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BRIEF REPORT

Recognition memory fluctuates with sustained attention regardless of task relevance

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Abstract
Sustained attention fluctuates over time, affecting task-related processing and memory. However, it is less clear how attentional state affects processing and memory when images are accompanied by irrelevant visual information. We first quantify behavioral signatures of attentional state in an online sample (N1=92) and demonstrate that images presented in high attentional states are better remembered. Next, we test how sustained attention influences memory in two online samples (N2=188, N3=185) when task-irrelevant images are present. We show that high attention leads to better memory for both task-relevant and task-irrelevant images. This suggests that sustained attentional state does selectively affect processing for task-relevant information, but rather affects processing broadly, regardless of task relevance. Finally, we show that other components of attention such as selective attention contribute to the mnemonic fate of stimuli. Our findings highlight the necessity of considering and characterizing attention's unique components and their effects on cognition.

Keywords Sustained attention · Recognition memory · Visual attention · Attentional state

Introduction

Our sustained attentional state, which fluctuates dynamically over time, influences what we remember. In particular, moments of high attentional engagement during a task are associated with better memory for task information presented in those moments. However, task-related information is often accompanied by information irrelevant to accomplishing the task at hand. What are the consequences of sustained attentional state fluctuations for task-irrelevant information? Specifically, do moments of high sustained attention "sharpen" the focus of selective attention, such that task-relevant stimuli are better processed and remembered while irrelevant stimuli are filtered and forgotten? Or do increases of sustained attention broaden the scope of selective attentional processing to include (or at least reduce filtering of) irrelevant stimuli, leading to better memory? Here, we examine the effects of dynamically changing sustained attentional state on visual memory as a function of task relevance.

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Significance statement Attention influences memory, such that information in the focus of selective attention is better remembered. More recent work investigates how cognitive processing is affected by *sustained attentional state*, which changes dynamically throughout a task. In a series of online studies, we tested the impact of sustained attentional state on memory for images relevant and irrelevant to a task. We first confirm that high sustained attentional state predicts better image memory. We then test how mnemonic effects of attentional state differ as a function of task relevance in two independent samples. We demonstrate with internal replication that increased sustained attentional state predicts better memory not only for task-relevant images, but also for task-irrelevant images. Results suggest that sustained attention may be characterized by a metaphorical floodlight whose diffuse scope affects processing globally.

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Sustained attention dynamics can be probed with continuous performance tasks (CPTs) which require vigilant attention to detect infrequent targets from a set of largely homogeneous stimuli (Mackworth, 1948). In these paradigms, the detection of infrequent stimuli is not perceptually demanding, such that discrimination of frequent and infrequent categories is trivial and errors can be attributed to lapses in attention. Additionally, paradigms that task participants with responding to all frequent-category stimuli and changing a response only to infrequent-category stimuli (not-X CPTs; Robertson et al., 1997; Rosenberg et al., 2013) provide a near-continuous readout of behavior which can be used to approximate sustained attentional state at every trial. Previous studies investigating fluctuations in sustained attention show that response time (RT) speed and variance predict upcoming lapses in sustained attention during CPTs (Corriveau et al., 2024; deBettencourt et al., 2018; Esterman et al., 2013; Rosenberg et al., 2013; Wakeland-Hart et al., 2022). Specifically, trials in which participants fail to change or inhibit a response to infrequent stimuli, i.e., trials in which participants are likely to be in a decreased sustained attentional state, are preceded by faster and more variable pressing. In this way, RT provides a momentary measure of sustained attention which predicts task performance.

Changes in processing due to fluctuating sustained attentional state impact later memory for task-relevant information (Corriveau et al., 2024; deBettencourt et al., 2018; Madore et al., 2020; Song et al., 2021; Wakeland-Hart et al., 2022). Images presented when individuals are in an engaged attentional state, as indexed by higher CPT accuracy and slower and less variable responses, are better remembered than those shown when people are in a lower attentional state (Corriveau et al., 2024; deBettencourt et al., 2018; Wakeland-Hart et al., 2022). This suggests that processing for task-relevant information may fluctuate with attentional state, affecting how stimuli are remembered later on. Further, salient infrequent stimuli presented amongst a set of homogeneous stimuli may exogenously increase attentional state. Increases in processing for infrequent stimuli may result in better subsequent memory for these stimuli, termed the von Restorff effect (von Restorff, 1933; Wallace, 1965).

Carefully designed studies demonstrate that task-irrelevant stimuli are processed and remembered (Butler & Klein, 2009; Hutmacher & Kuhbandner, 2020; Kuhbandner et al., 2017; Ruz et al., 2005a, b). How does processing of and memory for irrelevant stimuli change as a function of sustained attentional state? Recent work investigated this question using task-relevant and task-irrelevant stimuli presented in auditory and visual perceptual modalities (Corriveau et al., 2024). During an auditory-visual continuous performance task, participants saw trial-unique images and heard trial-unique sounds simultaneously. They were instructed to make a category frequency judgment on either the images (indoor vs. outdoor scenes) or sounds (natural vs. manmade sounds) and were told that they could ignore stimuli from the irrelevant modality. Results revealed that memory for stimuli from the task-relevant modality positively predicted memory for task-irrelevant items presented at the same time (i.e., in the same attentional state). This suggests that fluctuations in sustained attentional state affect task-relevant and task-irrelevant stimuli similarly. Additional evidence comes from observations that task-irrelevant stimuli presented alongside task-relevant targets are better remembered, termed the "attentional boost effect" (Lin et al., 2010; Swallow & Jiang, 2010). The increase in attention afforded by the presentation of a rare target may increase processing for all stimuli regardless of task relevance, leading to better memory for stimuli.

These findings align with prior work by Esterman et al. (2014) which showed that increases in sustained attentional state resulted in greater neural repetition suppression to irrelevant repeated images, suggesting that sustained attention increased processing for irrelevant information. There is also evidence that other forms of cognitive processing, such as working memory capacity, are increased during heightened sustained attentional states (deBettencourt et al., 2019). These and similar results can also be understood in light of perceptual load theory which posits that processing of task-irrelevant stimuli changes as a function of task load (Lavie, 1995). In conditions of low load, spare attentional capacity can be reallocated to the processing of task-irrelevant information. Do engaged attentional states act similarly, freeing up selective attentional capacity to process task-irrelevant information?

The present study explores the effect of sustained attentional state on selective attention, which has often been characterized in lay terms with a spotlight analogy (Posner, 1980). While much work has debated whether this metaphor appropriately captures all aspects of visual attention (Cave & Bichot, 1999) and instead proposed that multiple mechanisms bias attention in favor of locations, objects, and features based on current goals and stimulus salience (Desimone & Duncan, 1995), the current study will test how sustained attentional fluctuations impact processing in selective attention's scope, which can be diffuse, focused, or divided (LaBerge et al., 1997; Pylyshyn & Storm, 1988; Sperling & Weichselgartner, 1995). Specifically, we test the two opposing hypotheses visualized in Fig. 1. If sustained attentional state sharpens the focus of selective attention, moments of high attention should see increased processing for stimuli in the focus of selective attention (task-relevant stimuli) and decreased processing for stimuli outside the focus (task-irrelevant stimuli). In this case, we would expect sustained attention to *positively* predict memory for task-relevant stimuli and *negatively* predict memory for task-irrelevant stimuli. Conversely, if sustained attentional

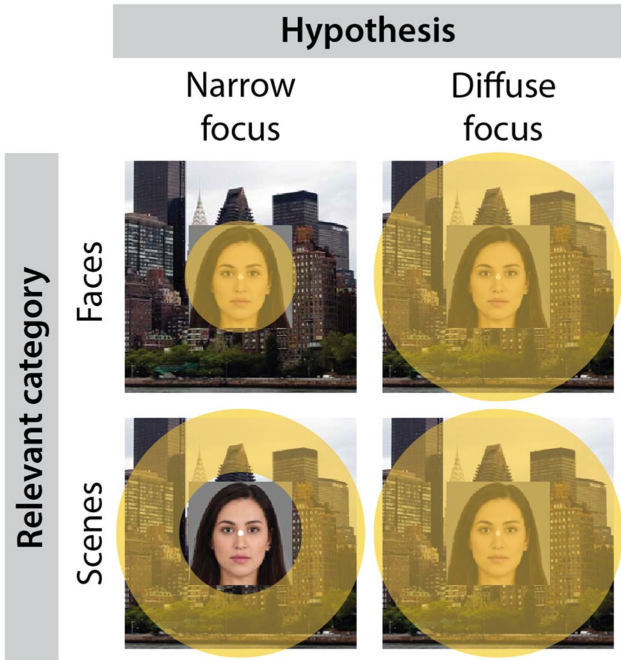

Fig. 1 Predictions for the impact of high attentional state on memory for task-relevant and task-irrelevant stimuli. A narrow focus hypothesis predicts that individuals in high attentional states will selectively process and remember task-relevant stimuli. Alternatively, the diffuse processing hypothesis predicts that processing during periods of high attention would broaden to include both task-relevant and task-irrelevant information, resulting in higher processing and memory for both

state affects processing diffusely, in a manner more akin to a floodlight, moments of high sustained attention should be associated with increased processing of task-relevant stimuli and decreased filtering of task-irrelevant stimuli. If this is the case, we should observe a positive relationship between sustained attention and memory for both task-relevant and task-irrelevant stimuli. While past work found evidence for sustained attention impacting processing in a diffuse manner, this previous work tested memory for irrelevant stimuli presented in separate perceptual modalities (Corriveau et al., 2024). It is not clear whether this pattern would persist when task-relevant and irrelevant stimuli are superimposed images and may therefore compete for limited visual attentional capacity. Clarifying this relationship would further characterize the multifaceted relationship between sustained attention dynamics and memory.

We tested these questions in a set of experiments conducted online. First, we validated the finding that sustained attentional state influences subsequent visual memory in an online experiment. This replication of previous work by deBettencourt et al. (2018) provides an important foundation for further characterizing how sustained attention dynamics influence memory. Next, we probed this relationship by testing how sustained attention affects memory for task-relevant and task-irrelevant images in two independent samples. Results show that, in addition to a positive relationship between sustained attentional state and task-relevant memory, increases in sustained attentional state also positively predicted task-irrelevant item memory. These results suggest that, in this context, sustained attention *decreases* filtering of task-irrelevant information. Thus, stimuli encountered in a higher sustained attentional state are better remembered, regardless of task relevance.

Experiment 1 methods

Before testing *how* sustained attention dynamics influence memory, we first sought to replicate foundational work demonstrating that behavioral signatures of sustained attention predict recognition memory in an online sample, for which the testing environment is less constrained and potentially more distracting than it is for in-lab studies. A total of 101 adults ages 18–35 were recruited to participate in an online study hosted by the platform Prolific (www.prolific.com). Participants were excluded for falling 2.5 standard deviations outside the sample mean for a number of criteria, determined a priori. Five participants were excluded based on the number of timed-out attention and memory task trials, two participants for low attention performance (A'), one participant for low memory performance (A'), and one participant for slow mean reaction time during the memory task. The final sample was composed of 92 participants. A power analysis using a previously reported effect size of attentional state on memory (preceding RT slope = .18) confirms that the final sample is above the minimum sample size (N = 46) needed to achieve sufficient power (0.8) with a significance level of .05 (Wakeland-Hart et al., 2022).

Participants first performed a continuous performance task (CPT) of sustained attention consisting of a two-alternative forced-choice between frequent-category (90%) and infrequent-category (10%) images. All experiment code was implemented using PsyToolkit (Stoet, 2010, 2017). Stimuli were 550 indoor and 550 outdoor scenes drawn from the SUN image database (Xiao et al., 2010). Participants were presented with a continuous stream of 500 unique images, each lasting 1 second, and were tasked with responding on each trial by pressing the "i" key for an indoor image or the "o" key for an outdoor image.

Following the CPT, participants performed a surprise recognition memory task for scene images. Participants were presented with 200 images from the SUN image database, 100 of which had been presented during the CPT (old) and 100 previously unseen images (new). Of the old images, 50 belonged to the frequent stimulus category and 50 belonged to the infrequent stimulus category. Foil images were category-matched such that 50 belonged to the frequent category and 50 belonged to the infrequent category. Participants rated their recognition memory on a 4-point scale (1 = *definitely new*, 2 = *maybe new*, 3 = *maybe old*, 4 = *definitely old*). Memory for old stimuli was considered correct if a participant reported a judgment of 4 (*definitely old*) and incorrect if a participant provided any other rating, replicating previous work (Corriveau et al., 2024; deBettencourt et al., 2018; Kim et al., 2014; Wagner et al., 1998; Wakeland-Hart et al., 2022). This criterion ensures confident memory judgements and reduces the chance that guesses are counted as correct recognitions (Turk-Browne et al., 2006). Memory trials with no response timed-out after 20 seconds. Timed-out trials are not analyzed.

Finally, to ensure participant compliance, the study concluded with three easy multiple choice questions asking participants to report the kinds of images presented during the task, task instructions for the CPT, and task instructions for the memory task. Participants who failed to answer two of these questions correctly were excluded from the study. No participants were excluded from any of the present studies based on this criterion.

Analysis

Performance for both attention and memory tasks was quantified using the performance measure A'. This measure provides a non-parametric quantification of sensitivity using the proportion of hits to false alarms that can be compared against random chance, in this case .5. A' is calculated using the following formula (Grier, 1971):

$$\begin{aligned} &\text{if } hit > fa, A' = \frac{1}{2} + \frac{(hit-fa)*(1+hit-fa)}{4*hit*(1-fa)} \\ &\text{if } fa > hit, A' = \frac{1}{2} - \frac{(fa-hit)*(1+fa-hit)}{4*fa*(1-hit)}. \end{aligned} \tag{1}$$

As a confirmation that overall memory performance measures were not biased by our accuracy criteria, we also calculated the area under each participants receiver operating characteristic curve (AUC). AUC quantifies an unbiased estimate of memory accuracy by fitting the relationship between false alarm rates and hit rates at all possible criteria (Brady et al., 2023). An equal proportion of false alarm and hit rates is reflected in an AUC value of 0.5 or chance-level performance.

Sustained attention was probed during the CPT using infrequent trials. Errors on infrequent trials reflect lapses in sustained attentional state. RT speed and variance were calculated from a three-trial window preceding infrequent trials, replicating previous work (deBettencourt et al., 2018, 2019; Decker et al., 2023a, b; Wakeland-Hart et al., 2022; Corriveau et al., 2024; Fig. 2). RT speed was calculated as the trailing window average of the three correct, frequent trials preceding an infrequent stimulus, after subtracting the overall linear trend (Corriveau et al., 2024; deBettencourt et al., 2018, 2019; Decker et al., 2023a; Wakeland-Hart et al., 2022). This three-trial window was determined a priori. RT variance was calculated using the smoothed variance time course, which quantifies deviation from the mean reaction time over the entire trial (Esterman et al., 2013; Rosenberg et al., 2013). The variance time course is calculated from correct, frequent trials. Missing RTs were interpolated from anchoring trials and the entire time course was smoothed with a gaussian kernel of 8.5 trials. RT variance values were calculated as the mean variance time course values from the three trials preceding an infrequent stimulus (Decker et al., 2023a, b).

Binomial logistic models were used to test relationships between predictors and performance accuracy, modeled as correct (1) or incorrect (0). Trial-wise CPT accuracy was quantified using categorization judgements on infrequent trials. Trial-wise memory accuracy for previously seen (old) stimuli was considered correct if a stimulus received a memory confidence rating of "definitely old," based on previous work (Corriveau et al., 2024; deBettencourt et al., 2018; Kim et al., 2014; Turk-Browne et al., 2006; Wagner et al., 1998; Wakeland-Hart et al., 2022). Models were built using the *lme4* package in R (Bates et al., 2015). All models included a subject-level random intercept to account for differences in performance between individuals. Additionally, the built-in *bobyqa* optimizer (bound optimization by quadratic approximation; Powell, 2009) was applied to all models. This optimizer did not affect model outputs but ensured convergence for one model which failed to converge when using nonlinear optimization. Data and analysis scripts are publicly available online (https://osf.io/vxuba/).

Experiment 1 results

RT speed and variance uniquely predict lapses in sustained attention

CPT performance (A') in the final sample was high (M = .904, SD = .052, 95% CI [.893, .914]) and participants made a category judgement on the vast majority of trials (M = .984, SD = .017, 95% CI [.980, .987]). We do not report group-level significance above chance because the sample excluded low performers (n = 2). However, high performance does ensure the sample is appropriate to further test the relationship between RTs, CPT accuracy, and memory. Therefore, we next tested whether behavioral variables RT speed and variance predicted lapses in sustained attention during the CPT.

We constructed a logistic model predicting trial-wise CPT accuracy with effects of pretrial RT speed, variance, and their interaction. We only analyzed accuracy to

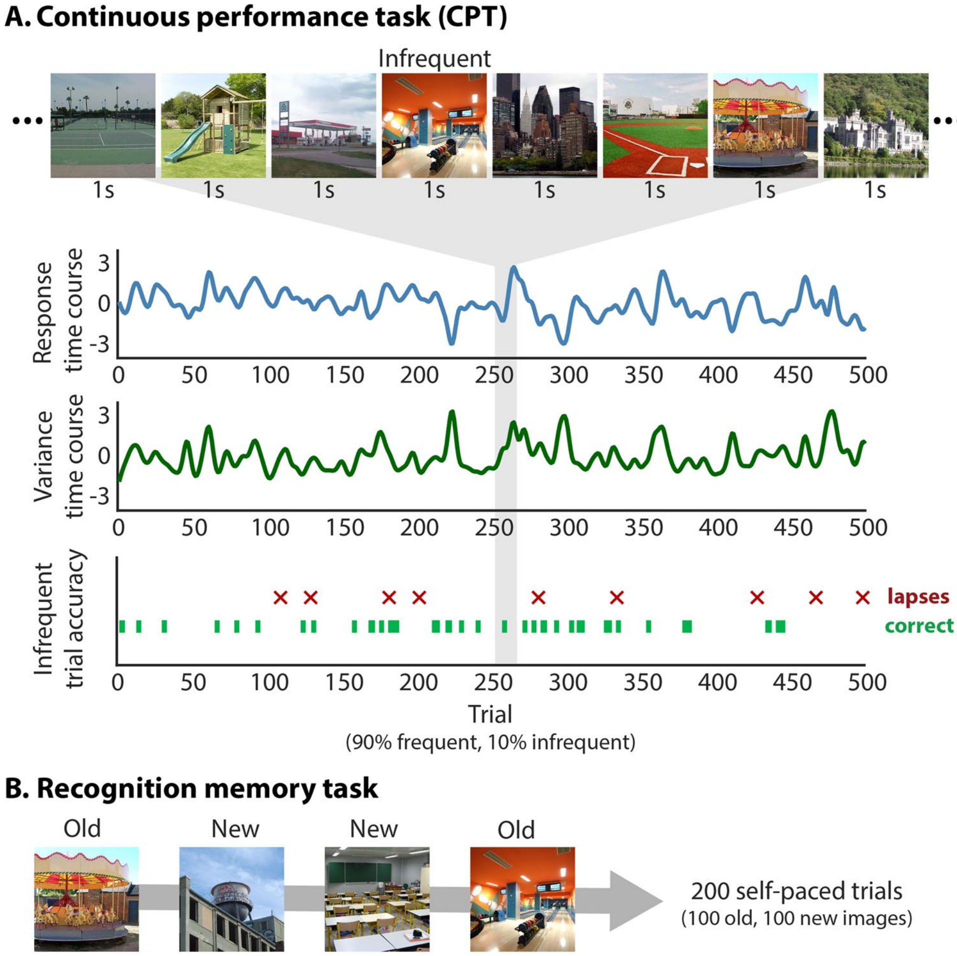

Fig. 2 **A** In the online CPT, participants viewed streams of frequent (90%) and infrequent (10%) images and made a response indicating whether the image was indoor or outdoor by pressing the 'i' and 'o' keys, respectively. Incorrect responses to infrequent trials reflect lapses in sustained attention. RT and variance time courses quantify speed and variability of pressing throughout the task. Here, the RT time course is smoothed for visualization. **B** Participants completed a recognition memory task following the CPT, rating memory using a 4-point scale (1 = *definitely new*, 2 = *maybe new*, 3 = *maybe old*, 4 = *definitely old*)

infrequent-category trials because accuracy to frequent-category trials was near ceiling (mean infrequent trial accuracy: 66.7%; mean frequent trial accuracy: 97.6%). RT speed and variance were largely unrelated within-participant (mean r = .046, SD = .250), mitigating concerns about multicollinearity. We also included a random intercept effect of subject.

$$CPT\ performance \sim RT\ speed * RT\ variance + (1|subject). \quad (2)$$

Both RT speed (b = .629, SE = .041, p < .001) and variance (b = −.191, SE = .035, p < .001) uniquely predicted lapses in sustained attention such that faster and more variable RTs preceded incorrect presses to infrequent stimuli. The interaction between RT speed and variance also predicted errors (b = −.064, SE = .033, p = .049). These results replicate previous work demonstrating RT speed (deBettencourt et al., 2018; Wakeland-Hart et al., 2022) and variance (Esterman et al., 2013; Rosenberg et al., 2013) predict sustained attentional lapses, as well as a recent observation that they do so uniquely (Corriveau et al., 2024). Therefore, RT measures provide indices of sustained attentional state which may allow us to test its effects on memory.

Sustained attentional state predicts memory for images

Recognition memory (A') for stimuli was also high (M = .712, SD = .089, 95% CI [.693 .730]; Fig. 3A), demonstrating that participants remembered images presented during the CPT. Memory accuracy as determined by AUC was similarly high (M = .668, SD = .068, 95% CI [.654, .682]). Memory performance (A') for infrequent-category stimuli (M = .718, SD = .132, 95% CI [.691, .745]) was higher than memory

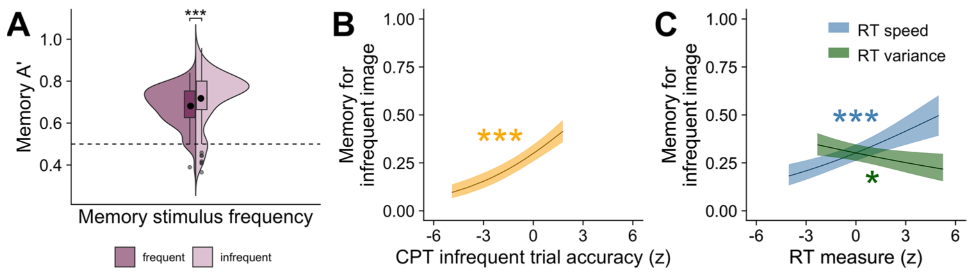

Fig. 3 **A** Memory for infrequent images was higher than for frequent images. Infrequent stimuli presented during moments of high attentional state as measured by (**B**) CPT accuracy and (**C**) RT speed and variance were better remembered. Models contained a fixed effect of CPT accuracy or fixed effects of RT speed and RT variance, and their interaction, respectively. Both models also included a random subject effect

for frequent-category stimuli (M = .681, SD = .092, 95% CI [.662, .700]), $t(91) = -2.81$, $p = 6.14\times10^{-3}$), in line with the von Restorff effect (Wallace, 1965). Additionally, CPT performance was positively related to memory (Spearman's *rho* = .218, p = .037), such that individuals with higher sustained attention performance had better image memory.

Finally, we tested whether trial-wise indices of attentional state predicted memory for images. Infrequent-category images require deviation from a prepotent response and therefore provide an assay of sustained attentional state during the CPT. We constructed two logistic models to investigate the effects of sustained attention on memory. The first model contains a fixed effect of infrequent-category CPT trial accuracy and a subject-level random intercept. The outcome variable is memory accuracy for infrequent images. We did not perform this analysis for frequent-category images because CPT accuracy for these images was near ceiling:

$$Memory\ accuracy \sim CPT\ accuracy + (1|subject). \quad (3)$$

Lapses in CPT performance significantly predicted lapses in memory (b = .284, SE = .036, p < .001), providing initial evidence that sustained attentional state during encoding impacts which stimuli are later remembered (Fig. 3B).

Next, we tested whether pretrial RT signatures of sustained attention also predicted memory for infrequent images. A logistic model with fixed effects of RT speed, RT variance, and their interaction was constructed to compare the unique contribution of these effects. A subject-level random intercept was also included in this model:

$$Memory\ accuracy \sim RT\ speed * RT\ variance + (1|subject). \quad (4)$$

RT speed (b = .165, SE = .038, p < .001) and RT variance ($b = -.084$, SE = .035, p = .017) significantly predicted memory for infrequent stimuli, such that stimuli preceded by faster and more-variable pressing were more likely to be forgotten (Fig. 3C). The interaction between RT speed and variance was not significant ($b = -.045$, SE = .031, p = .154). These results indicate that behavioral signatures of attentional state predict unique variance in memory for upcoming infrequent images.

Experiment 2 methods

Experiment 1 provides an important extension of previous work demonstrating that behavioral signatures of sustained attention predict memory for images. These results provide a foundation to further characterize this relationship in Experiments 2 and 3. In particular, the following experiments test how sustained attention dynamics impact the filtering of—and later memory for—task-irrelevant information. Previous work investigating the consequences of sustained attentional state on memory have focused on the mnemonic fate of task-relevant items. Do fluctuations in sustained attention impact the mnemonic fate of task-relevant and task-irrelevant stimuli similarly? Or do increases in sustained attentional state selectively increase processing for task-relevant stimuli while filtering task-irrelevant stimuli? To probe the effects of trial-wise dynamics of attention on memory, we conducted two related experiments.

In Experiment 2, 201 participants were recruited using Prolific (www.prolific.com). Targeted total sample size was twice that of Experiment 1 (n = 101) because Experiment 2 included two groups with a between-groups manipulation. As in Experiment 1, participants were excluded for performance metrics exceeding 2.5 standard deviations from the mean. Nine participants were excluded based on the number of CPT and memory trials with no response, two for extreme attention performance and two for extreme memory performance. The resulting sample analyzed in Experiment 2 consists of 188 participants.

Participants again performed a 500-trial CPT of sustained attention in which they were tasked with categorizing frequent and infrequent stimuli using a two-alternative forced-choice paradigm (Fig. 4). However, in this experiment the stimuli comprised face images superimposed on the center of scene images drawn from the SUN image database (Xiao

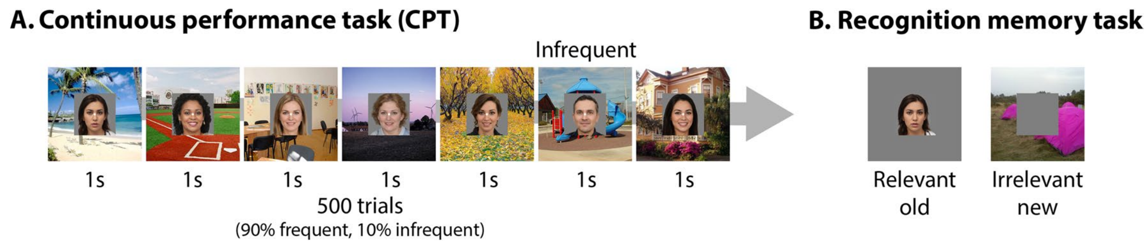

Fig. 4 **A** During the CPT, participants viewed a stream of images composed of faces superimposed on scene images. Participants responded with a button press to either frequent and infrequent faces (depicted) or scenes. **B** Following the CPT, participants performed a memory judgment for relevant and irrelevant stimuli. The recognition memory task contained 400 trials in Experiment 2 and 300 trials in Experiment 3

et al., 2010). In Experiment 2, faces were selected from a group of artificially generated images (https://generated.photos/). Each of these artificial faces was accompanied by a set of metrics describing the generative model's input parameters' association, in [0, 1], with various facial image attributes such as age, sex, emotional expression, and 3D orientation. Faces were selected for our final stimuli on the basis of two criteria: (1) each face must fall within 2.5 standard deviations of the sample mean with respect to each of the above-listed attributes save sex, and (2) each face must fall beyond an absolute threshold of 0.8 with respect to either maleness or femaleness. These criteria were designed to preclude the confounding influence of age, expression, and pose on task performance while supporting unambiguous distinction during the CPT. However, these criteria may have inadvertently disadvantaged memory for our stimuli by restricting image variability (see Experiments 2 and 3, Results). All CPT stimuli included a central fixation dot.

Task-relevant category (faces or scenes) was manipulated between participants such that participants were assigned to perform a frequent- or infrequent-category judgment on either the face images (male or female) or the scene images (indoor or outdoor). Frequent and infrequent categories were counterbalanced across face and scene images and across participants.

Following the CPT, participants were given a surprise recognition memory task to which they responded with a 4-point scale. Participants were presented with 400 images in total. This was twice as many trials as the memory task in Experiment 1 in order to test memory for both relevant and irrelevant stimulus types. Of these images, 200 had been previously presented during the CPT, 100 as task-relevant (i.e., faces or scenes) and 100 as task-irrelevant stimuli. Within each of these sets, 50 images belonged to the frequent category and 50 to the infrequent stimulus category. The remaining 200 images were category-matched foil images not previously presented.

As in Experiment 1, participants were asked to complete three attention-check questions to ensure compliance after the surprise recognition task. No participants responded incorrectly to more than one attention check question and therefore no participants were excluded on this basis.

Experiment 3 methods

Two-hundred participants completed Experiment 3 using Prolific. Six participants were excluded based on the number of attention and memory trials with no response, three for attention performance, and nine for memory performance. The resulting sample in Experiment 3 was 185 participants.

Face images for Experiment 3 stimuli were drawn from a web-scraped and curated database of face photographs, the 10K US Adult Faces Database (Bainbridge et al., 2013). Selection criteria for these face images were less strict than in Experiment 2. Specifically, the age and head orientation criteria were relaxed to exclude only the youngest-rated faces and face images with averted gaze or head posture. Low-quality images and famous faces were excluded. We did not select images based on facial expression. Finally, images were selected to be maximally unambiguous with regards to sex to facilitate the discrimination task. Differences in selection criteria may have resulted in Experiment 3 face images having more variability in some dimensions (e.g., expression, age, head position) which could result in higher memory.

The memory task for Experiment 3 was designed to probe memory for stimuli that were presented simultaneously, and therefore encoded during the same sustained attentional state. Participants were presented with 300 images, 150 old and 150 foils matched for task relevance and category frequency. This number was lowered from Experiment 2 to reduce overall task length. The previously seen images comprised 75 pairs: 25 task-relevant infrequent stimuli plus their task-irrelevant pairs, 25 task-irrelevant infrequent stimuli plus their task-relevant pairs, and 25 task-relevant frequent stimuli plus their task-irrelevant pairs presented simultaneously during the CPT.

Analysis

Sustained attention and memory performance were again calculated using the sensitivity measure A'. AUC values were also calculated for each participant to confirm that memory accuracy criteria did not bias overall performance measures. Pretrial RT speed and variance were calculated using the same methods as Experiment 1. In Experiments 2 and 3, logistic models again included a random intercept for subject and were fit for each experiment separately. Comparing model results across experiments provides a measure of consistency for results across independent datasets.

Experiments 2 and 3 results

CPT performance positively predicts relevant and irrelevant item memory

CPT performance (A') across participants was high in both Experiment 2 (M = .917, SD = .052, 95% CI [.909, .924]) and Experiment 3 (M = .904, SD = .052, 95% CI [.897, .912]). Additionally, participants responded with a categorization judgement key press on the vast majority of CPT trials (M_2 = .986, SD_2 = .014, 95% CI_2 [.984, .988]; M_3 = .983, SD_3 = .015, 95% CI_3 [.981, .986]) suggesting that participants were responding appropriately. Accuracy was .711 (SD = .169) and .674 (SD = .163) for infrequent-category images and .978 (SD = .018) and .974 (SD = .023) for frequent category images in Experiments 2 and 3, respectively.

Memory performance (A') was relatively high for both relevant (M_2=.589, SD_2=.116, 95% CI_2 [.572, .606]; M_3 = .658, SD_3 = .078, 95% CI_3 [.647, .669]) and irrelevant stimuli (M_2 = .551, SD_2 = .134, 95% CI_2 [.532, .570]; M_3 = .563, SD_3 = .125, 95% CI_3 [.545, .581]) across experiments. AUC values of memory performance were numerically above chance for both relevant (M_2 = .550, SD_2 = .054, 95% CI_2 [.542, .558]; M_3 = .597, SD_3 = .057, 95% CI_3 [.589, .606]) and irrelevant stimuli (M_2 = .521, SD_2 = .037, 95% CI_2 [.515, .526]; M_3 = .517, SD_3 = .040, 95% CI_3 [.511, .522]). Again, we do not statistically compare performance against chance levels because participants were excluded for low performance in these measures. However, overall performance values suggest that participants were not simply guessing and, therefore, that individual trials contain information about sustained attentional state and memory.

Individual differences analyses revealed that overall performance on the CPT was not related to relevant-item memory in Experiment 2 (Spearman's *rho* = .043, p = .561) nor Experiment 3 (Spearman's *rho* = −.033, p = .660). Better overall CPT performance was related to better memory for irrelevant stimuli in Experiment 2 (Spearman's *rho* = .209, $p = 4.09 \times 10^{-3}$) but this relationship was not significant in Experiment 3 (Spearman's *rho* = −.021, p = .775).

Our main question of interest was how sustained attention fluctuations affected task-relevant and task-irrelevant stimulus memory. Therefore, we next tested the relationship between performance on infrequent CPT trials (i.e., correct presses vs. lapses) and memory for task-relevant stimuli. Both narrow and diffuse models of sustained attention, respectively predicting more and less irrelevant-item filtering during engaged states, would predict that moments of higher sustained attention would lead to greater processing for task-relevant stimuli than moments of low sustained attention. Therefore, we expected a positive relationship, such that correct performance on infrequent CPT trials leads to better memory for images presented during those trials.

We constructed logistic models to test whether sustained attention (i.e., CPT performance) predicted memory. We restricted our analysis to task-relevant, infrequent stimuli, because those trials represent momentary probes of attentional state during the CPT when participants are tasked with changing a prepotent response, whereas accuracy for frequent-category stimuli during the CPT was at ceiling (mean hit rate Experiment 2 = 97.8%; mean hit rate Experiment 3 = 97.4%). The following model was used to test the relationship between sustained attentional state and subsequent memory for individual images:

$$\begin{aligned} &\textit{Memory for task-relevant, infrequent stimuli} \\ &\quad \sim \textit{CPT accuracy} + (1|\textit{subject}). \end{aligned} \tag{5}$$

CPT accuracy predicted memory for infrequent, task-relevant stimuli in both Experiment 2 (b = .134, SE = .029, p < .001) and Experiment 3 (b = .202, SE = .034, p < .001; Fig. 5). This result confirms findings from Experiment 1 and other work (Corriveau et al., 2024; deBettencourt et al., 2018; Wakeland-Hart et al., 2022) that sustained attentional state predicts memory for task-relevant images. Images presented when sustained attention is high are likely to be remembered, a finding that is predicted by both the narrow and diffuse attentional hypotheses.

The key question is then, what is the mnemonic fate of task-irrelevant stimuli presented in the CPT where selection demands were low? While the narrow and diffuse models of sustained attention predict a positive relationship between sustained attention and memory, they provide different predictions for the mnemonic fate of task-irrelevant stimuli. A narrow model suggests that, during moments of high attention, processing of irrelevant stimuli will be decreased such that they are better filtered. Another possibility is that participants may shift spatial attention to irrelevant stimuli during an attentional lapse, leading to filtering of task-*relevant* stimuli during lapses. In both cases, we would expect a *negative* relationship between sustained attention performance during the CPT and memory for

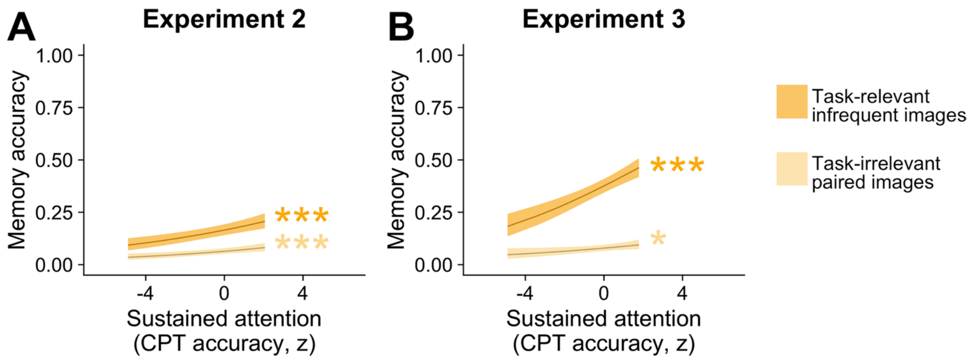

Fig. 5 Model fits from (**A**) Experiment 2 and (**B**) Experiment 3 predicting memory for task-relevant and task-irrelevant images from CPT accuracy. Models were fit separately for task-relevant infrequent images and their paired task-irrelevant images. Models included fixed effects of CPT accuracy and a subject-level random intercept

task-irrelevant stimuli. On the other hand, a diffuse processing model proposes that moments of high attention are characterized by greater processing of all stimuli, such that we would expect a *positive* relationship between CPT performance and memory for irrelevant stimuli.

To distinguish between these narrow and diffuse hypotheses of sustained attention, we next investigated the effect of sustained attention on memory for task-irrelevant stimuli presented alongside infrequent, task-relevant stimuli:

$$\begin{aligned}&\textit{Memory for task-irrelevant, paired stimulus}\\&\quad\sim \textit{CPT accuracy} + (1|\textit{subject}).\end{aligned} \tag{6}$$

We found a positive relationship between CPT accuracy and memory for task-irrelevant stimuli in both Experiment 2 (b = .127, SE = .037, p < .001) and Experiment 3 (b = .111, SE = .051, p = .029; Fig. 5), suggesting that stimuli presented during moments of high attention were better remembered even if they were not relevant for the task at hand. These results align with the diffuse processing view of sustained attentional state, such that a high sustained attentional state does not increase the filtering of task-irrelevant information, but rather results in more processing for all stimuli regardless of task relevance.

Stimulus features do not drive the diffuse processing of sustained attention

One possibility is that these results are driven by the attentional boost effect, such that irrelevant stimuli presented alongside infrequent, relevant stimuli are better remembered (Lin et al., 2010; Swallow & Jiang, 2010). To test this, we asked whether the frequency of the task-relevant stimuli predicted memory for task-irrelevant stimuli presented at the same time. We find that irrelevant stimuli paired with infrequent, task-relevant stimuli were indeed better remembered in Experiment 3 (b = .318, SE = .062, p < .001) but this was not the case in Experiment 2 (b = −.061, SE = .111, p = .582). Therefore, while the attentional boost effect may contribute to the relationship between sustained attention and task-irrelevant memory in Experiment 3, this effect cannot entirely explain the present results.

Another possibility is that these effects are driven by one condition due to the different categories of stimuli presented. For example, perhaps irrelevant scenes are easily ignored because they surround relevant faces whereas irrelevant faces are always in the center of relevant scenes so may be harder to disregard. We tested whether CPT accuracy predicted relevant-item and irrelevant-item memory within face-relevant and scene-relevant conditions. In face-relevant sessions, CPT accuracy predicted relevant face memory in Experiment 3 (b = .105, SE = .048, p = .030) but not in Experiment 2 ($b = -3.47\times10^{-3}$, SE = .043, p = .936) where face memory was poor (mean A' = .535, SD = .108, 95% CI [.513, .558] for task-relevant faces). In face-relevant sessions, CPT accuracy predicted irrelevant scene memory in Experiment 2 (b = .169, SE = .054, $p = 1.62\times10^{-3}$) but not Experiment 3 (b = .126, SE = .068, p = .064). When scenes were the relevant stimulus category, CPT accuracy predicted relevant stimulus memory in Experiment 2 (b = .232, SE = .038, p < .001) and Experiment 3 (b = .287, SE = .047, p < .001). Prediction for irrelevant face memory was positive but non-significant in both Experiment 2 (b = .087, SE = .052, p = .095) and Experiment 3 (b = .092, SE = .080, p = .249). While the strength of predictions was reduced when considering sessions separately, the relationship between CPT accuracy and stimulus memory does not seem to be specific to face-relevant or scene-relevant sessions.

CPT accuracy predicts confident memory accuracy

Memory accuracy was determined using confident ratings for old stimuli. In other words, correct memory for an old stimulus constituted a rating of 4 ("definitely old") during the memory task, whereas less confident ratings were marked as incorrect. This decision was based on previous work which utilized the same confidence threshold for memory judgements (Corriveau et al., 2024; deBettencourt et al., 2018; Kim et al., 2014; Wagner et al., 1998; Wakeland-Hart et al., 2022). However, memory judgements were rated using a 1–4 scale which provides insight into memory confidence for each image. Does infrequent CPT trial accuracy predict memory confidence for infrequent stimuli? To test this, we constructed ordinal models predicting memory strength (1–4; 1 = *definitely new*, 2 = *maybe new*, 3 = *maybe old*, 4 = *definitely old*) with a fixed effect of CPT infrequent trial accuracy and a subject-wise random intercept. Models were built using R's *clmm* function from the package *ordinal* (Christensen, 2022). CPT accuracy positively predicted relevant-item memory strength in both Experiment 2 (b = .091, SE = .019, $p \leq .001$) and Experiment 3 (b = .157, SE = .028, $p \leq .001$). For irrelevant-item memory, CPT accuracy positively predicted memory strength in Experiment 2 (b = .046, SE = .020, p = .020) but this prediction was not significant in Experiment 3 ($b = 4.22\times10^{-3}$, SE = .028, p = .881). Therefore, CPT accuracy is related to relevant-item memory confidence but may be less reliable in predicting the memory strength of irrelevant stimuli.

Memory for a task-relevant image does not predict memory for its task-irrelevant pair

Since task-relevant and irrelevant stimuli are presented in pairs, each pair was seen in the same attentional state. Therefore, we asked whether memory for task-relevant stimuli predicted memory for their irrelevant pairs. A narrow focus model of sustained attention would predict a negative relationship, whereby better memory for task-relevant stimuli would be accompanied by better filtering of task-irrelevant stimuli. On the other hand, a diffuse processing model of sustained attention would predict a positive relationship such that better memory for task-relevant stimuli would co-occur with better memory for other information presented simultaneously. To test this, we constructed linear models predicting memory for task-irrelevant stimuli with a fixed effect of task-relevant item memory. This analysis included all pairs of simultaneously presented stimuli tested for memory. Models were constructed for Experiments 2 and 3 separately and intercept varied by subject.

Memory for task-relevant information positively but non-significantly predicted memory for irrelevant paired items in Experiment 3 (b = .047, SE = .030, p = .109) in which the task design maximized the number of task-relevant and task-irrelevant stimulus pairs tested (Experiment 2, M = 55.14, SD = 2.29 pairs tested; Experiment 3, M = 74.76, SD = .80 pairs tested). There was no relationship between memory for task-relevant and task-irrelevant pairs in Experiment 2 (b = .001, SE = .034, p = .965). While the predictions of task-irrelevant item memory from task-relevant memory were positive and therefore in the direction of predictions from the diffuse processing model, this result does not replicate previous findings that task-relevant item memory predicts memory for task-irrelevant information presented simultaneously (Corriveau et al., 2024). On their own, these null findings do not lend strong support to the hypotheses that sustained attention increases or decreases processing of task-irrelevant information.

Stimulus relevance and frequency predict memory

What factors, in addition to sustained attentional state, affect memory? For example, prior work on the effect of selective attention would predict that relevant stimuli are better remembered than irrelevant stimuli (Rees et al., 1999). Previous work would also suggest that infrequent stimuli are more salient and therefore may also lead to higher memory performance than observed for frequent stimuli (Corriveau et al., 2024; deBettencourt et al., 2018; Decker et al., 2023b; Wallace, 1965). To test how individual factors influenced memory, we constructed a comprehensive model with sustained attention measures, as well as other stimulus characteristics that may have contributed to memory. For this model, RT speed, RT variance, and their interaction were included as sustained attention measures because they provide a continuous index of attentional state, whereas accuracy was near-ceiling for frequent-category trials.

We first confirmed that, as in Experiment 1, RT speed and variance were reliable predictors of sustained attentional state in Experiments 2 and 3. Within-subject RT speed and variance were again largely unrelated within subjects (Mean r_2 = .146, SD_2 = .232; Mean r_3 = .110, SD_3 = .276), suggesting these predictors are not collinear. Linear models predicting CPT performance from RT variables in Experiments 2 and 3 again find that both speed (b_2 = .633, SE_2 = .031, p_2 < .001; b_3 = .604, SE_3 = .042, p_3 < .001) and variance (b_2 = −.293, SE_2 = .027, p_2 < .001; b_3 = −.219, SE_3 = .036, p_3 < .001) predicted lapses in sustained attention. The interaction between RT speed and variance predicted infrequent trial accuracy in Experiment 2 (b = .064, SE = .027, p = .019) but prediction was not significant in Experiment 3 (b = −.046, SE = .035, p = .195). These results validate RT measures as reliable and unique signatures of sustained attention during the CPT, even when task-irrelevant distractors are present.

We next constructed comprehensive mixed effects models to determine what measures, in addition to sustained attentional state, predicted trial-level memory for stimuli. Models included fixed effects of stimulus relevance (irrelevant vs. relevant), frequency (infrequent vs. frequent), and category (scenes vs. faces). RT speed, RT variance, and their interaction were included as measures of sustained attention. CPT accuracy was not included in the model because CPT performance on frequent trials was near ceiling. Models included a random intercept term for individual subjects. Models were fit for Experiments 2 and 3 separately for internal replication of significant predictors. Results are shown in Table 1.

$$memory\ accuracy \sim relevance + frequency + category + RT\ speed * RT\ variance + (1|subject) \quad (7)$$

We observed the expected effect of selective attention such that task-relevant images were better remembered in both experiments. This suggests that participants processed the images relevant for successful CPT performance more than irrelevant images. Stimulus frequency also predicted image memory but the pattern differed between experiments. In Experiment 2, frequent stimuli were remembered better than infrequent stimuli whereas in Experiment 3, we observed the opposite, expected pattern: infrequent stimuli were remembered better than frequent stimuli. Possible explanations of this finding are discussed later. Scenes were remembered better than faces in Experiment 3, but this category effect was not observed in Experiment 2 when controlling for other predictors of memory. Finally, RT variance predicted memory in Experiment 3 such that stimuli preceded by more erratic pressing were more likely to be forgotten. RT speed and the interaction between RT speed and variance did not predict memory in either Experiment 2 or 3. RT measures of sustained attentional state did not significantly predict memory for stimuli in Experiment 2 when other variables were included in the comprehensive model. While this may be due in part to worse overall memory for face stimuli in Experiment 2, it also suggests that the effects of sustained attention on memory are smaller than other those of predictors (e.g., selective attention) and may be lost when all variables are considered together. These results demonstrate that many factors, including selective and sustained attention, contribute to the mnemonic fate of images.

The finding that infrequent stimuli in Experiment 3 were better remembered aligns with the von Restorff effect and replicates previous work (Corriveau et al., 2024; deBettencourt et al., 2018; Decker et al., 2023b; Wallace, 1965). However, the inverse effect in Experiment 2 across scene and face categories was puzzling. We wondered whether this was a result of the criteria for memory accuracy, such that only confidently-remembered stimuli were considered correctly-remembered. To test this, we refit the models to predict whether stimulus relevance, frequency, and their interaction predicted whether a stimulus received *at least* a memory confidence rating of 3. That is, stimuli were considered correctly remembered if they were reported as "definitely old" or "maybe old," whereas the previous results only considered "definitely old" responses to indicate correct recognition. Here, we will focus on the effects of stimulus frequency on memory. However, full results of this analysis can be found in Supplementary Table 1. Interestingly, across both experiments, lowering the threshold for correct memory found a reverse in the effect of stimulus frequency on memory, such that frequent stimuli were better remembered in both Experiment 2 ($b = -.343$, $SE = .022$, $p < .001$) and Experiment 3 ($b = -.207$, $SE = .027$, $p < .001$). Therefore, the von Restorff effect may not apply to less-confident judgements of memory, which were more common in Experiment 2, $t(29333) = -14.89$, $p < .001$.

Discussion

This series of experiments investigated the impact of sustained attentional state on recognition memory for images. We first tested whether behavioral predictors of sustained attention also predicted memory in an online sample. In

Table 1 Results from models predicting stimulus memory from fixed effects of stimulus relevance, frequency, category, RT speed, RT variance, and the interaction between RT speed and variance

	Experiment 2			Experiment 3		
	Coef.	*SE*	Sig.	Coef.	*SE*	Sig.
Relevance *(irrelevant vs relevant)*	−.835	.031	<.001 ***	−1.601	.036	<.001 ***
Frequency *(infrequent vs frequent)*	−.101	.030	<.001 ***	.282	.034	<.001 ***
Category *(scenes vs faces)*	.009	.031	.777	.336	.036	<.001 ***
RT speed	−.004	.017	.825	.032	.018	.077
RT variance	.001	.016	.959	−.034	.017	.040 *
RT speed: RT variance	.014	.013	.292	.021	.015	.145

Models were fit within-experiment. A subject-level random intercept term was included in each model

***$p < .001$. **$p < .01$. *$p < .05$

Experiment 1, infrequent-category images were better remembered, in line with previous work showing better memory for unique stimuli (von Restorff, 1933; Wallace, 1965). Images presented during lapses in attention were more likely to be forgotten, replicating previous work (Corriveau et al., 2024; deBettencourt et al., 2018; Decker et al., 2023b; Wakeland-Hart et al., 2022) in a sample for whom testing conditions were less controlled than in-laboratory studies. RT speed and variance, which predicted lapses in the CPT, also predicted recognition memory for infrequent stimuli. Images preceded by fast and variable presses were more likely to be forgotten, in agreement with previous findings (Corriveau et al., 2024; deBettencourt et al., 2018; Wakeland-Hart et al, 2022). Results from Experiment 1 demonstrate effects of attentional state on memory replicate in less-constrained online samples.

Subsequent experiments tested the impact of sustained attentional state on memory when images were accompanied by irrelevant stimuli. Two independent samples of online participants (n = 373 total) were presented with both task-relevant and task-irrelevant faces and scenes simultaneously. We tested whether sustained attentional state impacted memory for relevant and irrelevant memory in the same direction, as predicted by a diffuse processing view of sustained attention in which engaged attention increases processing of irrelevant items, or opposite directions, as predicted by a narrow focus or tradeoff view of sustained attention in which engaged attention increases filtering of irrelevant items. To do so, we constructed logistic models predicting memory for infrequent task-relevant and task-irrelevant items from sustained attention measured using CPT performance accuracy. Stimuli presented during moments of high attentional state as quantified by accurate CPT performance were better remembered, regardless of task relevance, whereas stimuli presented during moments of low attention were more likely to be forgotten. In other words, attentional state impacted memory similarly for both task-relevant and task-irrelevant stimuli, lending support to the diffuse processing view of sustained attentional state. This view suggests that sustained attention does not enhance selective attentional filtering of task-irrelevant information when task selection demands are low, but rather supports processing of both task-relevant *and* task-irrelevant stimuli.

Previous work shows that recognition memory is impacted by whether information is attended (Rees et al., 1999; Ruz et al., 2005a) and how attention is directed (Uncapher & Wagner, 2009). The current findings expand on this work by demonstrating that effects of selective attention are impacted by sustained attention dynamics: when sustained attention is engaged, task-irrelevant information is filtered less and remembered better. Related work has investigated differences in recall for task-irrelevant stimuli. The attentional boost effect describes a phenomenon in which irrelevant stimuli paired with a rare task-relevant target are better remembered (Lin et al., 2010; Swallow & Jiang, 2010). Salient targets may be accompanied by an increase in sustained attentional state which may result in the enhanced processing and memory observed. Here, we found evidence for the attentional boost effect in Experiment 3 but not in Experiment 2, suggesting the relationship between sustained attentional state and irrelevant-item memory is not fully driven by stimuli paired with salient targets. Rather, sustained attentional state may fluctuate throughout the task due to a number of reasons in addition to salient stimuli, leading to changes in stimulus processing. Perceptual load theory (Lavie, 1995) provides another framework for understanding the current results. Specifically, previous work has shown that processing of irrelevant items varies as a function of how perceptually demanding task goals are, such that lower task-relevant demand results in increased processing for irrelevant information. Here, high sustained attentional state may be analogous to low perceptual demand, allowing spare capacity for processing and encoding of task-irrelevant stimuli.

Our findings suggest that sustained attention does not affect processing specifically for relevant items in the focus of selective attention, as might be suggested by previous work characterizing selective attention with a spotlight analogy (Posner, 1980) or by other hypotheses such as biased competition theory positing that bottom-up salience and top-down goals drive attention to behaviorally relevant objects, features, and locations (Beck & Kastner, 2014; Desimone & Duncan, 1995; Vecera & Behrmann, 2001). In the CPT, neither bottom-up salience nor top-down goals should prioritize irrelevant-item processing during moments of engaged relative to disengaged sustained attention. Rather, sustained attentional state may modulate the amount of overall processing that can occur at a given time, including processing of task-irrelevant information. Previous work has similarly questioned the aptness of a spotlight analogy for visuospatial attention (Cave & Bichot, 1999). In particular, work testing the scope of a visuospatial spotlight has found evidence that the distribution of attention over space as well as the strength of processing within this scope changes over time (Eriksen & St. James, 1986; Jonides, 1983; LaBerge & Brown, 1989; LaBerge et al., 1997; Sperling & Weichselgartner, 1995). The current work tests how the amount of processing, both in selective attention's focus (task-relevant stimuli) and outside its focus (task-irrelevant stimuli), varies as a function of sustained attentional state.

It is important to note that the current study cannot distinguish whether a high sustained attentional state enhances memory and/or a low sustained attentional state impedes memory because we have no measure of participants' baseline memory performance. It is possible that high sustained attentional states allow more overall stimulus processing than moments of low sustained attention and therefore result in enhanced memory representations. Another nonmutually exclusive possibility is that during low sustained attentional states, attentional capacity may be redirected to cognitive processes which impede encoding of stimuli into memory, such as mind wandering (Smallwood & Schooler, 2006), although the link between mind wandering and sustained attentional state is complex (Kucyi et al., 2016, 2017). Given that the current study investigates relative sustained attention and memory performance within individuals, we can only conclude that the relative differences in processing between high and low sustained attentional states lead to relative differences in memory performance.

The current study also does not speak to whether effects of sustained attention dynamics on selective attention vary with cognitive and/or perceptual demands of the central task. The CPT was designed with low selection demands, such that task-relevant image categorization could be performed without necessarily filtering task-irrelevant stimuli. It is possible, therefore, that results would differ under conditions in which task-irrelevant stimuli interfered with task-relevant goals. Additionally, task difficulty in the current study (i.e., categorization of faces and scenes) was low. Increasing the perceptual or cognitive demands of the central task may affect how irrelevant stimuli are processed (Lavie, 1995; Lavie et al., 2004), and this may change as a function of sustained attentional state. These are important areas for future work.

While stimuli in the current study were visual and always consisted of a central face superimposed on a scene image, sustained attention need not affect only visuospatial processing. If this were the case, we might expect the current results to be driven by scene-relevant sessions where irrelevant faces occlude relevant scenes and therefore are difficult to filter. However, the prediction of memory from CPT accuracy within both face- and scene-relevant sessions demonstrates that sustained attention affects stimulus processing similarly across conditions and spatial arrangements of stimuli. Further, previous work testing the effects of sustained attention on auditory and visual stimuli found similar evidence of diffuse processing when relevant and irrelevant stimuli were presented in separate perceptual modalities (Corriveau et al., 2024). Future work should aim to test the contexts in which attentional fluctuations impact processing in a diffuse manner.

Unsurprisingly, we saw a robust effect of selective attention: memory for relevant images was better than memory for irrelevant images across experiments and stimulus types, suggesting that stimuli are better encoded if they are necessary for a task. A comprehensive model which included predictors of selective attention (stimulus relevance) and sustained attention (RT measures) found evidence that these explain unique variance in image memory. These results highlight that attention is not one process but contains separable components that may uniquely affect cognition (Amengual et al., 2022; Chun et al., 2011). We also saw evidence of the von Restorff effect in Experiment 3 such that infrequent stimuli were better remembered than their frequent counterparts. However, lowering the criteria for correct memory judgments saw a flip of this effect in both experiments, such that frequent stimuli were better remembered. Therefore, the von Restorff effect may be specific to confident memory judgements.

The current results demonstrate that sustained attention, which fluctuates over time, predicts subsequent memory. Importantly, it predicts memory for task-relevant and task-irrelevant stimuli similarly, such that moments of high attention lead to higher memory, whereas lapses in attention were associated with forgetting for both task-relevant and task-irrelevant stimuli. This provides further evidence that sustained attention affects visuospatial processing like a flickering floodlight, varying the capacity for processing of both relevant and irrelevant items in tandem. These findings demonstrate the importance of further testing the impact of sustained attention on information processing and cognition.

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Authors' contributions ACo: Formal analysis, Visualization, Writing–original draft; ACh: Conceptualization, Data curation, Formal analysis, Investigation, Writing–review and editing; MTdB: Conceptualization, Data curation, Formal analysis, Methodology, Project administration, Supervision, Writing–review and editing; MDR: Conceptualization, Project administration, Resources, Supervision, Writing–review and editing.

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Data availability Data are publicly available online (https://osf.io/vxuba/).

Code availability Analysis scripts are publicly available online (https://osf.io/vxuba/).

Declarations

Ethics approval All experiments were conducted with approval by the Social and Behavioral Sciences Institutional Review Board at the University of Chicago.

Consent to participate All participants provided their written informed consent prior to participation.

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Conflict of interest All authors declare no conflicts of interest.

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