No Role for Activated Long-term Memory in Attentional Control Settings

Lindsay Plater, Maria Giammarco, Chris Fiacconi, and Naseem Al-Aidroos

Department of Psychology, University of Guelph

Author Note

Lindsay Plater, Maria Giammarco, Chris Fiacconi, and Naseem Al-Aidroos, Department of Psychology, University of Guelph.

Parts of this work were presented at the Canadian Society for Brain, Behaviour and Cognitive Science conference (2018), the Vision Sciences Society conference (2018), and the Lake Ontario Visionary Establishment conference (2018). Data, experiment code, and analyses are available on the Open Science Framework: https://osf.io/wrty2/.

This research was supported in part by an NSERC Canada Graduate Scholarship and a Queen Elizabeth II Graduate Scholarship in Science and Technology to Lindsay Plater, and an NSERC Discovery Grant (418507-201) and a CFI Grant (30374) to Dr. Naseem Al-Aidroos.

Correspondence concerning this article should be addressed to Lindsay Plater, Department of Psychology, University of Guelph, Guelph, ON N1G 2W1. E-mail: lplater@uoguelph.ca

Abstract

Visual spatial attentional capture is contingent on an observer's goals, or attentional control settings. Recent research has demonstrated that observers can adopt attentional control settings based on numerous visual objects represented in episodic long-term memory (LTM). But why do LTM representations that comprise an attentional control set bias attentional capture, when other LTM representations do not? In the present study, we tested the activated LTM account—that LTM representations form an attentional control set if, and only if, they are represented in activated LTM—by mixing a working memory task to test for representation in activated LTM, with a spatial blink task to test for the state of participants' attentional control settings. In Experiments 1 and 2, inducing participants to represent complex visual objects in activated LTM did not result in those objects forming an attentional control set. In Experiment 3, we found a dissociation between activated LTM and attentional control settings; objects that were represented in activated LTM produced greater intrusion effects (indicating representation in activated LTM) than objects that were part of an attentional control set, yet smaller capture effects. These results do not support the activated LTM account. We conclude that representation in activated LTM is not the factor that determines which LTM representations comprise an attentional control set, and discuss the implications of these findings for research on attentional templates and hybrid visual and memory search.

Keywords: attentional control set, activated long-term memory, attentional capture, attention, attentional template

No Role for Activated Long-term Memory in Attentional Control Settings

While it may sometimes feel like our attention is automatically drawn to salient sensory visual events, such as the flashing lights on a passing ambulance, the ability for such events to capture our attention is under our control. When we actively search our environment for one type of visual information (e.g., a friend wearing a *red* baseball cap), we adopt an attentional control setting (ACS) for the property that defines our target (i.e., red), which ensures that only ACS-matching stimuli possessing that property will capture our attention (Folk, Remington, & Johnston, 1992; Folk, Remington, & Wright, 1994). Formally, attentional capture is said to be contingent on ACSs; red stimuli will capture our attention when we are looking for something red, but not when we are looking for something green (Folk & Remington, 1998).

At present, we do not have a full understanding of how ACSs control capture. One aspect of this control process that is under active investigation is the memory system that stores the identity of the searched-for target, or (in cases of multiple targets) the searched-for target set (Berggren & Eimer, 2018; Giammarco, Paoletti, Guild, & Al-Aidroos, 2016; Goodhew, Kendall, Ferber, & Pratt, 2014; Olivers, Peters, Houtkamp, & Roelfsema, 2011; Woodman, Carlisle, & Reinhart, 2013; Wyble, Folk, & Potter, 2013). Interestingly, episodic long-term memory (LTM) is one of the memory systems that has been shown to maintain the contents of ACSs; we can simultaneously search our environment for at least 30 different visual objects by adopting an ACS based on representations of those objects in LTM, with the result that only those 30 objects will capture attention (Giammarco et al., 2016). But this finding also raises a question: Given the vast amount of information represented in LTM, what is special about the LTM representations that comprise an ACS, such that these representations bias attentional capture when other LTM representations do not?

Visual LTM and Visual Working Memory Both Contribute to ACSs

The most direct evidence that ACSs can be established based on representations in LTM comes from a recent study by our research group (Giammarco et al., 2016; see also Carlisle, Arita, Pardo, & Woodman, 2011, for related work on attentional templates in LTM). Attentional control settings are typically studied by measuring attentional capture using a Posner cueing task (Posner & Cohen, 1984) with task-irrelevant attentional cues. The conventional finding is that, when participants are monitoring the environment for the appearance of a particular visual target, only pre-cues that possess the target defining property (e.g., are the same colour as the target) will capture attention and produce a cueing effect (i.e., faster target response times when the target appears at the cued location than elsewhere; Folk & Remington, 1998; Folk, Remington, & Johnston, 1992; Folk, Remington, & Wright, 1994). To assess the possibility that ACSs can be defined based on representations in LTM, Giammarco et al. (2016) had participants memorize a list of 30 everyday, complex visual objects—a feat accomplished through LTM (Brady, Konkle, Alvarez, & Oliva, 2008; Guild, Cripps, Anderson, & Al-Aidroos, 2014; Wolfe, 2012)—and then used these target set items as the targets in a Posner cueing task. They found that the only cue stimuli to produce attentional capture were the objects from the memorized list, suggesting that participants had adopted an ACS for these LTM representations.

To provide converging evidence for their findings, Giammarco et al. (2016) measured attentional capture using another task commonly used to study ACSs: the spatial blink task (Folk, Leber, & Egeth, 2002). We also used this type of task in the present study. Giammarco et al. (Experiment 3, 2016) had participants memorize two separate lists that each contained 15 everyday visual objects (“List A” and “List B”), and then designated one of the lists as the target set for the spatial blink task. They used two lists in this experiment to show that ACSs can be constrained to a particular memory source (recollective memory), rather than being defined based on all recently memorized/familiar objects (Yonelinas, 2002). For the spatial blink task, participants monitored a centrally presented flashing stream of objects for the appearance of any one of the 15 target set objects, and indicated at the end of the stream which one they had seen. Notably, a pair of spatial distractors was presented before the target appeared, with one distractor object above and one below the central stream. In such spatial blink tasks, if either of the distractors are part of an ACS, the distractor will capture attention, and detection of a target appearing shortly thereafter is impaired (Folk et al., 2002). Notably, this attentional capture is only measurable when the distractors and the target are close together temporally; with more time between the distractors and the target, attention recovers to the central stream, and the target is easily detected. Giammarco et al. (2016) found that the only stimuli that captured attention were the 15 target set objects; novel objects and, critically, the equally familiar 15 memorized non-target set objects had no effect on participants’ ability to report the target. Based on these findings, the authors concluded that ACSs can be defined based on episodic long-term memory representations. Yet our question remains: What is special about the LTM representations of the 15 target set objects that allows capture to be constrained to only those objects?

While Giammarco et al.'s (2016) study demonstrates a role for LTM in establishing ACSs, it is not the only memory system that is capable of doing so. Indeed, the majority of past research examining memory and ACSs has focussed on visual working memory, an online memory system that is limited to storing accurate representations of about three to four visual objects (Luck & Vogel, 1997; Phillips, 1974). It may be possible to derive insights into the mechanisms underlying LTM-based ACSs from this visual working memory research. Much of the evidence that ACSs are supported by visual working memory comes from the demonstration that having participants remember a particular object using visual working memory (e.g., a red square) often causes attention to be drawn to similar stimuli in the environment (i.e., other red stimuli; Olivers, Meijer, & Theeuwes, 2006; Soto, Heinke, Humphreys, & Blanco, 2005). However, not all representations in visual working memory will necessarily bias attentional capture; for example, when participants are asked to remember two colours, it is often the case that at most one of these representations will bias attention (Olivers, 2009; although see Beck, Hollingworth, & Luck, 2012). As an account of this observation, Olivers, Peters, Houtkamp, and Roelfsema (2011) proposed that capture is determined by the state of representation in visual working memory: one representation can be in an active state, forming an *attentional template* that biases attention, and any other representations are in an accessory state that do not interact with attention. Accordingly, it appears that observers can adopt an ACS for, say, the colour red, by representing a red stimulus in visual working memory in the active state.

Perhaps a similar distinction between states of representation also determines which LTM representations bias attention. Might it be that the objects that comprise an LTM ACS capture attention when encountered in the environment because they are represented in an active state within LTM? Relevantly, the embedded-processes model of memory (Cowan, 1988; Oberauer, 2002) proposes a distinction between active and non-active LTM representations, and, beyond the similarity in nomenclature, aspects of this active LTM state make it well suited to supporting LTM ACSs.

The Embedded-processes Model of Memory

According to the embedded-processes model of memory, “memory” is a single, hierarchically organized store. The components of this model have changed slightly over time; that said, according to a recent version (Oberauer & Hein, 2012), memory comprises: 1) *LTM*, a potentially limitless store; 2) *active long-term memory (ALTM)*, the subset of LTM representations that were recently, or are currently, attended; 3) the *region of direct access*, a subset of ALTM representations that are currently within the broad focus of attention; and 4) the *narrow focus of attention*, a single representation within the region of direct access. Information represented within the region of direct access is consciously accessible; however, because attention is capacity limited, the amount of information stored in this region is constrained to about four items or chunks. Thus, the region of direct access is comparable to what we referred to above as working memory, with the narrow focus of attention being equivalent to the active state within working memory[1]. In contrast to *attention*, which is capacity limited, *activation* is time limited (Cowan, 1999); accordingly, the capacity of ALTM is larger than that of the region of direct access, and, indeed, has no known limit. Moreover, unlike other LTM representations, those in ALTM can directly interact with aspects of ongoing cognition, including recognition judgements of perceptual objects (Oberauer, 2001). Given the large potential capacity of ALTM, and the ability for ALTM representations to influence behaviour, this component of memory may be well suited to serve as the basis for LTM ACSs.

The main evidence that objects can be represented outside of working memory, yet still influence behaviour (i.e., be represented in ALTM), comes from Oberauer (2001), who measured *intrusion effects* with a modified Sternberg task. We also used a similar task in the present study. Oberauer (2001) had participants memorize and retain two short lists of words in working memory, and then tested memory at the end of the trial by presenting a single probe that required a recognition judgement. Prior to the probe, a cue was presented indicating that one list was no longer relevant, the idea being that participants may stop attending to these irrelevant items, leaving the items to only be represented in ALTM and not working memory. To assess whether irrelevant items were represented in working memory, Oberauer (2001) manipulated the set size of the irrelevant list (one vs. three words) and the time between the cue and memory probe. He

[1] According to embedded-processes memory models, ALTM is also a component of working memory (Cowan, 1988; Oberauer, 2002), reflecting the fact that ALTM representations are sufficiently accessible to guide behaviour (i.e., do work). For the present paper, however, we refer to ALTM as a form of LTM to align with the typical characterization that working memory is limited to representing 3 to 4 chunks of information, and items stored beyond this limit are represented outside of working memory, in LTM (Carlisle et al., 2011; Luck & Vogel, 1997; Olivers, 2009).

found that response times (RTs) to memory probes that appeared within one second of the cue were longer for the larger irrelevant set size, suggesting that the irrelevant items were initially stored in working memory (Sternberg, 1966). After about one second, however, irrelevant list set size had no effect on probe RTs, suggesting they were no longer represented in working memory. While the *number* of irrelevant items ceased affecting probe RTs about one second after the cue, the *identities* of these items continued to affect RTs for up to five seconds, the longest cue-probe interval used in the study. Specifically, on some trials an irrelevant item was presented as the memory probe, and participants took longer to correctly identify these probes as not being part of the relevant list than completely novel probes. This slowing of RTs is referred to as an *intrusion effect*, and demonstrates that ALTM representations outside of working memory can influence behaviour.

The Present Study

In the present study we investigated the potential role of ALTM in supporting LTM ACSs. Given the large capacity of ALTM, and given that ALTM representations can directly influence behaviour (i.e., without representation in working memory), we asked whether adopting an LTM ACS for a set of everyday visual objects is accomplished by representing those objects in ALTM. We henceforth refer to this possibility as the *ALTM account* of LTM ACSs. To investigate this account, across three experiments we combined a working memory task with a spatial blink task, allowing us to concurrently assess ALTM and ACSs, respectively. To preview the results, inducing participants to represent complex visual objects in ALTM (Experiments 1 and 2) was not sufficient to induce an ACS for those objects. Additionally, representation in ALTM can be dissociated from ACSs (Experiment 3). These findings lead us to reject the ALTM account, and conclude that representation in ALTM is not the factor that determines which representations in LTM comprise an ACS, and which do not.

Experiment 1

As a first step in investigating whether LTM ACSs are accomplished through ALTM, Experiment 1 tested the prediction that inducing a set of objects to be represented in ATLM would cause those objects to form an ACS and preferentially capture attention. Accordingly, in Experiment 1 we used a modified version of Oberauer's (2001) working memory task to manipulate the contents of ALTM on every trial, and then tested either the state of ALTM by measuring intrusion effects, or the state of participants' ACSs by measuring the spatial blink. At the beginning of the experiment, participants were shown the task instructions along with three visual objects that would serve as the target set for the spatial blink task for the duration of the experiment. On each trial, participants first memorized two lists of visual objects (set sizes 1 or 3), and were then provided a cue indicating which list was relevant for that trial, and which list could be ignored. Because the objects from the ignored list are task *irrelevant*, participants should only maintain representations of these objects in ALTM, and not working memory (Oberauer, 2001). Some trials ended with a memory probe, allowing us to verify whether objects from the irrelevant list were only represented in ALTM (i.e., no effect of irrelevant list set size, yet slower RTs when irrelevant list objects appeared as the memory probe than novel objects). Other trials ended with a spatial blink task, in which participants searched for any one of the three designated target set objects in a rapidly presented stream of images. Distractor objects appeared before the target, allowing us at assess the state of participants' ACSs. If representation in ALTM is indeed the factor that determines whether an LTM representation is part of an ACS or not, then the irrelevant list objects from the working memory task should capture attention and produce a spatial blink.

Method

Participants[2]. For all studies, informed consent was obtained from each participant, experimental protocols were approved by the University of Guelph ethics board, and all participants reported having normal, or corrected-to-normal, visual acuity. A sample of 56 undergraduate students from the University of Guelph (mean age 19.8 years, 48 females) participated in Experiment 1 for partial course credit. Multiple participants had to be excluded from analyses due to the difficulty of the two tasks; this included four participants with error rates at 40% or higher on the working memory task, and two participants with error rates at 40% or higher on the spatial blink task. Thus, Experiment 1 had a final sample size of 50 participants. Notably, including all participants in the analyses reported below does not alter the pattern of statistically significant effects.

Apparatus, stimuli, and procedure. All experiments were conducted on a desktop computer with a 1280 × 1024 resolution 75 Hz CRT display, and responses were made on a standard keyboard. Participants used a head and chin rest to keep their gaze distance constant at 52 cm from the computer screen for the duration of the experiment. All object images were presented on a white background, and were unique objects selected from Brady, Konkle, Alvarez, and Oliva (2008); these were the same objects used in Giammarco et al. (2016). Objects were from many categories, including: food, animals, general household objects, tools, clothing, appliances, vehicles, and buildings. The three objects that served as the target set for the spatial blink task were randomly selected without replacement for each participant from a pool of 125 objects. All other object images were randomly selected from a separate pool of 2,152 objects.

All trials started with a working memory array, and ended with either a memory probe (working memory task) or a spatial blink trial (spatial blink task)

Working memory task. Participants completed 144 trials of a modified version of Oberauer's (2001) modified Sternberg task; see Figure 1A. Each trial started with a white fixation screen that contained a black central fixation cross measuring 1 × 1°, presented for 1,000 ms. Next, a memory array appeared, which consisted of two lists that each contained either one or three objects per trial. One list was presented 10° above the center of the screen, and was presented in a red rectangular frame. The other list was presented 10° below the center of the screen, and was presented in a blue rectangular frame. Both frames were 5° high, 30° wide, with lines that were 0.04° thick. Each object subtended 3 × 3° and appeared in one of three possible locations within the rectangular frame: 10° to

---

[2] At the suggestion of the editor and reviewers, participants were added to this experiment during the review process in order to increase our confidence in the reported effects. The original submission had a sample size of 36 (with five participants removed for a final sample size of 31, mean age 19.5 years of age, 29 females). To ensure precise estimates of the critical measured effects, we stopped data collection once the 95% CIs were less than 5% wide for the critical "lag 2" and "lag 8" differences between irrelevant and novel distractor conditions (Kruschke, 2015, Chapter 13).

the left of center, central, or 10° to the right of center. Objects and frames during the memory array were presented for 1,000 ms per object. For example, on a trial with one object in each frame, the memory array was presented for 2,000 ms. The memory array was followed by an 800 ms memory delay, which was followed by a cue screen. On the cue screen, a rectangular frame (5° high, 30° wide, lines 0.04° thick) was centrally presented. The cue was randomly presented in red or blue, and indicated to participants which memory list would be probed at the end of the trial (i.e., the *relevant list*) and, consequently, which list was now *irrelevant*. This cue was 100% valid. Oberauer (2001) reported that, for young adults, within 1,000 ms the irrelevant items were no longer represented in working memory. Since we changed the stimuli used from words to complex visual objects, to be conservative we presented the cue for 2,400 ms before adding the 3 × 3° memory probe to the display. The probe object could be: a relevant list object (relevant probe, 50% of trials, requires a "yes" response), an irrelevant list object (irrelevant probe, 25% of trials, requires a "no" response), or a novel object (novel probe, 25% of trials, requires a "no" response). Participants had 1,600 ms to respond whether the probe had been present in the relevant list; if participants made an incorrect response, or failed to respond in time, a 500 Hz error tone sounded for 50 ms. The levels of relevant list set size (1 vs. 3), irrelevant list set size (1 vs. 3), and probe type (relevant vs. irrelevant vs. novel) were fully crossed for each participant.

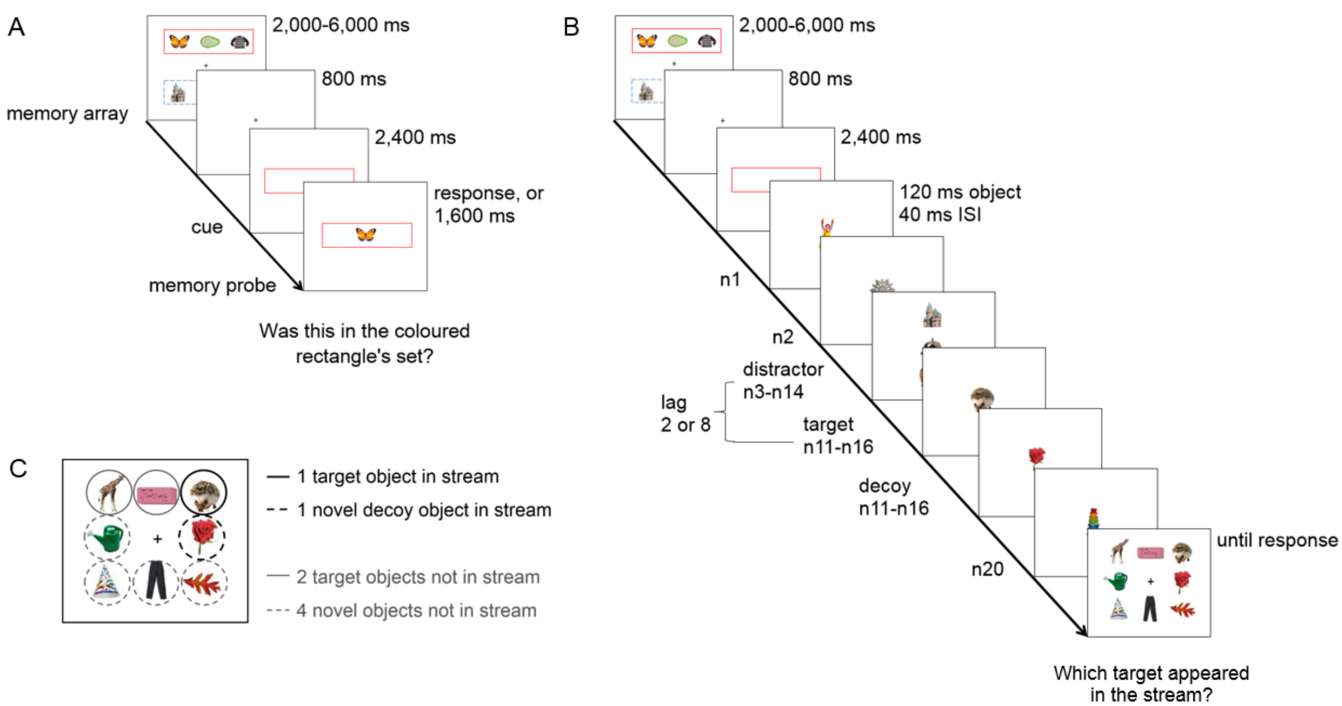

Figure 1. Sample trial sequences for Experiments 1, 2, and 3. The dashed line in the memory array represents the blue rectangle, which was a solid line during the experiment. A) Trial sequence for the working memory task. Participants must report whether the object that appears was located in the cued coloured rectangle's set. B) Trial sequence for the spatial blink task. On the final response screen, participants must select the target object that had appeared in the stream. On this trial, the critical distractor is an irrelevant object. C) Breakdown of the object types on the spatial blink selection screen for Experiment 1.

Spatial blink task. Randomly mixed with the working memory task, participants completed 144 spatial blink trials (Giammarco et al., 2016); see Figure 1B. Participants were instructed to keep their gaze on the middle of the screen and to look for one of the three spatial blink target set objects in the rapidly presented stream of objects. Each trial started identically to trials from the working memory task, but a spatial blink stream was presented after the cue screen, rather than a memory probe. During the stream, 20 random objects that each subtended 3.4 × 3.4° were presented centrally one at a time for 120 ms, separated by an inter-stimulus interval of 40 ms. Both a target object and a novel decoy object appeared within the stream, and could be at position 11 – 16. Notably, two distractor objects were presented either two or eight screens before the target (i.e., distractor–target lag 2 or 8), centered 4.24° above and below the central stream. Distractor objects subtended 4.58 × 4.58°, and appeared and disappeared with the central stream object. One distractor was the critical distractor, which was either an object from the irrelevant list in the working memory task (irrelevant distractor, 50% of trials), or a novel object (novel distractor, 50% of trials). The critical distractor was never the target object or the decoy object for that trial. The other distractor was a randomly selected novel object that was different from all other novel objects presented during the trial. Critical distractor type (irrelevant or novel) and distractor–target lag (2 or 8) were fully crossed and occurred with equal frequency for each participant. All other objects presented during the spatial blink task were novel objects randomly selected from the pool of 2,152 objects.

At the end of the stream, there was a response screen with a 1 × 1° black central fixation cross and eight 3 × 3° objects arranged in a 10 × 10° grid around fixation. Participants were instructed to select the target object that had appeared in the spatial blink stream on the current trial by pressing the corresponding key on the keyboard numeric keypad. The objects presented on the spatial blink response screen (see Figure 1C) always included: the target set object that appeared in the stream (i.e., the target for this trial); the other two target set objects that did not appear in the stream; one of the novel objects that appeared in the stream, which served as the decoy object; and four novel objects that did not appear in the stream. The decoy object was included on the response screen to ensure participants selected only the target object that appeared within the stream. The critical distractor object, which should be ignored, was never included as an option on the response screen in order to prevent participants from attempting to strategically use distractor objects. There was no time limit for response selection, and participants were encouraged to be as accurate as possible for this task. If the participant selected the wrong object, a 500 Hz tone was played for 50 ms.

Statistical analyses. As is conventional, we predominately conducted inferential statistical analyses using null-hypothesis significance tests. We also made use of Bayes factors (*BF*s), in particular when interpreting null effects (for a review of *BF*s, see Morey & Rouder, 2011). Briefly, a BF_{01} compares the null model against the alternative, with a BF_{01} value greater than 1 indicating evidence in favour of the null model (i.e., no difference between conditions), and less than 1 indicating evidence in favour of the alternative model. A BF_{10} compares the alternative model against the null model (i.e., $BF_{10} = 1 / BF_{01}$). *BF* values from 1–3 indicate anecdotal (insufficient) evidence, 3–10 moderate evidence, and greater than 10 strong evidence. We calculated *BF*s using JASP version 0.8.3.1 (JASP-Team, 2017), and used the default priors as they are appropriate for the critical, novel tests in the present study where we have no strong predictions about how the data should look (Wagenmakers et al., 2018). JASP was also used for null-hypothesis significance tests. For all experiments, data was collected until at least 80% of the critical analyses had, at minimum, moderate evidence using Bayesian statistics (*BF*s ≥ 3), whether that be evidence for the null model or the alternative model (Rouder, 2014; Schönbrodt & Wagenmakers, 2018).

Results and Discussion

Working memory task. Data were trimmed of outliers; for each participant, trials with a RT greater than 2.5 standard deviations from the condition mean were removed (1.40% of trials). Incorrect response trials (16.5%) and timeout trials (6.19%) were also excluded from RT analyses.

As with Oberauer (2001), we examined the effects of set size and probe type using separate analyses; see Figures 2 and 3, respectively. Starting with set size, we collapsed across probe type and conducted a 2 (relevant set size: 1 vs. 3) × 2 (irrelevant set size: 1 vs. 3) within subjects ANOVA on RTs. The resulting two-way interaction was not statistically significant, $F < 1$, $BF_{01} = 4.73$. The main effect of relevant set size was statistically significant, $F(1, 49) = 278$, $p < .001$, $\eta_p^2 = .851$ ($CI_{90\%}$ [.800, .886]), and the Bayesian ANOVA strongly favoured the alternative model, $BF_{10} = 2.48 \times 10^{34}$. These results are consistent with the conclusion that participants stored relevant objects in working memory; that is, the more relevant objects they were asked to remember, the longer it took them to make working memory judgements (Sternberg, 1966). Critically, the effect of irrelevant set size was non-significant, $F(1, 49) = 1.83$, $p = .182$, $\eta_p^2 = .036$ ($CI_{90\%}$ [.000, .151]), and the Bayesian ANOVA moderately favoured the null model, $BF_{01} = 5.15$; RTs did not differ when participants were asked to remember one or three irrelevant objects, suggesting that irrelevant objects were not represented in working memory.

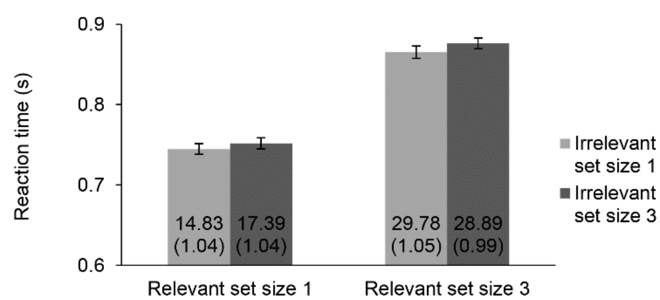

Figure 2. Reaction time data for Experiment 1's working memory task. Numbers inside the bars indicate the error percentage for each condition. Participants exhibited a relevant set size effect, but not an irrelevant set size effect. Error bars in this figure, and all subsequent figures, are corrected (Morey, 2008) within-subject standard errors (Cousineau, 2005).

In order to examine whether the irrelevant objects were represented in ALTM, we collapsed across relevant and irrelevant set sizes and examined the intrusion effect by comparing RTs for irrelevant probes to novel probes using a one-tailed planned paired-samples *t*-test; see Figure 3. Participants took significantly longer to respond to irrelevant probes than to novel probes, $t(49) = 7.51$, $p < .001$, $BF_{10} = 1.04 \times 10^7$. This intrusion effect indicates that the working memory task successfully induced participants to represent irrelevant list objects in ALTM (Oberauer, 2001).

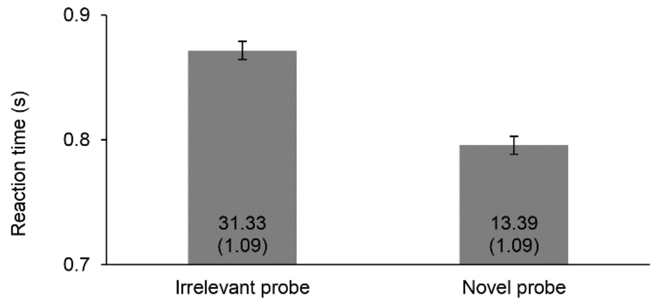

Figure 3. Reaction time data for Experiment 1’s working memory task. Participants exhibited an intrusion effect (longer reaction times to irrelevant probes than to novel probes). Numbers inside the bars indicate the error percentage for each condition.

Error rates are indicated using numerals in Figures 2 and 3. To assess speed-accuracy trade-offs for the conditions of interest, the same 2 × 2 ANOVA and *t*-test were conducted on error rates. The ANOVA revealed a statistically significant relevant set size effect, $F(1, 49) = 148$, $p < .001$, $\eta_p^2 = .752$ ($CI_{90\%}$ [.641, .810]), $BF_{10} = 2.98 \times 10^{22}$, but a non-significant irrelevant set size effect, $F < 1$, $BF_{01} = 5.69$, and interaction, $F(1, 49) = 3.53$, $p = .066$, $\eta_p^2 = .067$ ($CI_{90\%}$ [.000, .198]), $BF_{01} = 1.39$. Additionally, the paired-samples *t*-test revealed significantly more errors for the irrelevant probe condition than for the novel probe condition, $t(49) = 11.6$, $p < .001$, $BF_{10} = 5.80 \times 10^{12}$. Importantly, for instances of significant differences in error rates, participants made more errors for the slower condition, thus it is unlikely that the observed differences in RTs were due to speed/accuracy trade-offs.

Spatial blink task. Accuracy data for the spatial blink task are plotted in Figure 4. As can be seen in this figure, the presence of irrelevant distractors had a minimal effect on accuracy (i.e., less than a 3% difference at lag 2). Despite this small difference, a 2 (distractor–target lag: 2 vs. 8) x 2 (distractor type: irrelevant vs. novel) within-subjects ANOVA on accuracy revealed a statistically significant two-way interaction, $F(1, 49) = 9.92$, $p = .003$, $\eta_p^2 = .168$ ($CI_{90\%}$ [.037, .316]), $BF_{10} = 23.1$; the main effects were not statistically significantly different, both *F*-values < 1, both BF_{01}s > 6.27.

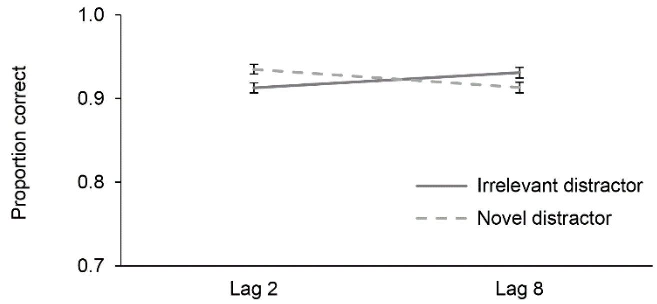

Figure 4. Accuracy data for the spatial blink task for Experiment 1.

Two planned paired samples *t*-tests were conducted as a more direct test of whether participants exhibited contingent capture at lag 2, but not at lag 8. Accuracy for the lag 2 irrelevant distractor condition was significantly lower than for the novel distractor condition, $t(49) = 2.72$, $p = .005$, one-tailed; lag 8 accuracy for the irrelevant distractor condition was not significantly different from the novel distractor condition $t(49) = 1.87$, $p = .068$. To investigate these differences further, two Bayesian *t*-tests were conducted, revealing moderate evidence to support the alternative model for a difference at lag 2, $BF_{10} = 8.17$, one-tailed, and anecdotal evidence to support the alternative model for a difference at lag 8, $BF_{10} = 1.30$.

While the statistically significant drop in accuracy at lag 2 is consistent with the conclusion that representing irrelevant items in ALTM caused those items to capture attention, it is important to note that the differences in accuracy at both lag 2 and lag 8 are small, at only 2.22% ($CI_{95\%}$ [0.62, 3.82]) and 1.78% ($CI_{95\%}$ [-0.09, 3.64]), respectively. By comparison, in previous spatial blink tasks ACS-matching distractors at lag 2 caused decreases in accuracy of 10-30% compared to novel distractors (Folk et al., 2002; Giammarco et al., 2016). Thus, the present results suggest that objects represented in ALTM produce, at most, only a small modulation of attentional capture. To better evaluate this finding, we re-examined these conditions in Experiment 2, and incorporated a baseline measure of typical attentional capture.

Experiment 2

In Experiment 2 we tested the same question as Experiment 1—do objects represented in ALTM preferentially capture attention?—and included a baseline measure of typical attentional capture by sometimes presenting the spatial blink target set objects as distractors in that task. Accordingly, Experiment 2 included irrelevant, novel, and target set distractor conditions. To prevent participants from strategically attending to the target set distractors, we ensured that the target set objects included on the spatial blink probe screen were always different from the target set distractor on that trial; to accomplish this control, we increased the number of spatial blink target set objects from three to six. By virtue of searching for these six target set objects in the spatial blink task, they should form an ACS and exhibit typical contingent capture, thus providing a suitable baseline for assessing capture by irrelevant list objects.

Method

Participants. A new sample of 28 undergraduate students from the University of Guelph (mean age 18.3 years, 9 females) participated in Experiment 4 for partial course credit. Two participants with error rates at 40% or higher on the working memory task, and one participant with an error rate at 40% or higher on the spatial blink task, were excluded from analyses. Thus, Experiment 2 had a final sample size of 25 participants.

Apparatus, stimuli, and procedure. All equipment and visual stimuli were identical to those in Experiment 1. For Experiment 2, participants studied six objects at the beginning of the experiment, which were used as target set objects for the spatial blink task; these objects were randomly selected without replacement from the pool of 125 visual objects.

Working memory and spatial blink tasks. There were 144 working memory trials and 144 spatial blink trials. These two tasks were identical to Experiment 1, with the only difference being the addition of a "target set distractor" condition in the spatial blink task; the critical distractor object was equally likely to be: one of the six spatial blink target set objects memorized at the beginning of the experiment (target set distractor), an object from the irrelevant list in the working memory array (irrelevant distractor), or a novel object (novel distractor).

Results and Discussion

Working memory task. Data were trimmed of outliers; for each participant, trials with a RT greater than 2.5 standard deviations from the condition mean were removed (1.42% of trials). Incorrect response trials (18.5%) and timeout trials (4.67%) were also excluded from RT analyses.

Again, we collapsed across probe type and conducted a 2 (relevant set size: 1 vs. 3) × 2 (irrelevant set size: 1 vs. 3) within subjects ANOVA on RTs; see Figure 5. Similar to Experiment 1, the ANOVA revealed a non-significant interaction, $F < 1$, $BF_{01} = 3.01$, a significant main effect of relevant set size, $F(1, 24) = 86.4$, $p < .001$, $\eta_p^2 = .783$ ($CI_{90\%}$ [.618, .846]), $BF_{10} = 2.25 \times 10^{16}$, and a non-significant main effect of irrelevant set size, $F(1, 24) = 1.43$, $p = .244$, $\eta_p^2 = .056$ ($CI_{90\%}$ [.000, .238]). Additionally, the Bayesian ANOVA moderately favoured the null model for the main effect of irrelevant set size, $BF_{01} = 4.12$, suggesting that irrelevant objects were not represented in working memory.

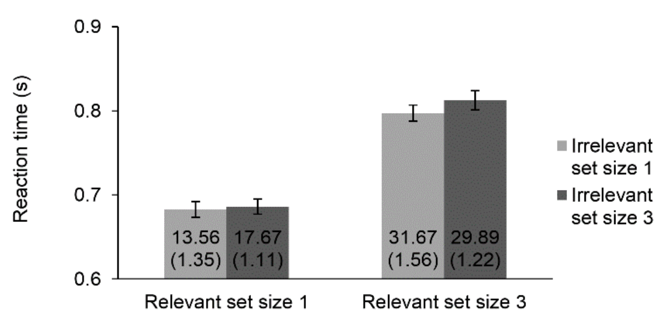

Figure 5. Reaction time data for Experiment 2's working memory task. Numbers inside the bars indicate the error percentage for each condition. Participants exhibited a relevant set size effect, but not an irrelevant set size effect.

In order to examine whether the irrelevant objects were represented in ALTM, we again collapsed across relevant and irrelevant set sizes to examine the intrusion effect; see Figure 6. The one-tailed planned paired-samples *t*-test revealed longer RTs when participants responded to irrelevant probes than novel probes, $t(24) = 4.13$, $p < .001$, $BF_{10} = 82.5$. This intrusion effect indicates that the working memory task successfully induced participants to represent irrelevant list objects in ALTM.

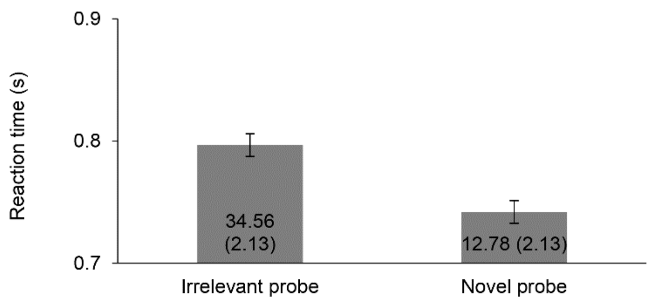

Figure 6. Reaction time data for Experiment 2's working memory task. Participants exhibited an intrusion effect (longer reaction times to irrelevant probes than to novel probes). Numbers inside the bars indicate the error percentage for each condition.

Error rates are indicated using numerals in Figures 5 and 6. To assess speed-accuracy trade-offs, the same 2 × 2 ANOVA and *t*-test were run on error rates. The ANOVA revealed a statistically significant interaction, $F(1, 24) = 6.89$, $p = .015$, $\eta_p^2 = .223$ ($CI_{90\%}$ [.026, .422]), $BF_{10} = 1.68$, a statistically significant main effect of relevant set size, $F(1, 24) = 104$, $p < .001$, $\eta_p^2 = .812$ ($CI_{90\%}$ [.667, .867]), $BF_{10} = 1.60 \times 10^{15}$, and a non-significant main effect of irrelevant set size, $F(1, 24) = 0.55$, $p = .466$, $\eta_p^2 = .022$ ($CI_{90\%}$ [.000, .178]), $BF_{01} = 4.36$. Additionally, the paired-samples *t*-test revealed significantly more errors for the irrelevant probe condition than the novel probe condition, $t(24) = 7.65$, $p < .001$, $BF_{10} = 2.14 \times 10^5$. As with Experiment 1, when participants made more errors, those conditions were associated with slower RTs, thus it is unlikely that the observed differences in RTs were due to speed/accuracy trade-offs.

Spatial blink task. Accuracy data for the spatial blink task are plotted in Figure 7. The 2 (distractor–target lag: 2 vs. 8) x 3 (distractor type: irrelevant vs. novel vs. target set) within-subjects ANOVA yielded a significant main effect of distractor–target lag, $F(1, 24) = 18.8$, $p < .001$, $\eta_p^2 = .439$ ($CI_{90\%}$ [.176, .599]), $BF_{10} = 8.98 \times 10^3$, a significant main effect of distractor type, $F(2, 48) = 16.0$, $p < .001$, $\eta_p^2 = .401$ ($CI_{90\%}$ [.205, .522]), $BF_{10} = 68.8$, and a significant interaction, $F(2, 48) = 17.0$, $p < .001$, $\eta_p^2 = .414$ ($CI_{90\%}$ [.218, .533]), $BF_{10} = 3.80 \times 10^3$.

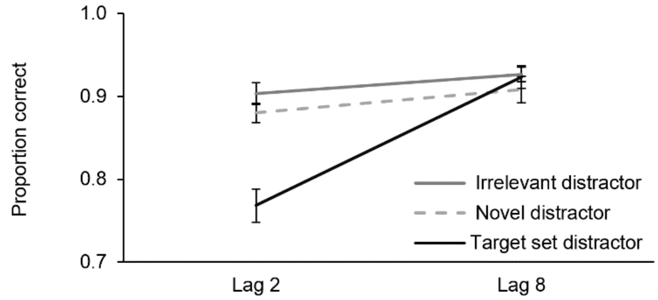

Figure 7. Accuracy data for the spatial blink task for Experiment 2, revealing contingent capture by target set distractors, but not irrelevant distractors.

To assess for contingent capture, four planned paired-samples *t*-tests were conducted. Exhibiting a typical spatial blink, accuracy for the target set distractor condition was significantly lower than accuracy for the novel distractor condition at lag 2, $t(24) = 4.82$, $p < .001$, $BF_{10} = 786$, one-tailed, but not at lag 8, $t(24) = 1.01$, $p = .319$, $BF_{01} = 2.99$. While the target set distractor condition showed typical spatial blink results, the irrelevant distractor condition did not; accuracy did not significantly differ between the irrelevant distractor condition and the novel distractor condition at lag 2, $t(24) = 1.43$, $p = .917$, $BF_{01} = 10.5$, one-tailed, or at lag 8, $t(24) = 1.02$, $p = .319$, $BF_{01} = 2.98$. Though not significantly different, it is interesting to note that accuracy for the irrelevant distractor condition was higher than accuracy for the novel distractor condition during the spatial blink task, which would not be the case if the irrelevant distractor objects had formed an ACS and captured attention. Finally, accuracy was significantly higher for the irrelevant distractor condition than the target set distractor condition at lag 2, $t(24) = 6.95$, $p < 0.001$, $BF_{10} = 4.71 \times 10^4$, supporting the conclusion that participants did not adopt an ACS for the irrelevant objects.

Summary

By incorporating target set distractors in the spatial blink task, Experiment 2 provides a clear demonstration of the limited role ALTM plays in ACSs. Here, we observed that the target set objects participants searched for in the spatial blink task formed an ACS and captured attention. However, the task irrelevant objects—which were represented in ALTM—did not. Thus, it appears that representing stimuli in ALTM is not sufficient for those same stimuli to form an ACS and capture visual attention in the way that searched-for objects do. These results converge with those of Experiment 1 on the conclusion that ALTM is not the factor that determines which LTM representations will form an ACS, and which will not.

Experiment 3

Experiments 1 and 2 provide evidence against the ALTM account by showing that irrelevant list items are represented ALTM, yet produce little-to-no evidence of attentional capture. What about the spatial blink target set objects, which were shown to capture attention in Experiment 2? The ALTM account predicts that these objects should be represented in ALTM and produce large intrusion effects; alternatively, if these objects produce smaller intrusion effects than irrelevant list objects (which do not capture attention), this finding would be counter to the ALTM account. Participants again memorized six spatial blink target set objects at the beginning of the experiment, and, new to this experiment, occasionally those target set images appeared as memory probes during the working memory task. Thus, in Experiment 3 there are two sets of objects for which we measured both attentional capture and intrusion effects: spatial blink target set objects and irrelevant list objects. If the ALTM account is correct, then for each object set we should see similar magnitudes of attentional capture and intrusion effects (i.e., both small or both large). Alternatively, if irrelevant list objects produce a larger intrusion effect than spatial blink target set objects, while spatial blink target set objects capture attention more than irrelevant list objects, this dissociation would provide evidence against the ALTM account.

Method

Participants. Thirty-one undergraduate students from the University of Guelph (mean age 18.42 years, 28 females) participated in Experiment 3 for partial course credit. Five participants with error rates at 40% or higher on the spatial blink task, and one participant with an error rate at 40% or higher on the working memory task, were excluded from the analyses below. Thus, Experiment 3 had a final sample size of 25 participants.

Apparatus, stimuli, and procedure. All equipment and visual stimuli were identical to those in Experiments 1 and 2. For Experiment 3, we were most interested in comparing the effects elicited by spatial blink target set objects, and working memory irrelevant list objects. To minimize the differences in stimulus properties between these two sets of objects, the six target set objects and 72 working memory objects were randomly selected without replacement from the same pool of 125 visual objects for each participant.

Working memory and spatial blink tasks. There were 192 working memory trials and 96 spatial blink trials. The ratio of working memory to spatial blink trials was increased given the addition of the target set probe condition for the working memory task, and the removal of the lag 8 condition from the spatial blink task (see below). These two tasks were identical to those in Experiment 2, with the exception of three procedural changes. First, there was a “target set probe” condition added to the working memory task; the memory probe object could be: a relevant list object (relevant probe, 50% of trials, requires a “yes” response), one of the six spatial blink target set objects memorized at the beginning of the experiment (target set probe, 16.7% of trials, requires a “no” response), an irrelevant list object (irrelevant probe, 16.7% of trials, requires a “no” response), or a novel object (novel probe, 16.7% of trials, requires a “no” response). Second, in order to increase the power for the conditions of interest, Experiment 3’s spatial blink task did not include a distractor-target lag 8 condition. Third, the identities of the objects on the spatial blink response screen were different, and always included: the target set object that appeared in the stream (i.e., the target for this trial); three target set objects that did not appear in the stream; one working memory object from the stream, which served as the decoy object; and three working memory objects that did not appear in the stream. The decoy object was included on the response screen to ensure participants selected only the target object that appeared within the stream. The working memory objects on the response screen were not memory array objects from the current trial, but were randomly selected from the remaining objects in the set of 72 working memory objects.

Results and Discussion

Spatial blink task. Accuracy data for the spatial blink task are plotted in Figure 8. A 3-level one-way (distractor type: target set vs. irrelevant vs. novel) within-subjects ANOVA was conducted to assess differences in accuracy. This analysis was statistically significant, $F(2, 48) = 53.3$, $p < .001$, $\eta_p^2 = .689$ ($CI_{90\%}$ [.546, .758]), $BF_{10} = 5.84 \times 10^{10}$. Planned paired samples *t*-tests revealed that, relative to novel distractors, both target set distractors, $t(24) = 9.04$, $p < .001$, $BF_{10} = 3.51 \times 10^6$, and irrelevant distractors, $t(24) = 4.19$, $p < .001$, $BF_{10} = 92.8$, caused statistically significant decreases in accuracy. The decrease in accuracy for irrelevant distractors is interesting to note, as this is a change from the results of Experiment 2; we revisit this finding in the Experiment 3 summary below. Critically, of primary interest for the present experiment, the decrease in accuracy was larger for target set distractors than irrelevant distractors, $t(24) = 6.49$, $p < .001$, $BF_{10} = 1.73 \times 10^4$.

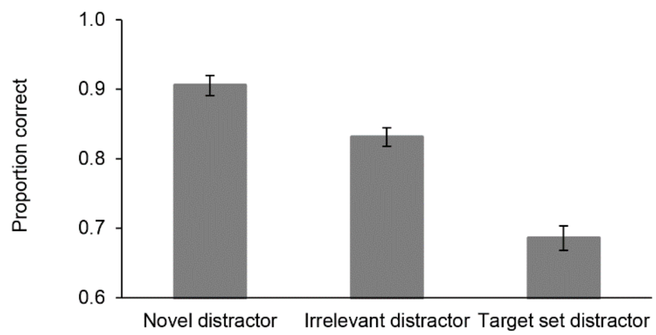

Figure 8. Accuracy data for the spatial blink task for Experiment 3, revealing contingent capture by the target set distractor objects.

Working memory task. Data were trimmed of outliers; for each participant, trials with a RT greater than 2.5 standard deviations from the condition mean were removed (1.90% of trials). Incorrect response trials (8.96%) and timeout trials (3.33%) were also excluded from RT analyses.

As with previous experiments, we collapsed across probe type and conducted a 2 (relevant set size: 1 vs. 3) × 2 (irrelevant set size: 1 vs. 3) within subjects ANOVA on RTs; see Figure 9. Similar to Experiments 1 and 2, the resulting two-way interaction was not statistically significant, $F < 1$, $BF_{01} = 2.80$, the main effect of relevant set size was statistically significant, $F(1, 24) = 215$, $p < .001$, $\eta_p^2 = .900$ ($CI_{90\%}$ [.816, .929]), $BF_{10} = 3.74 \times 10^{22}$, and the main effect of irrelevant set size was non-significant, $F(1, 24) = 0.09$, $p = .765$, $\eta_p^2 = .004$ ($CI_{90\%}$ [.000, .109]), $BF_{01} = 4.78$. These results suggest that the irrelevant list objects were not represented in working memory.

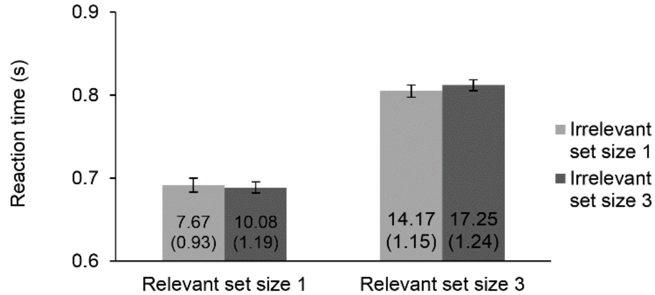

Figure 9. Reaction time data for Experiment 3's working memory task. Numbers inside the bars indicate the error percentage for each condition. Participants exhibited a relevant set size effect, but not an irrelevant set size effect.

In order to examine the state of ALTM, we collapsed across relevant and irrelevant set sizes and examined the intrusion effect by comparing RTs for irrelevant probes, target set probes, and novel probes using a 3-level one-way ANOVA; see Figure 10. This analysis was statistically significant, $F(2, 48) = 88.0$, $p < .001$, $\eta_p^2 = .786$ ($CI_{90\%}$ [.786, .773]), $BF_{10} = 3.30 \times 10^{13}$. Two planned paired samples *t*-tests revealed that, relative to novel probes, participants took significantly longer to respond to both irrelevant probes, $t(24) = 12.6$, $p < .001$, $BF_{10} = 1.83 \times 10^9$, and target set probes, $t(24) = 2.99$, $p = .006$, $BF_{10} = 7.06$. Of primary interest for the present experiment, irrelevant probes slowed RT to a greater extent than target set probes, $t(24) = 9.75$, $p < .001$, $BF_{10} = 1.37 \times 10^7$. This finding provides a contrast to the accuracy results from the spatial blink task; whereas irrelevant list objects produced the largest intrusion effect, target set objects produced the greatest spatial blink, suggesting a dissociation between these two effects.

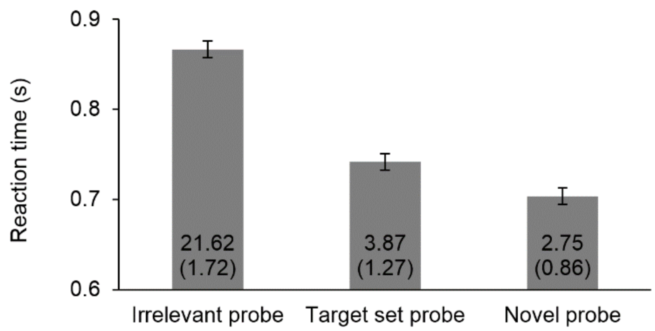

Figure 10. Reaction time data for Experiment 3's working memory task. Participants exhibited an intrusion effect (longer reaction times to irrelevant probes than to novel probes). Numbers inside the bars indicate the error percentage for each condition.

Error rates are indicated using numerals in Figures 9 and 10. To assess speed-accuracy trade-offs for the conditions of interest, the same 2 × 2 ANOVA, 3-level one-way ANOVA, and *t*-tests were run on error rates. The 2 × 2 ANOVA revealed no statistically significant interaction, $F < 1$, $BF_{01} = 3.51$, but a statistically significant relevant set size effect, $F(1, 24) = 22.2$, $p < .001$, $\eta_p^2 = .480$ ($CI_{90\%}$ [.217, .630]), $BF_{10} = 1.45 \times 10^5$, and irrelevant set size effect, $F(1, 24) = 7.72$, $p = .010$ $\eta_p^2 = .243$ ($CI_{90\%}$ [.036, .440]), $BF_{10} = 1.34$. The 3-level ANOVA revealed a statistically significant main effect, $F(1, 24) = 63.4$, $p < .001$, $\eta_p^2 = .725$ ($CI_{90\%}$ [.595, .786]), $BF_{10} = 3.88 \times 10^{14}$. Additionally, the paired-samples *t*-tests revealed significantly more errors for the irrelevant probe condition than for the novel probe condition, $t(24) = 9.61$, $p < .001$, $BF_{10} = 1.06 \times 10^7$, and for the irrelevant probe condition than for the target set probe condition, $t(24) = 7.51$, $p < .001$, $BF_{10} = 1.57 \times 10^5$, but no significant difference between the target set probe condition and the novel probe condition, $t(24) = 1.04$, $p = .308$, $BF_{01} = 2.92$. Importantly, for instances of significant differences in error rates, participants made more errors for the slower of the conditions, thus it is unlikely that the observed differences in RTs were due to speed/accuracy trade-offs.

Summary

The goal of Experiment 3 was to assess the ALTM account by comparing the intrusion effects and spatial blinks produced by two sets of objects. In contrast to the prediction of the ALTM account that these two effects should be related, we found a dissociation: Spatial blink target set objects produced greater attentional capture than irrelevant list objects, and irrelevant list objects produced greater intrusion effects than spatial blink target set objects. Thus, the objects that preferentially captured attention were not the ones that produced the largest intrusion effect, suggesting that something other than representation in ALTM determines which LTM representations comprise the prevailing ACS.

It is interesting to note that, compared to Experiment 2 where there was no evidence that irrelevant list objects captured attention, irrelevant list distractors in the present experiment moderately impaired performance on the spatial blink task compared to novel distractors. However, this impairment is still less than the 10-30% as seen in previous research (Folk et al., 2002; Giammarco et al., 2016), and, notably, the irrelevant distractor objects did not impair performance to the same extent as target set distractors. This increased evidence of capture may be a consequence of using only 72 working memory objects, compared to the pool of 2,152 objects used in Experiments 1 and 2. Because of the smaller number of working memory objects, participants may have learned some objects' identities, allowing them to sometimes incorporate these objects into their ACS (i.e., given that they were task relevant for the working memory task). Similarly, spatial blink target set objects produced a small intrusion effect compared to novel objects, potentially suggesting representation in ALTM; this effect may have been a consequence of participants' familiarity with these objects (Oberauer, 2001). Thus, while it is possible that there is some spill-over between ALTM and ACSs, the main contribution of this experiment is the dissociation between these two measures: Although the distracting effects of spatial blink target set objects was almost three times greater than that of irrelevant list objects, their intrusion effect was more than four times smaller.

General Discussion

In the present study, we investigated the ALTM account of LTM ACSs. In Experiments 1 and 2 we induced participants to represent complex visual objects in ALTM and tested the prediction that those objects should be incorporated into participants' ACSs, and capture attention when presented as distractors in a spatial blink task. We found that those objects did not consistently capture attention. In Experiment 3 we compared measures of ALTM and attentional capture across two sets of objects, and found them to be dissociated. These results suggest that both tested predictions of the ALTM account are incorrect, and that representation in ALTM is not the factor that determines which LTM representations form an ACS.

Is There Any Role for ALTM?

Our results speak to both the necessity and sufficiency of representing objects in ALTM when adopting an ACS for those objects. Experiment 2, in particular, provides a strong demonstration that ALTM is not *sufficient* for adopting an ACS; following from the work of Oberauer (2001), we know that irrelevant list objects were represented in ALTM, yet these objects did not preferentially capture visual attention. If representation in ALTM was, by itself, sufficient for participants to adopt an ACS, then—by virtue of being represented in ALTM—the irrelevant list objects should have formed an ACS and captured attention during the spatial blink task. Additionally, Experiment 3 suggests that ALTM may not be *necessary* for adopting an ACS, as the ACS objects captured attention during the spatial blink task, but these same objects did not produce an intrusion effect of the same magnitude as irrelevant list objects during the working memory task. That said, ACS objects did produce a small intrusion effect, so it remains a possibility that representation in ALTM is necessary.

To fully appreciate these conclusions of necessity and sufficiency, however, it is important to distinguish ALTM as a concept from how we have operationalised it. In the present study we chose to adapt Oberauer's (2001) modified Sternberg task to assess the state of ALTM for two reasons: first, this task allows the contribution of ALTM to be isolated from other components of memory; second, ever since it was developed, this task is typically cited as providing the main evidence for ALTM (for a summary see D'Esposito & Postle, 2015; see also, Cowan, 2001; Cunningham & Wolfe, 2014; Kessler & Meiran, 2010; Meiran & Kessler, 2008; Oberauer, 2005; Woltz & Was, 2007; Yi & Friedman, 2014). That said, ALTM has been operationalised in other ways, for example using priming effects (Woltz & Was, 2007). Might other measures of ALTM reveal relationships between ALTM and LTM ACSs? We believe this question highlights an additional contribution of the present paper. One broad conceptual definition is that ALTM encompasses any long-term memory representations that are capable of influencing behaviour or serving a current task (e.g., Oberauer & Hein, 2012). By this definition, LTM ACSs must constitute an ALTM memory effect, as ACSs are supported by LTM and influence behaviour by regulating attentional capture (Giammarco et al., 2016). Yet our present results indicate that the cognitive processes that allow some LTM representations to produce intrusion effects are somewhat distinct from the cognitive processes that allow some LTM representations to form ACSs, which suggests that these two effects do not measure a single ALTM process. Our position is that understanding the relationships between ALTM as a concept and its operational definitions remains an important avenue for further work. Regardless, when assessed using the leading definition of ALTM (i.e., intrusion effects), we find that ALTM is not sufficient to support attentional capture by LTM ACSs, and, moreover, that factors other than representation in ALTM determine whether an LTM representation will bias attentional capture.

Attentional Control Settings vs. Attentional Templates

The present ACS findings have potential implications for a closely related research topic: the attentional template. Attentional control settings and attentional templates share many core concepts. In particular, both describe how, when observers adopt a goal of searching their environment for a type of visual information, that goal shapes how attention is drawn to aspects of the environment (Bundesen, 1990; Duncan & Humphrey, 1989; Folk et al., 1992, 1994). These two research areas, however, tend to diverge in how they are studied. Whereas most ACS research employs cueing tasks and other tasks thought to measure spatial attention, such as the spatial blink, attentional template research typically measures distractor costs during visual search; this divergence in how these phenomena are studied can lead to differing conclusions (Al-Aidroos, Harrison, & Pratt, 2010; Folk & Remington, 1998). Despite these differences, the present results may contribute to an ongoing debate in attentional template research regarding which memory systems store the attentional template, and when.

While there are many demonstrations suggesting that attentional templates can be stored in working memory (Olivers et al., 2011; Soto, Hodsoll, Rotshtein, & Humphreys, 2008), some researchers have argued that templates are more commonly stored in LTM (Carlisle et al., 2011; Woodman et al., 2013). In particular, working memory may only store the identity of a search target that changes frequently (e.g., from trial to trial in an experiment); when the identity of the target remains constant over time, it can be offloaded to LTM, as evidenced by the absence of working memory-related electrophysiological activity (Carlisle et al., 2011). Conversely, recent evidence has emerged questioning the generalizability of this finding. In particular, when participants search for either of two targets, the attentional template continues to be stored in working memory, even when the identities of the targets are constant (Berggren & Eimer, 2018). While this finding would seem to suggest that more complex templates are always stored in working memory, the present findings clarify that there are situations where complex templates (i.e., for six complex visual objects) are maintained in LTM.

What Distinguishes ACS Representations in LTM, if not ALTM?

If representation in ALTM is not the mechanism through which LTM ACSs are accomplished, then what is special about the LTM representations that comprise an ACS, such that these representations bias attentional capture, when other LTM representations do not? While there is no answer to this question in the literature thus far, one possibility is that the status of an object as part of an ACS is stored directly within the episodic memory trace associated with that object (i.e., stored as memory content, rather than through memory state). Upon encountering a visual object, memory traces associated with that object may be partially retrieved, including any information about whether a shift in attention is warranted. Given the traditional characterization of episodic LTM retrieval as a slow and effortful process (Yonelinas, 2002), it may seem surprising that episodic memories could be retrieved quickly and efficiently enough to support this role. More recently, however, it has been argued that episodic retrieval follows a two-stage process where, in the first stage, external stimuli (and internal representations) can trigger the rapid, effortless retrieval of memory traces (Degonda et al., 2005; Guild et al., 2014; Hannula, Tranel, & Cohen, 2006; Moscovitch, 2008). Accordingly, the factor that distinguishes those LTM representations that comprise and ACS from those that do not may be stored within the contents of the memories themselves.

Hybrid Visual and Memory Search

The present findings also have implications for models of hybrid visual and memory search (Shiffrin & Schneider, 1977; Wolfe, 2012). Similar to the present experiments, participants in hybrid search studies typically memorize a large set of everyday visual objects and then search their visual field for any one of those objects. In contrast to the present experiments, however, the search target in hybrid searches is presented concurrently with numerous visual distractors, and the memory and visual set sizes are manipulated (Cunningham & Wolfe, 2014; Drew, Boettcher, & Wolfe, 2016, 2017; Folk et al., 1994; Guild et al., 2014; Wolfe, 2012; Wolfe, Boettcher, Josephs, Cunningham, & Drew, 2015). Thus, these studies examine how observers coordinate searching though their environment with searching through their memory, to find the visual stimulus that matches a target in memory. The main finding from these studies is that search RTs increase linearly with increasing numbers of visual distractors, and logarithmically with increasing numbers of targets in memory (Wolfe, 2012). Of minor interest, this research area adopted the term ALTM to describe the memory region where search targets are stored; though with some reservations as to their definition of ALTM (Cunningham & Wolfe, 2014, p. 3). The present findings suggest a new label may be warranted.

Cunningham and Wolfe (2014) proposed a three-stage model to describe the coordination of visual attention and LTM during hybrid search, which has since been elaborated. Search stimuli are attended serially (Drew et al., 2017) based on their low-level featural properties, with each selected item being submitted to a massively parallel categorization and identification process, represented in visual working memory (Drew et al., 2016), and compared against the list of target set objects stored in episodic (Guild et al., 2014) LTM. Notably, there are no direct interactions between visual attention and LTM in this model: Attention is only guided by low-level featural properties, not whole objects, and no comparison is made against the representations of the target set objects in LTM until well after visual items are selected by attention. The lack of an interaction between attention and LTM is, however, inconsistent with the present findings, and those of Giammarco et al. (2016). Specifically, we observed that attention is guided by (i.e., capture is contingent on) the identities of the target set objects, and thus LTM retrieval must have occurred early during processing. We suspect the difference between these two research areas relates to the two stages of episodic retrieval discussed above (Moscovitch, 2008). Whereas set size effects in hybrid search may be determined by a process that relies on the slow, conscious stage of retrieval, cueing effects and spatial blink costs may be more sensitive to attentional biases driven by rapid, unconscious recollection. As such, LTM ACS representations may be associated with both early and late effects during search.

Conclusions

The results from the experiments presented here add to the growing literature demonstrating that LTM can interact with visual attention. Participants memorized and searched for lists of *complex* visual objects—an ability thought to be achieved using

LTM—yet these objects captured attention when presented as distractors during a spatial blink task. To better understand the processes supporting LTM ACSs, we investigated the ALTM account that LTM ACSs are accomplished by representing target set objects in ALTM; however, the present findings do not support this account. The objects that comprise an LTM ACS are at most minimally represented in ALTM (Experiment 3), and representing objects in ALTM is not sufficient for inducing an LTM ACS (Experiments 1 and 2). These results suggest that a factor other than ALTM determines which LTM representations form an ACS, and which do not.

Disclosure statement

The authors report no known conflict of interest.

Context

The idea for this series of experiments is based on our previous work on long-term memory ACSs (Giammarco et al., 2016); in Experiment 3 of this previous work, participants memorized two lists of 15 complex visual objects, but only searched for one list on the subsequent spatial blink task. Intriguingly, only the 15 searched-for objects formed an ACS. These objects captured attention when presented as distractors during a spatial blink task, resulting in lower accuracy than trials where the distractors were novel objects; distractors from the not-searched-for list showed comparable accuracy to novel distractors. This finding raised the question: what is special about the long-term memory ACSs such that only the searched-for objects captured attention, but not the other recently studied objects? Oberauer's (2001) work presented an enticing possibility: perhaps long-term memory ACSs are capable of biasing attentional capture because they are represented in activated long-term memory (ALTM). Through our series of experiments presented here, we demonstrate that this is not the case; some other factor determines which LTM representations comprise an ACS, and which do not.

References

Al-Aidroos, N., Harrison, S., & Pratt, J. (2010). Attentional control settings prevent abrupt onsets from capturing visual spatial attention. *Quarterly Journal of Experimental Psychology*, *63*(1), 31–41. https://doi.org/10.1080/17470210903150738

Beck, V. M., Hollingworth, A., & Luck, S. J. (2012). Simultaneous control of attention by multiple working memory representations. *Psychological Science*, *23*(8), 887–898. https://doi.org/10.1177/0956797612439068

Berggren, N., & Eimer, M. (2018). Visual working memory load disrupts template-guided attentional selection during visual search. *British Journal of Psychology*, *110*, 357–371. https://doi.org/10.1111/bjop.12323

Brady, T. F., Konkle, T., Alvarez, G. A., & Oliva, A. (2008). Visual long-term memory has a massive storage capacity for object details. *Proceedings of the National Academy of Sciences of the United States of America*, *105*(38), 14325–14329. https://doi.org/10.1073/pnas.0803390105

Bundesen, C. (1990). A theory of visual attention. *Psychological Review*, *97*(4), 523–547. https://doi.org/10.1037//0033-295X.97.4.523

Carlisle, N. B., Arita, J. T., Pardo, D., & Woodman, G. F. (2011). Attentional templates in visual working memory. *Journal of Neuroscience*, *31*(25), 9315–9322. https://doi.org/10.1523/JNEUROSCI.1097-11.2011

Cousineau, D. (2005). Confidence intervals in within-subject designs: A simpler solution to Loftus and Masson's method. *Tutorials in Quantitative Methods for Psychology*, *1*(1), 42–45. https://doi.org/10.20982/tqmp.01.1.p042

Cowan, N. (1988). Evolving conceptions of memory storage, selective attention, and their mutual constraints within the human information-processing system. *Psychological Bulletin*, *104*(2), 163–191. https://doi.org/10.1037/0033-2909.104.2.163

Cowan, N. (1999). An embedded-processes model of working memory. In A. Miyake & P. Shah (Eds.), *Models of working memory: Mechanisms of active maintenance and executive control* (pp. 62–101). New York: Cambridge University Press. https://doi.org/10.1017/CBO9781139174909.006

Cowan, N. (2001). The magical number 4 in short term memory: A reconsideration of storage capacity. *Behavioral and Brain Sciences*, *24*(4), 87–114. https://doi.org/10.1017/S0140525X01003922

Cunningham, C. A., & Wolfe, J. M. (2014). The role of object categories in hybrid visual and memory search. *Journal of Experimental Psychology: General*, *143*(4), 1585–1599. https://doi.org/10.1037/a0036313

D'Esposito, M., & Postle, B. R. (2015). The Cognitive Neuroscience of Working Memory. *Annual Review of Psychology*, *66*, 115–142. https://doi.org/10.1146/annurev-psych-010814-015031

Degonda, N., Mondadori, C. R. A., Bosshardt, S., Schmidt, C. F., Boesiger, P., Nitsch, R. M., … Henke, K. (2005). Implicit associative learning engages the hippocampus and interacts with explicit associative learning. *Neuron*, *46*(3), 505–520. https://doi.org/10.1016/j.neuron.2005.02.030

Drew, T., Boettcher, S. E. P., & Wolfe, J. M. (2016). Searching while loaded: Visual working memory does not interfere with hybrid search efficiency but hybrid search uses working memory capacity. *Psychonomic Bulletin and Review*, *23*(1), 201–212. https://doi.org/10.3758/s13423-015-0874-8

Drew, T., Boettcher, S. E. P., & Wolfe, J. M. (2017). One visual search, many memory searches: An eye-tracking investigation of hybrid search. *Journal of Vision*, *17*(11), 5. https://doi.org/10.1167/17.11.5

Duncan, J., & Humphrey, G. W. (1989). Visual serach and stimulus similarity. *Psychological Review*, *96*(3), 433–458. https://doi.org/10.1037/0033-295X.96.3.433

Folk, C. L., Leber, A. B., & Egeth, H. E. (2002). Made you blink! Contingent attentional capture produces a spatial blink. *Perception & Psychophysics*, *64*(5), 741–753. https://doi.org/10.3758/BF03194741

Folk, C. L., & Remington, R. (1998). Selectivity in distraction by irrelevant featural singletons: Evidence for two forms of attentional capture. *Journal of Experimental Psychology: Human Perception and Performance*, *24*(3), 847–858. https://doi.org/10.1037/0096-1523.24.3.847

Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance*, *18*(4), 1030–1044. https://doi.org/10.1037/0096-1523.18.4.1030

Folk, C. L., Remington, R. W., & Wright, J. H. (1994). The structure of attentional control: Contingent attentional capture by apparent motion, abrupt onset, and color. *Journal of Experimental Psychology: Human Perception and Performance*, *20*(2), 317–329. https://doi.org/10.1037/0096-1523.20.2.317

Giammarco, M., Paoletti, A., Guild, E. B., & Al-Aidroos, N. (2016). Attentional capture by items that match episodic long-term memory representations. *Visual Cognition*, *24*(1), 78–101. https://doi.org/10.1080/13506285.2016.1195470

Goodhew, S. C., Kendall, W., Ferber, S., & Pratt, J. (2014). Setting semantics: Conceptual set can determine the physical properties that capture attention. *Attention, Perception, and Psychophysics*, *76*(6), 1577–1589. https://doi.org/10.3758/s13414-014-0686-3

Guild, E. B., Cripps, J. M., Anderson, N. D., & Al-Aidroos, N. (2014). Recollection can support hybrid visual memory search. *Psychonomic Bulletin & Review*, *21*(1), 142–148. https://doi.org/10.3758/s13423-013-0483-3

Hannula, D. E., Tranel, D., & Cohen, N. J. (2006). The long and the short of it: Relational memory impairments in amnesia, even at short lags. *Journal of Neuroscience*, *26*(32), 8352–8359. https://doi.org/10.1523/JNEUROSCI.5222-05.2006

JASP-Team. (2017). JASP [Computer Software]. Retrieved from https://jasp-stats.org

Kessler, Y., & Meiran, N. (2010). The reaction-time task-rule congruency effect is not affected by working memory load: Further support for the activated long-term memory hypothesis. *Psychological Research*, *74*(4), 388–399. https://doi.org/10.1007/s00426-009-0261-z

Kruschke, J. K. (2015). *Doing Bayesian data analysis: A tutorial with R, JAGS, and Stan* (2nd ed.). San Diego, CA: Elsevier.

Luck, S. J., & Vogel, E. (1997). The capacity of visual working memory for features and conjunctions. *Nature*, *390*(6657), 279–281. https://doi.org/10.1038/36846

Meiran, N., & Kessler, Y. (2008). The task rule congruency effect in task switching reflects activated long-term memory. *Journal of Experimental Psychology: Human Perception and Performance*, *34*(1), 137–157. https://doi.org/10.1037/0096-1523.34.1.137

Morey, R. D. (2008). Confidence intervals from normalized data: A correction to Cousineau (2005). *Tutorials in Quantitative Methods for Psychology*, *4*(2), 61–64. https://doi.org/10.20982/tqmp.04.2.p061

Morey, R. D., & Rouder, J. N. (2011). Bayes Factor Approaches for Testing Interval Null Hypotheses. *Psychological Methods*, *16*(4), 406–419. https://doi.org/10.1037/a0024377

Moscovitch, M. (2008). The hippocampus as a "stupid," domain-specific module: Implications for theories of recent and remote memory, and of imagination. *Canadian Journal of Experimental Psychology*, *62*(1), 62–79. https://doi.org/10.1037/1196-1961.62.1.62

Oberauer, K. (2001). Removing irrelevant information from working memory: A cognitive aging study with the modified Sternberg task. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *27*(4), 948–957. https://doi.org/10.1037/0278-7393.27.4.948

Oberauer, K. (2002). Access to information in working memory: Exploring the focus of attention. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *28*(3), 411–421. https://doi.org/10.1037//0278-7393.28.3.411

Oberauer, K. (2005). Control of the Contents of Working Memory — A Comparison of Two Paradigms and Two Age Groups. *Journal of Experimental Psychology: Learning Memory and Cognition*, *31*(4), 714–728. https://doi.org/10.1037/0278-7393.31.4.714

Oberauer, K., & Hein, L. (2012). Attention to information in working memory. *Current Directions in Psychological Science*, *21*(3), 164–169. https://doi.org/10.1177/0963721412444727

Olivers, C. N. L. (2009). What drives memory-driven attentional capture? The effects of memory type, display type, and search Type. *Journal of Experimental Psychology: Human Perception and Performance*, *35*(5), 1275–1291. https://doi.org/10.1037/a0013896

Olivers, C. N. L., Meijer, F., & Theeuwes, J. (2006). Feature-based memory-driven attentional capture: Visual working memory content affects visual attention. *Journal of Experimental Psychology: Human Perception and Performance*, *32*(5), 1243–1265. https://doi.org/10.1037/0096-1523.32.5.1243

Olivers, C. N. L., Peters, J., Houtkamp, R., & Roelfsema, P. R. (2011). Different states in visual working memory: When it guides attention and when it does not. *Trends in Cognitive Sciences*, *15*(7), 327–334. https://doi.org/10.1016/j.tics.2011.05.004

Phillips, W. A. (1974). On the distinction between sensory storage and short-term visual memory. *Perception & Psychophysics*, *16*(2), 283–290. https://doi.org/10.3758/BF03203943

Posner, M. I., & Cohen, Y. (1984). Components of visual orienting. *Attention and Performance*, *32*, 531–556. https://doi.org/10.1162/jocn.1991.3.4.335

Rouder, J. N. (2014). Optional stopping: No problem for Bayesians. *Psychonomic Bulletin & Review*, *21*, 301–308. https://doi.org/10.3758/s13423-014-0595-4

Schönbrodt, F. D., & Wagenmakers, E. J. (2018). Bayes factor design analysis: Planning for compelling evidence. *Psychonomic Bulletin and Review*, *25*, 128–142. https://doi.org/10.3758/s13423-017-1230-y

Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending and a general theory. *Psychological Review*, *84*(2), 127–190. https://doi.org/10.1037/0033-295X.84.2.127

Soto, D., Heinke, D., Humphreys, G. W., & Blanco, M. J. (2005). Early, involuntary top-down guidance of attention from working memory. *Journal of Experimental Psychology: Human Perception and Performance*, *31*(2), 248–261. https://doi.org/10.1037/0096-1523.31.2.248

Soto, D., Hodsoll, J., Rotshtein, P., & Humphreys, G. W. (2008). Automatic guidance of attention from working memory. *Trends in Cognitive Sciences*, *12*(9), 342–348. https://doi.org/10.1016/j.tics.2008.05.007

Sternberg, S. (1966). High-speed scanning in human memory. *Science*, *153*(3736), 652–654. https://doi.org/10.1126/science.153.3736.652

Wagenmakers, E.-J., Love, J., Marsman, M., Jamil, T., Ly, A., Verhagen, J., … Morey, R. D. (2018). Bayesian inference for psychology . Part II : Example applications with JASP. *Psychonomic Bulletin & Review*, *25*, 58–76. https://doi.org/10.3758/s13423-017-1323-7

Wolfe, J. M. (2012). Saved by a log: How do humans perform hybrid visual and memory search? *Psychological Science*, *23*(7), 698–703. https://doi.org/10.1177/0956797612443968

Wolfe, J. M., Boettcher, S. E. P., Josephs, E. L., Cunningham, C. A., & Drew, T. (2015). You look familiar, but I don’t care: Lure rejection in hybrid visual and memory search is not based on familiarity. *Journal of Experimental Psychology: Human Perception and Performance*, *41*(6), 1576–1587. https://doi.org/10.1037/xhp0000096

Woltz, D. J., & Was, C. A. (2007). Available but unattended conceptual information in working memory: Temporarily active semantic content or persistent memory for prior operations? *Journal of Experimental Psychology: Learning Memory and Cognition*, *33*(1), 155–168. https://doi.org/10.1037/0278-7393.33.1.155

Woodman, G. F., Carlisle, N. B., & Reinhart, R. M. G. (2013). Where do we store the memory representations that guide attention? *Journal of Vision*, *13*(3), 1–17. https://doi.org/10.1167/13.3.1

Wyble, B., Folk, C., & Potter, M. C. (2013). Contingent attentional capture by conceptually relevant images. *Journal of Experimental Psychology: Human Perception and Performance*, *39*(3), 861–871. https://doi.org/10.1037/a0030517

Yi, Y., & Friedman, D. (2014). Age-related differences in working memory: ERPs reveal age-related delays in selection- and inhibition-related processes. *Aging, Neuropsychology, and Cognition*, *21*(4), 483–513. https://doi.org/10.1080/13825585.2013.833581

Yonelinas, A. P. (2002). The nature of recollection and familiarity: A review of 30 years of research. *Journal of Memory and Language*, *46*, 441–517. https://doi.org/10.1006/jmla.2002.2864