 ms to at least 1,500 ms, which is the majority of the encoding time.

If attention is not immediately drawn toward memorable stimuli due to bottom-up mechanisms (e.g., attentional capture), but is instead drawn to memorable stimuli late in viewing (i.e., around 450 ms), then when does the competitive benefit emerge within VWM? More specifically, can we rule out the possibility that the emergence of the competitive benefit is what leads to the differences in attention allocation?

Figure 5

Probe Task Results for Experiment 1: Differences in the Allocation of Attention



Note. The *Y* axis represents the average proportion of probes recalled at the memorable (solid grey bars) and forgettable face (striped bars) locations out of the total number of probes correctly recalled. Participants were equally likely to recall memorable and forgettable probes at 150 ms. At 450, 900, and 1,500 ms, participants recalled more probes that were in the same location as a memorable face versus a forgettable face, suggesting that attention was more likely to be on the memorable face stimuli at these time points. The dotted line represents no difference in attention allocation (exactly 50% of the probes recalled were memorable and the other 50% were forgettable). Error bars represent Morey's SEM (Morey, 2008). SEM = standard error of the mean.
* $p < .05$. ** $p < .01$.

Experiment 2: When Does the Competitive Benefit Emerge?

Little is known about the time course of the memorability benefit. Most studies that examined the memorability benefit in VWM used long encoding durations (e.g., more than 1 s; e.g., Gillies et al., 2023; Green et al., 2023; Thibeault et al., 2024; Torres et al., 2024). Therefore, it is unclear how the memorability benefit may emerge over the course of an encoding period or via postperceptual processes during a retention interval.

One study directly tested whether the memorability benefit in VWM manifests early (i.e., at short encoding durations) and whether any benefits persist even when preventing postperceptual processing with a mask (Ye et al., 2024). Participants encoded arrays of three face stimuli (all memorable or all forgettable) at different encoding durations (100, 200, or 500 ms) followed by a 1,600-ms retention interval. Participants were then shown a test face and indicated if it was from the previous array. They found that at very short encoding durations, memorable faces were better remembered than forgettable faces (this is akin to what we have called the "efficiency benefit"). This finding held when the face stimuli were followed by a mask. Overall, they found that some memorability benefits emerge as early as 100 ms and were resistant to postperceptual interruption. However, it is not possible to examine competition between memorable and forgettable stimuli with this design, as doing so requires that (a) memorable and forgettable stimuli are encoded together and (b) VWM is saturated such that resources must be "fought over."

Though there is some evidence to suggest that the efficiency benefit is present in VWM very early on, no study to date has investigated when (or how) the competitive benefit develops over the course of VWM encoding. We considered two possible timelines for the competitive benefit.

First, if the competitive benefit *precedes* any differences in attention allocation (i.e., the competitive benefit would be present prior to 450 ms), then the competitive benefit is a likely source of the differences in attention allocation. VWM is interconnected with attention (Hutchinson & Turk-Browne, 2012), such that stimuli in the environment that match the contents of VWM attract attention (Olivers et al., 2006). Therefore, the competitive benefit in VWM may lead to those same faces then attracting attention.

The second possible timeline is that the competitive benefit emerges *after* differences in attention allocation (i.e., the competitive benefit would *not* be present prior to 450 ms). If this is the case, then attention is a possible origin of the competitive benefit. To preview our results, we find that the competitive benefit emerges after 450 ms, ruling out the possibility that the competitive benefit gives rise to differences in attention allocation.

To investigate these two possible timelines, we examined when the competitive benefit emerges during the VWM task. We know from the results of Experiment 1 and previous work in Gillies et al. (2023) that the competitive benefit is present when observers are given 2,000 ms of encoding time. The results of experiment 1 suggest that attention is drawn towards the memorable faces by 450 ms. Therefore, in experiment 2, we varied the encoding duration of the face stimuli to examine timepoints before and after we knew differences in attention allocation should emerge. The encoding durations were 150, 500, and 2,000 ms.

In addition, we also included an immediate 100-ms mask in between the face stimuli and retention interval. This was to disrupt the postperceptual processing of the face stimuli that may occur over the retention interval (Ricker et al., 2018; Vogel et al., 2006; Ye et al., 2024). This was important, as we wanted to examine the competitive benefit in VWM at specific moments in time (i.e., without any additional benefits imbued to successfully encoded items during VWM consolidation).

Method

Participants

Participants were recruited from Prolific (2021) using the same prescreening procedure and payment details as in experiment 1. Participants who completed experiment 1 were not permitted to participate in experiment 2.

A total of 170 participants were recruited, and 14 were excluded (see Participant Exclusion Criteria section), leading to a final sample size of 156. We used the same power analysis as described in Experiment 1.

The mean age of the final sample was 30.98 years ($SD = 5.83$), with 62 females and 94 males. One-hundred forty were right-handed, 13 were left-handed, and three were ambidextrous. Sixty-two wore glasses, 16 wore contacts, 77 wore neither and one declined to answer.

Participant Exclusion Criteria

Participants were excluded based on performance. We excluded participants who performed at or below chance on the pure memorable condition (i.e., an AUC of less than .5) when the face duration was 2,000 ms. The average AUC for this condition was .68 (without exclusions), and we excluded 14 participants using this criteria.

We also repeated the below analyses with all 166 participants (available on the Open Science Framework at https://osf.io/7jpvf) and found a similar pattern of results. The only difference was that at the 150-ms stimulus duration, there was no significant effect on memorability. This does not change our interpretation of the results.

Apparatus

The apparatus was identical to that used in experiment 1.

Stimuli

The stimuli were similar to those used in experiment 1. Experiment 2 included the use of stimulus masks. To create the masks, we used an additional 24 face stimuli (12 memorable and 12 forgettable) from the Bainbridge et al. (2013) image database. Images were selected randomly from the database and were not used anywhere else in the experiment. Each mask was composed of two memorable and two forgettable faces overlayed such that no one facial feature was more visible than others from the other faces. Six masks were selected randomly for every trial out of 12 total masks.

Procedure

The VWM task was similar to that in Experiment 1, but the six faces were on the screen for either 150, 500, or 2,000 ms (128 trials for each of the possible face durations) and were followed by a 100-ms mask in the same location as the faces (see Figure 6). After the mask, there was a 1,000-ms retention interval followed by the response screen as described in experiment 1.

Within each duration condition, participants performed 32 trials of the pure memorable, pure forgettable, mixed memorable, and mixed forgettable conditions (see Experiment 1 for details), for a total of 384 trials in the experimental session.

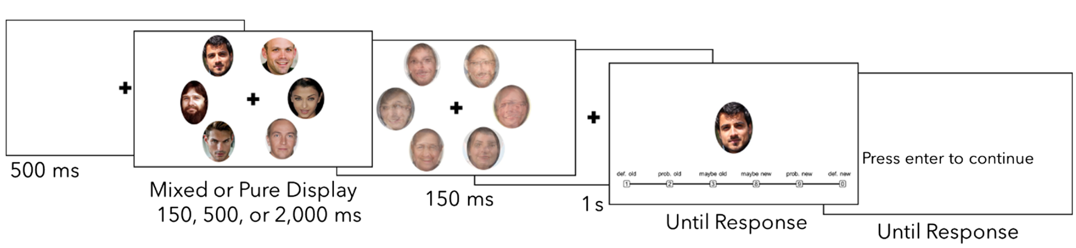
Analysis

We used the ROC curve analysis as described in experiment 1. For experiment 2, we calculated the AUC for the pure memorable, pure forgettable, mixed memorable, and mixed forgettable conditions for each of the three stimulus durations.

To examine memory performance, we conducted a 2 × 2 × 3 repeated measures ANOVA to examine the effects of stimulus memorability (memorable, forgettable), array type (pure, mixed),

Figure 6

Sample Trial Sequence for Experiment 2



Note. Participants saw six face stimuli in the middle of the screen at varying durations. The faces could be entirely memorable or forgettable (pure condition) or consist of three memorable and three forgettable faces (mixed condition). Faces were then followed by a 150-ms mask. Participants were then shown a test face and were asked to indicate if they had seen that face before (old) or not (new) and how confident they were. Face images are from "The Intrinsic Memorability of Face Photographs," by W. A. Bainbridge, P. Isola, and A. Oliva, 2013, *Journal of Experimental Psychology: General, 142*(4), p. 1326 (https://doi.org/10.1037/a0033872). Copyright 2013 by the American Psychological Association. Def. = definitely; prob. = probably. See the online article for the color version of this figure.

and stimulus duration (150, 500, 2,000 ms) on AUC. This was followed by three planned comparison 2 × 2 repeated measures Bayesian ANOVAs.

Results and Discussion

A 2 (array type: pure, mixed) × 2 (stimulus memorability: memorable, forgettable) × 3 (face duration: 150, 500, 1,500 ms) repeated measures ANOVA revealed a significant three-way interaction (see Figure 7), $F(2, 310) = 5.98$, $p < .01$, *partial* $\eta^2 = .04$. This three-way interaction was explored with separate 2 (array type: pure, mixed) × 2 (stimulus memorability: memorable, forgettable) ANOVAs for each level of face duration.

At 150 ms, there was a significant effect of stimulus memorability, $F(1, 155) = 4.48$, $p = .036$, *partial* $\eta^2 = .03$, $BF_{10} = 0.87$. The main effect of array type was not significant, $F(1, 155) = 0.23$, $p = .63$, *partial* $\eta^2 = .001$, $BF_{01} = 9.95$. There was also no interaction between memorability and array type, $F(1, 155) = 0.07$, $p = .79$, *partial* $\eta^2 = 4.56 \times 10^{-4}$, $BF_{01} = 8.17$.

At 500 ms, there was a significant main effect of stimulus memorability, $F(1, 155) = 9.46$, $p = .002$, *partial* $\eta^2 = .06$, $BF_{10} = 14.3$. The main effect of array type was not significant, $F(1, 155) = 2.81$, $p = .096$, *partial* $\eta^2 = .02$, $BF_{01} = 3.162$. The interaction between memorability and array type was also not significant, $F(1, 155) = 0.19$, $p = .668$, *partial* $\eta^2 = .001$, $BF_{01} = 7.46$.

At 2,000 ms, there was a significant main effect of stimulus memorability, $F(1, 155) = 164.14$, $p < .001$, *partial* $\eta^2 = .51$, $BF_{10} = 5.25 \times 10^{29}$. There was no significant effect of array type, $F(155) = 2.66$, $p = .104$, *partial* $\eta^2 = .02$, $BF_{01} = 4.85$. Unlike at 150 and 500 ms, the interaction between memorability and array type was significant at 2,000 ms, $F(1, 155) = 21.86$, $p < .001$, *partial* $\eta^2 = .12$, BF10 $= 4.64 \times 10^{32}$. As in experiment 1, memorable faces were associated with higher AUCs when encoded with forgettable faces than when all the faces were memorable, $t(155) = 2.41$, $p = .017$, Cohen's $d = .19$, 95% CI [.03, .35], $BF_{10} = 1.46$, and forgettable faces were associated with lower AUCs when encoded with memorable faces compared to when all the faces were forgettable, $t(155) = 4.18$, $p < .001$, Cohen's $d = .34$, 95% CI [.17, .49], $BF_{10} = 305.59$.

This pattern of results shows that the competitive benefit is *not* present prior to any differences in attention allocation. Though attention was more likely to be on memorable faces by 450 ms (based on the results of experiment 1), the competitive benefit did not appear until long after 450 ms (it was present at 2,000 ms). These results rule out the possibility that the differential allocation of attention was caused by the competitive benefit within VWM.

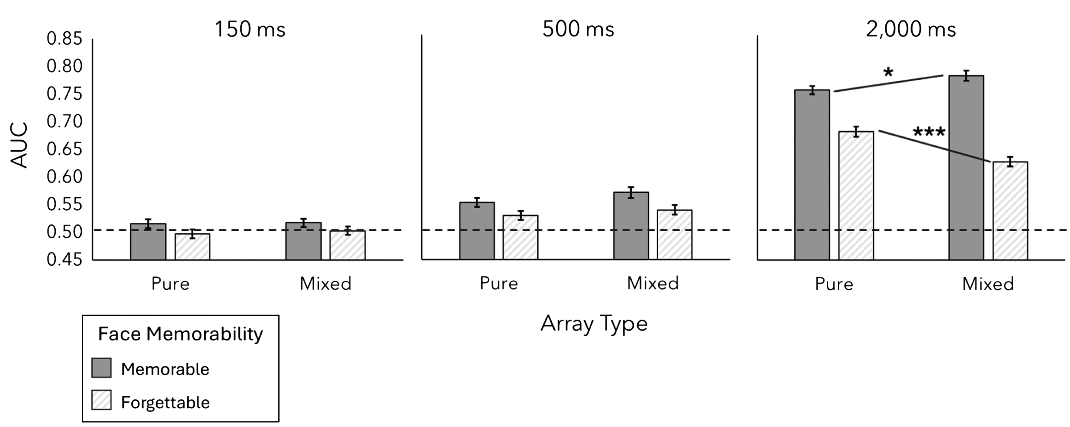
General Discussion

Across two experiments, we examined the origin of the competitive benefit experienced by memorable face stimuli in VWM. First, we investigated if and when attention was more likely to be drawn to memorable faces when encoded alongside forgettable ones in a VWM task. We found that attention was indeed attracted to the memorable stimuli. However, attention was not *immediately* captured by the memorable faces, which is in line with previous work (Bainbridge, 2020). Rather, spatial attention was more likely to be on the memorable faces by around 450 ms into the encoding period, and this difference in attention allocation persisted until at least 1,500 ms.

Next, we determined when the competitive benefit emerges in relation to when differences in the allocation of attention can be observed. We found that attention was drawn toward the memorable faces (around 450 ms) and *then* the competitive benefit emerged afterward (by 2 s). Based on these results, we can conclude that the competitive benefit itself is not the source of the differential attention allocation. In addition, we can also conclude that the competitive benefit is not due to automatic attentional capture.

Figure 7

Visual Working Memory Task Results for Experiment 2



Note. At 150 ms, there is some evidence for an efficiency benefit (AUC is higher for memorable faces than forgettable), but no competitive benefit. At 500 ms, there is strong evidence of the efficiency benefit, but again no competitive benefit. By 2,000 ms, we see both the efficiency benefit and the competitive benefit (significant interaction between memorability and array type). The dotted line represents the guess rate. Error bars represent Morey's SEM (Morey, 2008). AUC = area under the curve; SEM = stard error of the mean.

* $p < .05$. *** $p < .001$.

Is Attention the Source of the Competitive Benefit?

Differences in attention allocation were present prior to the competitive benefit, suggesting that attentional processing is a probable source of the competitive benefit. We speculate that because the memorable faces received more attention than the forgettable faces, they also received a subsequent boost in memory, while the forgettable faces experienced a cost.

If attention is indeed the source of the competitive benefit, then manipulations to attention allocation should therefore alter the competitive benefit. A future study should examine if directing attention towards forgettable stimuli when needing to encode both memorable and forgettable stimuli will possibly reduce, eliminate, or invert the competitive benefit in VWM.

One possible alternative for the source of the competitive benefit is encoding time. With increasing encoding durations, participants may engage in additional cognitive processes that aid memory performance. There may be an advantage for memorable faces when engaging in these processes, which could only emerge with additional encoding time. However, there is evidence that some strategies such as cognitive control or depth of encoding do not interact with stimulus memorability (Bainbridge, 2020). More specifically, even when told to "forget" memorable stimuli or "remember" forgettable stimuli, participants are still more likely to remember memorable stimuli than forgettable, suggesting that memorability's role in memory performance is more implicit than explicit (Bainbridge, 2020). When controlling for depth of encoding between memorable and forgettable stimuli, memorable stimuli are still more likely to be remembered than forgettable ones (Bainbridge, 2020). This suggests that strategies such as effort or elaborative encoding do not explain memorability. It is possible that participants were engaging in other strategies such as using verbal working memory or chunking, which may improve performance on VWM tasks (e.g., Nassar et al., 2018; Postle et al., 2005). However, why or how it would be easier for memorable stimuli to be encoded into verbal working memory or grouped into chunks is not clear. To examine this possibility, verbal memory could be occupied by using an articulatory suppression task in conjunction with a VWM task in a future study.

Another fruitful direction for future studies is to delineate the contribution of covert and overt attention to the competitive benefit. Since the present study was conducted online, it is impossible to dissociate their contributions in the current data set. However, a future study can track and control participants' eye gaze to see whether an overt shift of attention is necessary to produce the preferential deployment of attention toward memorable stimuli that leads to the competitive benefit within VWM.

What May Cause Spatial Attention to be Drawn Toward the Memorable Stimuli?

A study by Bainbridge et al. (2013) found that about 24% of the variance in face memorability can be explained by 20 social and personality traits (e.g., facial attractiveness, trustworthiness). Is it possible that attention is being drawn to the memorable faces due to these higher-order perceptual differences? Though these features do not entirely explain memorability, they can contribute to it. It is possible that the observed differences in attention allocation are due to these higher order perceptual differences between the stimuli. Neurophysiological research has shown that both low- and high-level information can be extracted from a single face rather rapidly, as indexed by the N170 component (around 170-ms poststimulus onset; Rossion & Jacques, 2011). There is also behavioral research showing that attractive faces automatically capture attention (e.g., via pop-out; e.g., Lindell & Lindell, 2014; Sui & Liu, 2009); however, we did not find evidence of pop out in experiment 1.

There is no work, to our knowledge, that shows how long it may take to preferentially attend to an attractive face over an unattractive one (or a trustworthy face over an untrustworthy one) when multiple faces systematically varying in this dimension are displayed at the same time. If these perceptual differences are the source of the competitive benefit, then these features should be able to attract spatial attention prior to the emergence of the competitive benefit (i.e., by around 450 ms).

The idea that attention is drawn towards memorable faces due to perceptual differences is difficult to reconcile with other results that show that the competitive benefit is also present in VWM when using object stimuli (Gillies et al., 2023). If attention is the source of the competitive benefit, it should operate similarly across different stimulus categories, given the competitive benefit is present for different stimulus categories that do not share visual features. Rather than differences in attention being due to perceptual differences between memorable and forgettable faces, we instead posit that the competitive benefit is a byproduct of the efficiency benefit. Below, we expand on this and outline a speculative timeline of the memorability benefit within VWM.

A Possible Timeline of the Memorability Benefit

When Do Differences Between Memorable and Forgettable Stimuli Emerge?

In the present study, we found weak evidence for the presence of the efficiency benefit at 150 ms (We have strong evidence that the efficiency benefit is present by 500 ms, but this is 50 ms after we observed differences in attention allocation.) However, another study that used short encoding durations (i.e., 100–200 ms) and masks to interfere with postperceptual processes did find that memorable stimuli are more likely to be remembered than forgettable stimuli (Ye et al., 2024). The efficiency benefit may be more obvious in that study because the set size was much smaller (only three faces, compared with six used in the present study). As our primary interest was in the competition for VWM resources between memorable and forgettable stimuli, this necessitated the need for VWM to be fully saturated (essentially, forcing competition to occur). Thus, the efficiency benefit may be getting "washed out" due to the overall effect of set size.

Recent neurophysiological data show that it takes some time for differences between memorable and forgettable stimuli to emerge after stimulus onset (Kolisnyk et al., 2023; Mohsenzadeh et al., 2019). An electroencephalogram study by Kolisnyk et al. (2023) found that when encoding highly memorable and forgettable stimuli (object images) in sequence (250-ms encoding time) for a subsequent VLTM task, memorable stimuli evoked greater frontal positivity (an index of successful encoding [Friedman & Johnson, 2000; Fukuda & Woodman, 2015; Sundby et al., 2019]) and greater parieto-occipital positivity than forgettable stimuli around 200 ms poststimulus onset. Similarly, a magnetoencephalography study by Mohsenzadeh et al. (2019) found that when observers viewed rapidly presented images of highly memorable and highly forgettable scenes (34 ms encoding time) for a subsequent VLTM task, memorable images showed greater decoding accuracy in specific brain regions (i.e., left parietal cortex, right inferior temporal cortex) between 150 and 230 ms poststimulus onset. These results also show that memorability is supported by enhanced perceptual processing of memorable stimuli in higher-order visual regions and not the primary visual cortex (see also Bainbridge et al., 2017; Rust & Mehrpour, 2020).

To our knowledge, no one has investigated the neural time course of stimulus memorability when stimuli need to be encoded for a subsequent VWM task (the aforementioned studies only tested long-term memory). Determining if differences in stimulus memorability at the neural level are also present when the stimuli need to be encoded for a VWM task is an avenue for future research.

Why Is Attention Drawn Toward the Memorable Faces?

Though we have evidence to suggest that memorable stimuli attract attention during encoding, what may attract attention to those stimuli to begin with? We posit that the competitive benefit may be a byproduct of the efficiency benefit. Memorable stimuli are more efficiently encoded and maintained in VWM than forgettable stimuli (memorable stimuli have "priority access" to VWM). Stimuli that match the contents of VWM are more likely to attract attention (e.g., Soto et al., 2007). Therefore, because the memorable faces are preferentially encoded into VWM, those same stimuli then attract attention while the observer is viewing them on the screen. In this case, one can hypothesize that the competitive benefit would be the outcome of memory-guided attention (driven by the efficiency benefit).

Here, we propose a speculative timeline of the memorability benefit (see Figure 8). Immediately after the presentation of memorable and forgettable stimuli, attention is no more likely to be on a memorable versus a forgettable face (e.g., attention allocation is equal between the stimuli). The memorable stimuli are more efficiently encoded and maintained into VWM, and this is evident around 150 ms into encoding. Then, because the memorable stimuli are present in VWM (or are more likely to be represented than forgettable stimuli), those same stimuli then attract attention as they match the contents of VWM (memory guided attention). This occurs by at least 450 ms. Last, because those memorable stimuli have been attended to, they receive a final memory boost, which is apparent by the appearance of the competitive benefit by 2,000 ms.

If the competitive benefit is a by-product of the efficiency benefit, then preventing the efficiency benefit from occurring should also prevent the competitive benefit from emerging. This could be done by allowing the forgettable stimuli to enter VWM first (e.g., display the forgettable faces for 450 ms, then have the memorable faces appear with the forgettable ones). This may equalize the competitiveness of both types of stimuli, which could in turn attenuate or eliminate the competitive benefit.

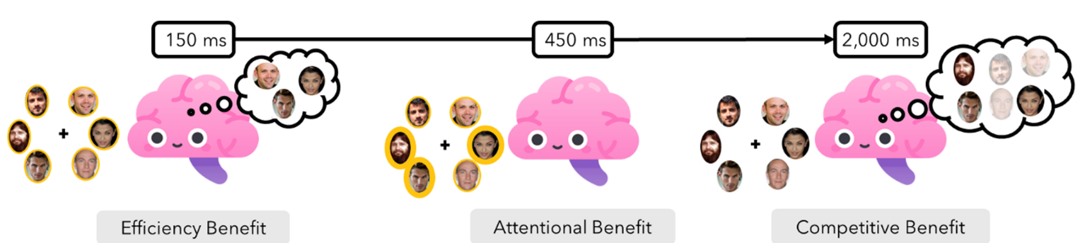
Another possibility is that the competitive benefit emerges as a consequence of VLTM. In this and previous studies, the stimuli are viewed at least twice. Memorable images could be preferentially represented in VWM (the efficiency benefit) during their very first presentation, and therefore are more likely to enter VLTM. Work from Gillies et al. (2023) shows that memorable images are "stickier" and more likely to be retained within VLTM compared to forgettable images. If these images are able to enter and persist in VLTM after a single presentation, attention may be biased towards those same stimuli on subsequent presentations in the VWM task, producing the competitive benefit. In this case, the competitive benefit is still a byproduct of the efficiency benefit, but via VLTM rather than via VWM. If this is the case, the competitive benefit in VWM would be extinguished after both memorable and forgettable stimuli are well encoded into VLTM.

The Persistence of the Competitive Benefit in VLTM

Our results are in line with previous studies that show that memorable stimuli do not attract attention via automatic pop out (Bainbridge, 2020), suggesting that the memorability benefit is not due to visual salience (i.e., memorable stimuli are not more visually distinct than forgettable stimuli). This is also supported by neurophysiological data that memorability is reflected by activity in higher-order visual regions (e.g., left parietal area, right inferior temporal area) and not by activity in primary visual cortex, and by the observation that memorability effects take some time to develop (Kolisnyk et al., 2023; Mohsenzadeh et al., 2019). However, we do

Figure 8

A Possible Timeline of the Memorability Benefit



Note. Memorable stimuli are more easily encoded into Visual Working Memory (VWM; efficiency benefit). At around 150 ms, attention is no more likely to be on a memorable face versus a forgettable face. Because the memorable stimuli are present in VWM, they then attract attentional resources (at around 450 ms). Because memorable stimuli have attracted attentional resources, they receive a subsequent boost in memory (competitive benefit) by 2,000 ms. The brain image is from Flaticon (https://www.flaticon.com/). CC-BY-NC. See the online article for the color version of this figure.

show that attention *can* exert an influence over the memorability benefit, in that memorable stimuli attract more attention than forgettable stimuli, though not immediately.

Interestingly, in Gillies et al. (2023), the competitive benefit did not translate to VLTM. In that study, participants first performed a VWM task as in the current work. After the VWM task, participants did a VLTM task, where they were shown a single test face and were asked to report if that face had appeared at any point during the VWM task ("old face") or not ("new face") (Participants were aware that the VLTM task would occur prior to beginning the VWM task.) In VLTM, we found evidence of an efficiency benefit (memorable faces were more likely to be recognized than forgettable faces). However, memorable faces that were encoded along with forgettable faces did not receive an additional boost in memory performance, and forgettable faces did not suffer in this same scenario (i.e., there was no competitive benefit present in VLTM).

This lack of a competitive benefit in VLTM could be due to several reasons. For example, the competitive benefit is very small to begin with, making it even more difficult to detect in VLTM. Indeed, the difference in magnitude between the efficiency and competitive benefits in VWM (efficiency benefit > competitive benefit) makes it difficult to make strong claims about whether or not these two effects are qualitatively different within VLTM.

Recent work has shown that attentional benefits in a VWM task do not automatically transfer to subsequent benefits in VLTM (A. L. Atkinson et al., 2024). Participants performed a VWM task where they encoded object images in sequence, followed by a four-alternative-forced-choice-task. Before encoding the items, they were told which items were associated with a higher "point value" (or if all the items were worth the same number of points). Objects associated with more points were better remembered at the test, showing that goal-directed attention can exert influence in a VWM task. However, on a surprise VLTM test, items that were associated with higher points did not benefit compared to the other items. Therefore, not all attention manipulations at VWM result in subsequent VLTM benefits (see also Jeanneret et al., 2023).

Conclusion

To summarize, we found that attention is drawn to memorable stimuli during encoding, but memorable stimuli do not automatically capture attention. When memorable and forgettable stimuli need to be encoded together in a VWM task, attention is more likely to be on the memorable faces than the forgettable faces at around 450 ms into the encoding period. Next, we found that the competitive benefit (where memorable stimuli get a memory boost when encoded with forgettable stimuli and forgettable stimuli are punished when encoded with memorable stimuli compared to when all the stimuli are of the same memorability) arose after there were differences in the allocation of attention. Therefore, the competitive benefit does not give rise to the differences in attention allocation. We posit that the competitive benefit is a result of attentional differences between memorable and forgettable stimuli. More specifically, we speculate that these differences in attention and the competitive benefit are a byproduct of the efficiency benefit via memory-guided attention. Specifically, (a) Memorable stimuli are more easily encoded into VWM (efficiency benefit); (b) Because they are present in VWM, they then attract attentional resources; and (c) Because they attract these attentional resources, memorable stimuli receive an additional memory boost (competitive benefit).

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