Attending to Behaviorally Relevant Moments Enhances Incidental Relational Memory

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Abstract

Memory for the items one has recently encountered is sometimes enhanced in divided attention tasks: Attending to behaviorally relevant items, such as a target in a detection task, boosts memory for unrelated background items (e.g., scenes or words). However, a central feature of episodic memory is memory for the spatiotemporal relationship between items and other elements of an event (*relational memory*), not just the item itself. Three experiments examined whether attending to a behaviorally relevant target-item boosts memory for the relationship between that item, its features, and a background scene. Participants memorized briefly presented scenes. At the same time, they pressed a button if a second unrelated item (a figure or face) was a particular target color (Experiments 1 and 2) or target gender (Experiment 3) rather than a distractor color or gender. Target and distractor items also varied in task-irrelevant features (shape, location, or facial identity). If attending to behaviorally relevant events influences relational memory, then participants should be better able to report both target-defining and irrelevant features of items that appeared with target-paired scenes rather than distractor-paired scenes. This was the case in all experiments: memory was enhanced for the target-paired scenes as well as the association between a scene and features of the paired target-item. Attending to behaviorally relevant moments therefore has broader effects on memory encoding than previously thought: In addition to boosting memory for unrelated background items, attending to targets facilitates relational memory in these tasks.

Keywords: attentional boost effect, temporal selection, relational memory, dual-task interference, episodic memory

Why do people remember some events better than others? You might easily recall having breakfast this morning – your kitchen, the taste of your toast, the smell of your coffee – but barely remember traveling to work afterwards. Although many factors play important roles in episodic memory formation (e.g., Chun & Turk-Browne, 2007; Craik & Tulving, 1975; Kelley & Jacoby, 2000), the contributions of attention are still being explored. This study asks whether variation in attention over time influences memory for which items (e.g., coffee and toast) appeared together during an event.

Episodic memory, event encoding, and attention

Episodic memories are memories for events that occurred at specific times and locations (Conway, 2009; Tulving, 1972). Memory for an event (e.g., having breakfast) is therefore more than memory for an individual item (e.g., your coffee): it involves the recollection of perceptual, conceptual, and affective details of the situation in which that item was previously encountered (Baddeley, 1982; Mandler, 1980; Eichenbaum, 2004), allowing for vivid recollection (Ranganath, Yonelinas, Cohen, Dy, Tom, & D'Esposito, 2004; Tulving, 1985; Wheeler, Stuss, & Tulving, 1997). The information defining an event may be presented in a *relational memory* framework, which binds together individual elements of an experience to represent the event as a whole (Eichenbaum, 2004; Rubin & Umanath, 2015). As a result, systems that support episodic memories are important for representing arbitrary combinations of items, item features, and their social, affective, task, semantic, temporal, and spatial context (Davachi, 2006; Hannula & Ranganath, 2008; Lee, Yeung, & Barense, 2012; Polyn, Norman, & Kahana, 2009; Wang, Cohen & Voss, 2015).

The systems involved in representing events exist alongside fundamental limitations in the mind's ability to represent perceptual information as it is encountered, both over space and over time (Ballard, Hayhoe, & Pelz, 1995; Hayhoe, 2000). It is therefore important to understand the extent to which attention mediates the encoding of items, their features, and their relationships as they appear over space and time. Some aspects of an event may be represented with minimal attention. People can extract and remember some conceptual and perceptual information from scenes that are viewed for as little as 150 ms (for a review, see Oliva, 2005; Potter, Staub, & O'Connor, 2004). In addition, memory for the spatiotemporal relationships between items can sometimes be formed in the absence of attention. For example, memory for relational information in a scene is similar when people are directed to attend to it or and when they are not (Ryan, Althoff, Whitlow, & Cohen, 2000). People can implicitly learn spatial configurations of unattended items (Chun & Jiang, 1998; Jiang & Leung, 2005) and these configurations may support memory for the locations and perceptual details of items in a scene (Hollingworth, 2007; Robin, Buchsbaum, & Moscovitch, 2018). Furthermore, incidental memory for fixated items and their orientation in visual scenes may be similar to what is observed under intentional encoding instructions (Castelhano & Henderson, 2005). Such findings suggest that memory for spatial configurations and gist may not require attention or the intention to remember during encoding.

Other data demonstrate that attention influences episodic memory. Change blindness and online task performance studies (Ballard et al., 1995; Hayhoe, 2000; Levin & Saylor, 2008), suggest that memory for scenes is limited to recently attended items and rapidly degrades once attention is removed (Brady, et al., 2013). In addition, task-relevant features of scenes are better represented in episodic memory systems than irrelevant features, particularly the hippocampus (Aly & Turk-Browne, 2016). Divided attention during encoding also impairs explicit memory (e.g., item recognition or cued recall; Mulligan, 1998), subsequent recollection, but not familiarity judgments (Baddeley, Lewis, Eldridge, & Thomson, 1984; Craik, Govoni, Naveh-Benjamin, & Anderson, 1996; Jacoby, Woloshyn, & Kelley, 1989), and source memory (Johnson, Hashtroudi, & Lindsay, 1993; Troyer, Winocur, Craik, & Moscovitch, 1999). Divided attention also affects visual long-term memory, which is impaired when participants perform simultaneous detection tasks or search for visual targets that are overlaid on the images (Cohen, Alvarez, & Nakayama, 2011; Swallow & Jiang, 2010; Wolfe, Horowitz & Michod, 2007).

Does attending to behaviorally relevant moments enhance relational memory?

Just as attention can prioritize the encoding of some objects or spatial locations, attention can vary over time to enhance memory for information presented during behaviorally relevant moments (Nobre & Van Ede, 2018). Frames and objects from a film, for example, are better remembered if they come from time periods in which an event changed than if they come from the middle of an event (Newtson & Engquist, 1976; Schwan, Garsoffky, & Hesse, 2000; Swallow, Zacks, & Abrams, 2009). Similarly, in the *attentional boost effect*, pictures that are presented during behaviorally relevant moments are better remembered than those presented at other moments, even when they are equally frequent (Swallow & Jiang, 2012; Swallow & Jiang, 2014a; Swallow & Jiang, 2014b). In these experiments participants perform a target detection task as they encode a second stream of unrelated images into memory (Lin, Pype, Murray, & Boynton, 2010; Swallow & Jiang, 2010). On a later recognition memory test, participants can better recognize images that appeared at the same time as a target than those that appeared before or after a target (Swallow & Jiang, 2011), despite increased attentional demands of target detection (Duncan, 1980; Raymond, Shapiro, & Arnell, 1992). Attending to a briefly presented target thus appears to enhance processing of multiple sources of information presented at that time, including sensory information (Pascucci & Turatto, 2013; Seitz & Watanabe, 2009; Spataro, Mulligan, & Rossi-Arnaud, 2013; Swallow, Makovski, & Jiang, 2012). Attending to briefly presented targets in these tasks enhances the processing of other, concurrently presented information, independent of task demands. We refer to the process that enhances information presented at these times as *temporal selection* (cf. Swallow, et al., 2012; Swallow & Jiang, 2013; Jiang & Swallow, 2014).

Though attending to targets enhances the encoding of and subsequent memory for background items, its effect on memory for the spatiotemporal relationship between items and their features is unclear. Four recent studies provide conflicting data. In one study, detecting a target increased the rate at which participants reported remembering, as opposed to knowing, that

a scene was recently presented (Leclercq, Le Dantec, & Seitz, 2014). In another study, participants were better able to report which pictures appeared with a target item than which pictures appeared with a distractor item during encoding (Swallow & Atir, 2018). In contrast, a recent experiment found no effect of target detection on memory for the context of concurrently presented words, such as their font, modality, or whether the words were presented during the first or second half of the encoding task (Mulligan, Smith, & Spataro, 2016). Differences in the effect of target detection on category cued recall and exemplar generation also suggest primarily item-based effects of target detection on memory (Spataro, Mulligan, Bechi Gabrielli, & Rossi-Arnaud, 2017).

The current study examined the effect of temporal selection on relational memory encoding, specifically the spatiotemporal relationships between stimuli. We adapted the attentional boost effect paradigm by testing memory for the background scene and the detection task item it appeared with during encoding. We also examined the effects of target detection on the inclusion of relevant and irrelevant item features in relational memory. Targets and distractors varied along multiple dimensions (i.e., color, shape, location, gender, and identity), that were either relevant or irrelevant for the detection task, and memory for both types of features was tested. In these experiments, we refer to memory for the background item as *scene memory*, memory for the detection task item (target/distractor) as *item memory*, memory for the features of that item as either *relevant or irrelevant feature memory*, and memory for the association between a scene and the features of the detection task item as *relational memory*. If target detection enhances incidental relational memory, then participants should be able to report both relevant and irrelevant features of target items better than those of distractor items. To preview the results, target detection enhanced memory for all three types of information, indicating that it facilitated relational memory.

Experiment 1

Experiment 1 examined the effect of target detection on memory for the relationship between scenes and the features of the detection task items they appeared with during encoding. Participants memorized visual scenes while they monitored an unrelated stream of items which varied in color and shape. They pressed the spacebar each time the item was in the predefined target color (*relevant feature*). The other feature, shape, was not important for the encoding or detection task (*irrelevant feature*). Participants were told they only needed to remember the scenes, but were tested on their memory for the scenes as well as the relevant and irrelevant features of the detection task item it appeared with.

In addition to replicating the attentional boost effect (scene memory), this experiment addressed two questions. Does detecting a target also facilitate memory for which item a scene appeared with (relational memory)? And, if it does, do these benefits extend to irrelevant features of that item (irrelevant feature memory)? The answers to these questions are important for two reasons.

First, explicit memory for the relevant and irrelevant features of attended items is sometimes used as a measure of context memory (e.g. Troyer & Craik, 2000). However, previous findings demonstrating relational memory advantage for items presented on target trials (Swallow & Atir, 2018) could reflect memory for the motor response, the status of the square as a target or distractor, or memory for the color of the square itself. In addition, because participants show no memory advantage for the features of words that appeared with targets rather than distractors (Mulligan, et al., 2016), the degree to which earlier findings reflect an effect of target detection on relational memory remains uncertain.

Second, the effect of attention on encoding an item's irrelevant features is unclear. There is some evidence that irrelevant features are encoded when an item is attended (Gajewski & Brockmole, 2006; Marshall & Bays, 2013; O'Craven, Downing, & Kanwisher, 1999; Schoenfeld, Hopf, Merkel, Heinze, & Hillyard, 2014) and the ability to remember the conjunctions of multiple object features may mediate episodic memory (Erez, Cusack, Kendall, & Barense, 2016). However, feature dimensions of the same item may be encoded and stored independently in memory (Brady, Konkle, Alvarez, & Oliva, 2013; Fougnie & Alvarez, 2011). In addition, a growing literature suggests that irrelevant features are not always maintained in memory (Chen, Swan, & Wyble, 2016; Marshall & Bays, 2013; Serences, Ester, Vogel, & Awh, 2009; Woodman & Vogel, 2008), particularly when perceptual load is high (Xu, 2010).

We expected memory to be better for scenes that appeared with a target during encoding. If target detection facilitates relational memory, then participants also should more accurately report that target-paired scenes appeared with the relevant feature. In addition, if the effects of target detection on relational memory are limited to relevant features then memory for irrelevant features of target and distractor items should be similar. Alternatively, target detection may enhance processing more globally, boosting relational memory for a scene and the concurrent item's relevant and irrelevant features. Finally, irrelevant features may be encoded whenever relevant features are attended. If so, irrelevant features should be remembered well whenever relevant features are accurately reported, regardless of whether they were part of a target.

Methods

Participants

Participants for all experiments were recruited from the Cornell University community and received $10 or course credit. They had normal or corrected-to-normal vision. Normal color vision was verified with the Hardy Rand & Ritler pseudoisochromatic color blindness test (Richmond Products, Albuquerque, NM, USA). Experimental procedures were approved by Cornell's Institutional Review Board. All participants provided informed consent and were debriefed about the nature of the study afterwards.

For all experiments, sample sizes were determined *a priori* with G*Power 3.1 (Faul, Erdfelder, Lang, & Buchner, 2007). For Experiments 1 and 3 (which were conducted first), a target sample size of 32 was selected to provide a power $(1-\beta)$ of .8 to detect an effect of $f = 0.256$ (equivalent to $\eta^2_p = .062$). A conservative estimate of the size of the standard attentional

boost effect was used to ensure adequate power to detect potentially smaller effects on relevant and irrelevant feature memory (Button et al., 2013). Because performance was near chance in some conditions in Experiment 1, and Experiment 2 included a test with four options, a larger target sample size of 48 was used for Experiment 2. This resulted in a power (1-β) of .8 to detect an effect of size $f = 0.207$ (equivalent to $\eta^2_p = .041$), with $\alpha = 0.05$ in a repeated measures ANOVA. Participants were excluded from the analyses if they responded to fewer than 80% of the target items (hits) or responded to more than 10% of distractor items (false alarms) during the encoding task. Participants were recruited until data from enough participants who met these criteria were acquired. Because multiple participants were recruited at once, sample sizes were sometimes larger than the a priori target.

For Experiment 1, a total of 36 participants (29 female; 18-22 years old; age M = 19.89, SD = 1.17) were recruited. All met the performance criteria.

Materials and equipment

Participants sat unconstrained in a normally lit room, approximately 50 cm away from a ViewSonic E70fB 17" CRT monitor (1024×768 pixels, 75 Hz refresh rate) and responded on a keyboard. All experiments were programmed using Psychtoolbox 3 (Brainard, 1997; Pelli, 1997) for MATLAB 2015a.

We acquired 650 color images of indoor and outdoor scenes (e.g., beaches, forests, mountains, cities, etc.) from personal collections and online databases, all used in previous studies (Swallow & Jiang, 2010). To strengthen generalizability, 200 scenes were randomly selected for each participant. A separate set of 22 scenes was used for the practice session (20) and during instructions (2). Items for the detection task (colored circles and stars) were generated in Psychtoolbox 3. For each participant, two colors were selected (counterbalanced) from a set of four (red: [255 0 0], green: [0 255 0], lilac: [255 0 255], yellow: [255 255 0]) to increase generalizability.

Procedure and Task Design

Encoding and Detection Task. For each participant 100 scenes were randomly selected for use in the encoding and detection task (*old scenes*). Old scenes were assigned to appear with one, and only one, of four items defined by the two shapes and two colors (e.g., red circle, red star, yellow circle, yellow star). Each of the four items was assigned to 25 old scenes. Half of the scenes were paired with an item in the target color and half were paired with an item in the distractor color. Pairings were maintained throughout the encoding and detection task. A second set of 100 scenes acted as *foil scenes* in the recognition phase.

Figure 1a provides an example of trials in the encoding and detection task in Experiment 1. On each trial, a scene (10.3°×10.3° visual angle) appeared for 1000 ms in the center of the screen. The item (circle, 1.15°×1.15°; star, 2.9°×2.9°) paired with that scene was initially overlaid on the scene, but disappeared after 200 ms (0 ms stimulus onset asynchrony). Trials were presented continuously, with no inter-trial interval. All 100 scene-item pairs were presented

10 times, for a total of 1000 trials. Trial order was pseudo-random: the full set of scene-item pairs was presented for each repetition and there were no more than four consecutive targets or distractors. The task paused every 200 trials for feedback and a self-paced break.

Participants were instructed to remember all the scenes for a subsequent memory task. They were told that an item would be superimposed in the center of each scene and to press the space bar when the item was the predefined target color (e.g., yellow) but not the distractor color (e.g., red). Target color was counterbalanced across participants. Participants were told the item's shape was irrelevant and no mention of the association between scenes and items was made. Prior to beginning the main task, participants completed sets of 20 practice trials until performance requirements were met ($\geq$80% hits, $\leq$10% false alarms).

Memory Task. The recognition memory task is illustrated in Figure 1b. On every trial, three two-alternative forced-choice questions tested participants' memory for the scene and the paired item. First, one old scene and one foil scene were presented on either side of the screen. Participants selected the scene they believed was old. Second, the old scene was displayed in the center of the screen and the two colors (relevant feature) were presented in a neutral shape (square) on either side. Participants selected the color of the item paired with the scene during encoding. Third, the correct old scene and the correct color (in the neutral shape) were displayed in the center of the screen. The circle and star (irrelevant feature) were presented in the correct color on either side. Participants selected the shape of the item paired with the scene during encoding. The second and third questions were included regardless of the accuracy of prior answers. Participants were informed they were viewing the actual old scene or old scene and color pair during those questions. For all questions, the side of the correct choice was counterbalanced and participants responded by pressing a key corresponding to the left or right option. Each question remained on screen for 10 seconds or until a response was given. Feedback was provided by displaying the scene and the item at the end of each trial, as they appeared during the encoding task.

Prior to the recognition task participants were informed, for the first time, they would also be answering questions about relevant and irrelevant features of the paired item. They then practiced the 2AFC for the first question with two otherwise unused scenes to learn the response keys.
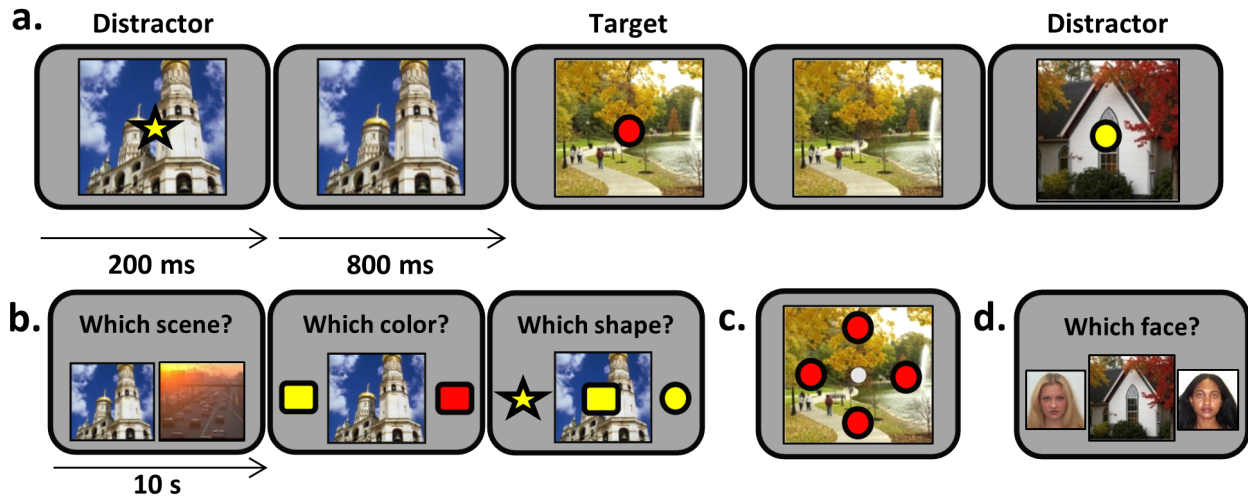
Figure 1. Task design. (a) Each trial of the encoding and detection task of Exp. 1 consisted of a scene and a superimposed item. Participants pressed the button when the item was a target (defined by color in Exp. 1 and 2 and by gender in Exp. 3). (b) During the recognition test of Exp. 1, participants were first tested on memory for the scene, then memory for the task-relevant color of the item it appeared with, and finally memory for the task-irrelevant shape. (c) In Exp. 2, the relevant feature was the color, but the item could appear in one of the four displayed locations around the central fixation point. The test of irrelevant location memory displayed the item in all four locations in the correct color with the central fixation dot. (d) In Exp. 3, after being asked about the background scene, participants chose which of two faces of the same gender (two targets or two distractors) from the encoding task had been paired with the scene. The on screen instructions have been simplified for this figure.

Results

Encoding and Detection Task

Participants correctly responded to most of the target colors and to few of the distractor colors (Table 1).

Table 1. Means and standard deviations (in parentheses) of response percentages and reaction times in milliseconds to targets (hits) and distractors (false alarms) in the detection task of Experiments 1-3

Experiment	Target		Distractor	
	Hits (%)	RT (ms)	False Alarms (%)	RT (ms)
Exp. 1	98.9 (1.1)	352.6 (81.6)	3.5 (2.0)	321.8 (160.6)
Exp. 2	98.83 (1.59)	355.1 (76.2)	3.95 (2.49)	332.6 (139.5)
Exp. 3	97.2 (2.72)	533.9 (95.0)	6.49 (2.18)	442.1 (176.3)

Scene Recognition and Relational Memory

Recognition analyses were performed on sensitivity (Macmillan & Creelman, 2005) obtained with the psyphy package in R (Knoblauch, 2014). Accuracy is reported in Table 2.

Planned analyses contrasted memory for scenes paired with a target or with a distractor during encoding in a paired t-test. Replicating the attentional boost effect (Figure 2a), participants better recognized target-paired scenes than distractor-paired scenes, $t(35) = 4.226$, $p < .001$, $d = 0.736$. Response time (RT) was shorter (Table 3) for tests of information encountered on target trials rather than distractor trials, providing no evidence of a speed accuracy trade-off in recognition memory.

Table 2. Means and standard deviations (in parentheses) of the percentage of correct responses during the recognition test of Experiments 1-3

Experiment	Scene	Relevant Feature	Irrelevant Feature	Irrelevant | Relevant & Scene
Exp. 1				
Target	86.22 (11.25)	67.57 (12.12)	54.85 (11.85)	58.03 (15.58)
Distractor	79.33 (9.93)	61.33 (12.87)	48.55 (12.81)	45.83 (15.72)
Exp. 2				
Target	87.54 (10.12)	68.30 (12.85)	37.78 (8.56)	41.81 (10.83)
Distractor	78.69 (12.20)	59.87 (16.87)	27.65 (7.20)	27.93 (10.08)
Exp. 3				
Target	83.06 (11.25)	N/A	70.99 (13.63)	N/A
Distractor	77.47 (10.21)	N/A	61.42 (10.99)	N/A

Note: N/A: Not applicable.

Table 3. Means and standard deviations (in parentheses) of response times in seconds during the recognition test of Experiments 1-3 for accurate responses

Experiment	Scene	Relevant Feature	Irrelevant Feature	Irrelevant | Relevant & Scene
Exp. 1				
Target	1.94 (1.02)	1.16 (0.97)	1.12 (0.95)	1.07 (0.84)
Distractor	2.17 (1.15)	1.40 (1.14)	1.15 (1.00)	1.18 (1.04)
Exp. 2				
Target	1.60 (0.95)	1.11 (1.05)	1.07 (1.02)	1.04 (1.04)
Distractor	1.80 (1.05)	1.31 (1.11)	1.15 (0.99)	1.19 (1.01)
Exp. 3				
Target	1.79 (0.97)	N/A	1.74 (1.10)	N/A
Distractor	1.92 (0.98)	N/A	1.77 (1.12)	N/A

Note: N/A: Not applicable.

Because relational memory is demonstrated only when the scene is accurately remembered and paired with the item it was encoded with, relational memory analyses were restricted to trials on which the scene was correctly recognized. Sensitivity for the item features

on these trials was entered into a 2x2 (encoding condition by relevance) repeated-measures ANOVA (Figure 2b). If target detection improves relational memory as well as scene memory, participants should better identify the item that a scene appeared with, if that item was previously a target rather than a distractor. Consistent with this possibility, participants more accurately identified the features of an item that appeared with a scene, when the item was a target rather than a distractor, main effect of encoding condition, $F(1,35) = 9.691, p = .004, \eta^2_p = .217$. Encoding condition had a similar effect on relevant and irrelevant features, resulting in a nonsignificant interaction between these factors, $F(1,35) = 0.017, p = 0.898$. Overall, relevant features were more accurately recognized than irrelevant features, main effect of relevance, $F(1,35) = 24.22, p < .001, \eta^2_p = 0.409$. Post hoc analyses indicated that sensitivity was greater than 0 for the irrelevant feature of target items, $t(35) = 2.446, p = .020, d = 0.408$, but not distractor items, $t(35) = -0.604, p = .55$.
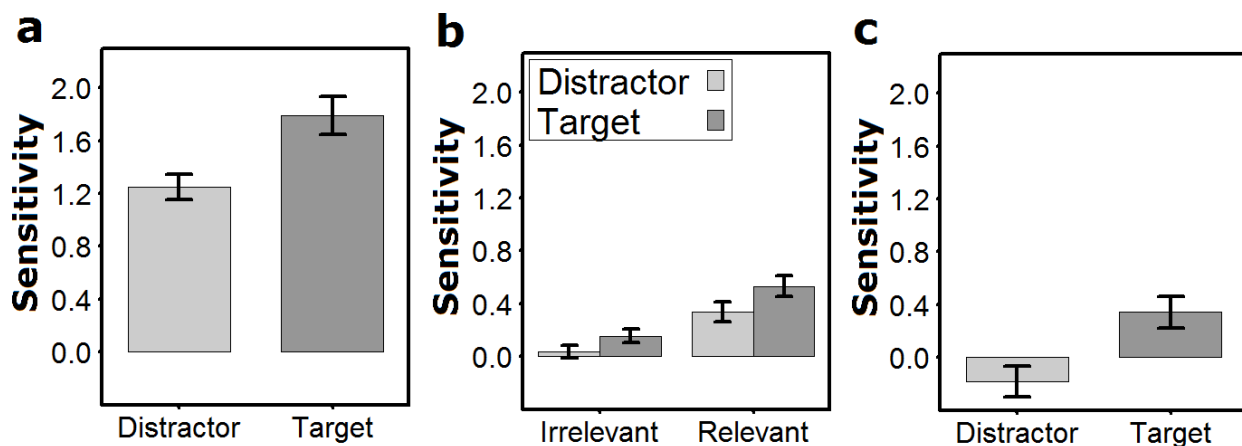

Figure 2. Sensitivity in Experiment 1 for the (a) scene memory, (b) relational memory of item features questions across conditions (given scene recognition), and (c) for task-irrelevant shape (given accurate recognition of scene and task-relevant color). Error bars represent +/- 1 standard error of the mean.

Target detection may have its strongest effects on irrelevant feature encoding if the scene and its paired relevant feature were also successfully encoded. Alternatively, all features of an attended item could be encoded into memory, whether they are relevant or not (e.g., O'Craven, et al., 1999; Schoenfeld, et al., 2014). If so, irrelevant features may be remembered equally well for target and distractor items when the relevant item feature is correctly paired with the scene. Planned analyses examined memory for irrelevant features when both scene and the relevant feature were correctly recognized. Results indicated that memory for irrelevant features was still influenced by target detection: irrelevant features were more accurately reported for target items than for distractor items (Figure 2c), $t(35) = 2.569, p = .015, d = 0.752$. Follow-up analyses indicated that memory for the irrelevant feature was better than chance for target items, $t(35) = 2.902, p = .006, d = 0.484$, but not distractor items, $t(35) = -1.601, p = .118$.

Experiment 1: Discussion

Experiment 1 examined whether target detection facilitates relational memory for a scene and a concurrently presented item. Results replicated the attentional boost effect for scene memory. In a novel finding, participants were better able to match the irrelevant feature (shape) of an item, as well as the relevant feature (color) to correctly recognized target-paired scenes. Relational memory between a scene and both the relevant and irrelevant features of an item it was encoded with was therefore boosted when that item was a target. The memory advantage for the irrelevant features of items paired with scenes cannot be attributed to learning the association between either a scene and the motor response or between the scene and the presence of a target. It also cannot be easily attributed to a response bias. Because both irrelevant feature values were equally likely to occur with target or distractor items, any bias in selecting a particular irrelevant feature would apply to target and distractor conditions. The data suggest that temporal selection modulates relational memory encoding as well as memory for the irrelevant features of items. However, chance recognition of irrelevant features of distractor items precludes conclusions about whether the magnitude of this advantage depends on the relevance of the feature.

A key characteristic of relational memory is that it often includes information about spatial relationships between items. Because the target and distractor items always appeared at the same location – centered on the scene – the data from Experiment 1 do not address this critical component of relational memory.

Experiment 2

Experiment 2 examined whether memory for an item's location is enhanced on target trials. Items were assigned to target or distractor conditions based on their color (relevant feature) and could appear in any of four locations (irrelevant feature; Figure 1c). There were several reasons for examining the effect of target detection on memory for spatial location. First, the spatial configuration of items appears to be preferentially encoded by episodic memory systems (Burgess, Maguire, & O'Keefe, 2002; Chen & Wyble, 2015; Epstein, 2008; Hannula & Ranganath, 2008; Jiang, Olsen, & Chun, 2000). In addition, though there is abundant evidence that the attentional boost effect includes item information, relatively little is known about its effect on memory for spatial locations and configurations. Two previous experiments suggest that target detection may allow participants to better distinguish original from mirror reversed images (Swallow & Jiang, 2010) or to indicate whether an image appeared on the left or right side of a screen (Leclercq, Le Dantec, & Seitz, 2014). However, the effects were weak or only present in a small subset of the data. In Experiment 2, we also increased the number of response options to bring chance performance to 25%. By varying the spatial location of the target and distractor items, Experiment 2 offered an opportunity to replicate the relational memory effects observed in Experiment 1, while testing whether they extend to a critical feature of event memory.

Methods

Participants

Of the 52 participants recruited, 50 met performance criteria (32 female; 18-22 years old; age M = 19.5, SD = 1.18). Two participants were excluded for high false alarm rates.

Procedure and Task Design

Encoding and Detection Task. The task was identical to Experiment 1, with a few exceptions. As in Experiment 1, items varied in color (*relevant feature*). However, rather than varying in shape, the location of the items changed from trial to trial (*irrelevant feature*). Items could appear 3.04° above, below, left, or right of the center of the scene for the first 200 ms of scene presentation. Participants were instructed to maintain fixation on a white fixation dot (0.15°) that was continuously presented at the center of the scene. A total of 104 scenes were presented 10 times for 1040 trials. Scenes were assigned to always appear with the same type of item (target/distractor) in the same location. Participants were instructed to memorize the background scenes, respond to items of the predefined target color, and told that the item's location on the screen was irrelevant to their task.

Memory Task. As in Experiment 1, participants' memory for the scene and the relevant and irrelevant features of the target and distractor items was tested, and feedback was provided. Following the test of scene memory and the color of the item that it appeared with (2AFC; like Experiment 1, except the items appeared in the correct shape), participants reported where the item was located in a four alternative forced choice (4AFC). For this question, the item appeared in the correct color in all four possible locations, with the fixation dot in the center. Participants selected a location with the arrow keys. The correct configuration of the scene, item color, and item location were displayed at the end of each trial as feedback.

Results

Encoding and Detection Task

Participants accurately discriminated between the targets and distractors with similar response times as in Experiment 1 (Table 1).

Scene Recognition and Relational Memory

As expected, participants better recognized target-paired scenes than distractor-paired scenes (Figure 3a), $t(49) = 6.634$, $p < .001$, $d = 0.779$. There was no evidence of a speed-accuracy trade-off (Table 2).
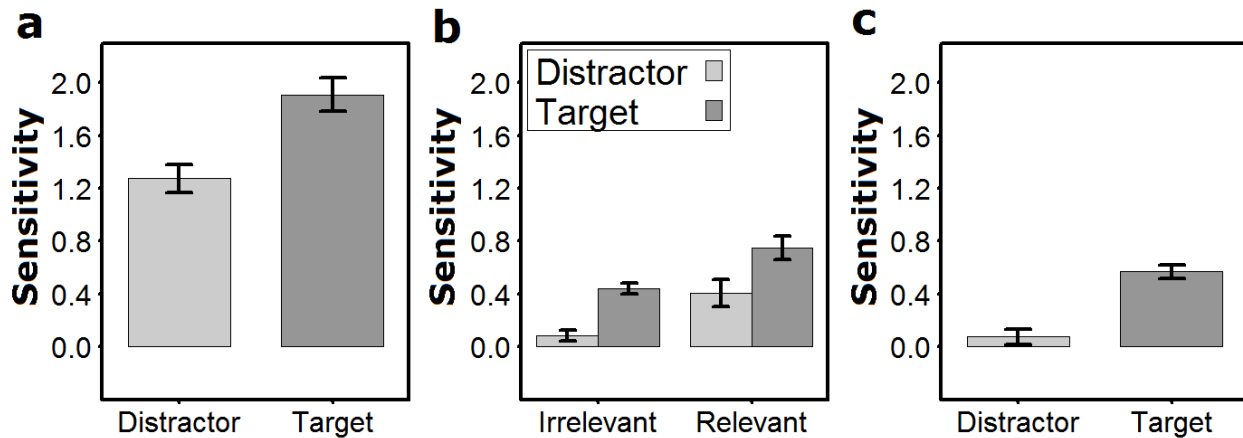
Figure 3. Sensitivity in Experiment 2 for (a) scene memory, (b) relational memory of the paired features (given scene recognition), and (c) for the task-irrelevant location (given accurate recognition of scene and task-relevant color). Error bars represent +/- 1 standard error of the mean. Chance-level performance for scene memory was 50% (2AFC) for relevant features (panels a, b) and 25% (4AFC) for the irrelevant location (panels b, c).

As in Experiment 1, planned analyses of memory for item features were limited to trials on which the scene was accurately recognized. Although chance level performance differed for relevant and irrelevant features, sensitivity could be directly compared in a 2x2 repeated-measures ANOVA with encoding condition and feature relevance as factors (MacMillan & Creelman, 2005). As expected, participants more accurately reported the relevant color of the item that appeared with a scene than its irrelevant location (Figure 3b), main effect of relevance, $F(1,49) = 22.368, p < .001, \eta^2_p = 0.313$. Importantly, participants also more accurately reported the item's features if it was a target rather than a distractor, main effect of encoding condition, $F(1,49) = 25.37, p < .001, \eta^2_p = 0.341$. The interaction was not significant, $F(1,49) = 0.019, p = 0.891$. Unlike Experiment 1, sensitivity in memory for the irrelevant location of both targets and distractors was better than chance, $t(49) = 10.924, p < .001, d = 1.545$, for targets and $t(49) = 2.126, p = .039, d = 0.301$, for distractors.

When both the scene and its associated item color were accurately reported, participants also better reported the location of a target than the location of a distractor (Figure 3c), $t(49) = 6.596, p < .001, d = 1.294$. Sensitivity for the irrelevant locations of the items on these trials was better than chance for targets, $t(49) = 11.141, p < .001, d = 1.576$, but not distractors, $t(49) = 1.307, p = .197$.

Experiment 2: Discussion

Experiment 2 demonstrated that the attentional boost effect pattern is present in tests of the spatial relationship between an item and the background scene and when the location of the target or distractor varies across trials. This finding further supports the claim that a temporal selection mechanism, underlying the attentional boost effect, facilitates memory for the spatiotemporal relationship between items, as well as memory for the items themselves.

Prior data suggest that the spatial locations of items may be incidentally and rapidly encoded (Golomb, Kupitz, & Thiemann, 2014; Huang, 2010), scaffolding events in episodic memory (Robin, et al., 2018). In fact, the spatial location of an item can be accurately reported under conditions that lead to rapid forgetting of the irrelevant features of an item, such as its color or identity, may be quickly forgotten (Chen & Wyble, 2015). However, Experiment 2 demonstrates that temporal selection enhances memory for the location of an item as well as its color, even when it is task-irrelevant.

In Experiments 1 and 2 the irrelevant features of the items were predictable and varied little from item to item (having two or four potential values). As a result, they did not address the detail with which the irrelevant features are encoded and later recognized. Experiment 3 begins to address this issue by testing whether the attentional boost effect extends to the relationship between scenes and specific faces.

Experiment 3

Experiment 3 investigated the effect of target detection on relational memory for the identity of an item that was paired with a scene during the encoding task. The task was identical to Experiment 1 except the items were replaced with male and female faces. Participants pressed the space bar whenever the face was a pre-specified gender, making gender relevant and face identity irrelevant to the detection task. For the relational memory test, participants were presented with two faces of the same gender that were both used in the detection task. Thus, to demonstrate relational memory, participants had to remember which of two equally familiar faces from the same gender had been paired with the scene. This experiment only tested memory for the irrelevant item feature for two reasons. First, the attentional boost effect for relevant item features has been repeatedly demonstrated (present manuscript; 3 experiments in Swallow & Atir, 2018), making a strong test of relational memory for irrelevant features most important. Second, testing gender requires some form of recoding (e.g., into verbal descriptors), which can influence visual recognition (Nakabayashi, Burton, Brandimonte, & Lloyd-Jones, 2012). As with the first two experiments, participants were not informed ahead of time that they needed to remember anything other than the scene. If target detection boosts relational memory for scenes and paired faces, participants should more accurately report which face appeared with a scene when choosing between faces of the target gender than faces of the distractor gender.

Methods

Participants

Thirty-four participants (23 female; 18-26 years old; age M = 20.44, SD = 2.0) met all performance criteria, out of 43 recruited. Nine participants were excluded due to high false alarm rates (false alarm rate M = 14.71%, SD = 3.84%). All analyses were repeated with the full sample but this did not substantively change the results.

Materials

A total of 113 faces were acquired from an online database (Minear & Park, 2004). They were emotionally neutral, grayscale portraits with a white background (100 x 100 pixels). Of the 113 faces, 12 faces were used exclusively in the practice session and 1 face exclusively for instruction. The remaining 100 faces consisted of five individual faces in each of 20 categories defined by crossing gender (male/female), age (young adult/old adult), and ethnicity (East Asian/South Asian/Black/Hispanic/White).

Procedure and Task Design

The procedure was identical to Experiment 1 except that the superimposed items were male and female faces (2.9°×2.9°). Whenever the face was of the target gender (e.g., male) but not the other (e.g., female), participants pressed the space bar as quickly as they could. The gender assigned to the target condition was counterbalanced across participants.

For the recognition test participants were first asked to indicate which of two scenes was presented during the encoding and detection task. Next, the correct scene was presented in the center of the screen and two faces, one that had appeared with that scene (*matched face*) and one that had appeared with another scene (*foil face*), were presented on the left and right (Figure 1d). The faces were of the same gender and were both presented 10 times during the encoding and detection task. Participants identified the matched face that went with that scene. Each face was presented once as the matched face and once as a foil. Results did not change when the data were limited to the first presentation of each face (first half of the memory task). There was no feedback.

<div align="center">Results</div>

Encoding and Detection Task

For the 34 participants who met the performance criteria, hit rates were similar to those observed in the previous experiments. However, Welch's two-sample t-tests indicated that false alarm rates were slightly higher (Table 1) in Experiment 3 than in Experiment 1, $t(66.644) = 5.972, p = < .001, d = 1.430$, and Experiment 2, $t(76.929) = 4.951, p < .001, d = 1.086$. Target RT (Table 1) was longer than in Experiment 1, $t(63.43) = 19.273, p < .001, d = 2.047$, and Experiment 2, $t(59.909) = 20.204, p < .001, d = 2.084$. These data, combined with the greater number of participants that did not meet the performance criteria, suggest that the detection task was more difficult when it was based on the gender of a face than on color.

Scene Recognition and Relational Memory

Though the target detection task was more difficult, participants better recognized target-paired scenes than distractor-paired scenes (Figure 4a), $t(33) = 3.584, p = .001, d = 0.606$.

Analysis of relational memory for the faces was again restricted to those trials on which the scene had been correctly recognized. If target detection facilitates relational memory for stimuli that differ along multiple dimensions, participants should more accurately pair a face to a scene when the face was of the target gender. Consistent with this prediction, participants more

frequently selected the matched face than the foil face, if they were targets rather than distractors (Figure 4b), $t(33) = 4.653$, $p < .001$, $d = 0.806$.
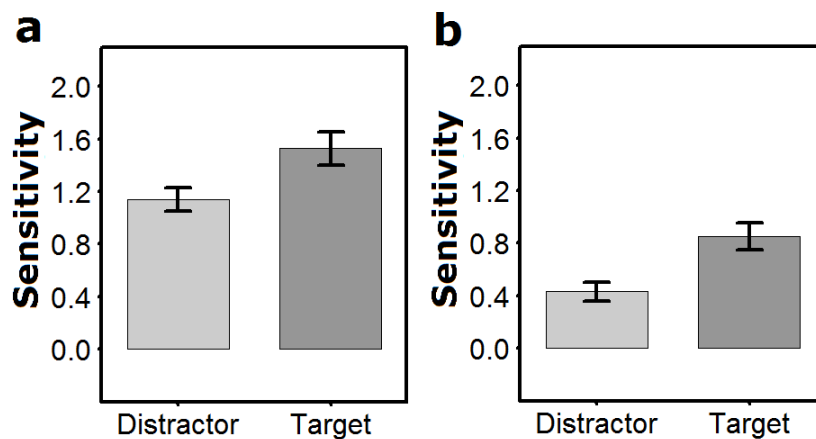

Figure 4. Sensitivity in Experiment 3 for the (a) scene memory and (b) relational memory of face identities given correct scene recognition. Error bars represent +/- 1 standard error of the mean.

Experiment 3: Discussion

As in previous experiments, participants in Experiment 3 incidentally encoded the association between background scenes and otherwise unrelated stimuli – this time faces – presented for a detection task. Relational memory was affected by the status of the face as a target or distractor: Participants more accurately paired the specific face that appeared with a scene when it was the target gender rather than the distractor gender.

This relational memory advantage demonstrates two critical points. First, although dividing attention negatively affects relational memory (e.g., Kim & Giovanello, 2011), relational encoding is enhanced by attention to behaviorally relevant moments. This advantage extended to irrelevant information that, in this case, distinguished one face from other faces of the same gender. Second, target detection resulted in representations sufficiently detailed to support individual differentiation within gender. Unlike the first two experiments in which the items differed from each other along only two dimensions (color and shape or color and location), the faces in Experiment 3 differed in their identity, including gender, age, ethnicity, and the facial features that distinguish one face from another, such as second order configural information and texture (Burton, Schweinberger, Jenkins, & Kaufmann, 2015; Taubert, Apthorp, Aagten-Murphy, & Alais, 2011). They were therefore more perceptually rich and complex than the shapes used in Experiments 1 and 2. Importantly, the effect was incidental. Participants were never informed they would be asked about the faces. Experiment 3 extends the findings of the first two experiments to complex items differing along multiple visual dimensions and uniquely associated with a single scene. An outstanding question, however, is which facial features contributed to relational memory in this task. Because the faces differed in age and ethnicity,

participants could have relied on this information to pair the matched face with the scene[1]. Future research should examine specific facial features such as second-order configurations and textures (Burton, et al., 2015; Taubert, et al., 2011).

These findings further demonstrate that the relational memory advantage for targets over distractors is not due to response bias (see also Swallow & Atir, 2018). Memory for encoding condition (target/distractor), association between scene and a motor response, gender (male/female) of the face, or familiarity with the face that was presented with a scene was not sufficient to accurately perform the recognition task. Therefore, these data provide the strongest evidence yet that target detection facilitates relational memory formation.

General Discussion

If attending to behaviorally relevant moments influences the encoding of an event, it must do so via its constituent items, their features, and their relationship to one another. Multiple studies have already demonstrated that such temporal selection enhances memory for items (e.g., Lin, et al., 2010; Makovski, Jiang & Swallow, 2013; Mulligan et al., 2016; Swallow & Jiang, 2010). The current study supports this conclusion. Across all experiments, attending to targets facilitated scene memory. More importantly, it also enhanced memory for the relationship between those scenes and detection task items, their features, and their locations.

Several key findings suggest that temporal selection facilitates memory for the perceptual and spatial details of an event. First, target detection enhanced relational memory for the visual scene and the relevant feature of a consistently paired and concurrently presented item. Second, target detection facilitated memory for features of the paired item that were not explicitly required for task performance. Because this advantage was also present on those trials in which the relevant feature was accurately reported, it could not be due to the automatic encoding of irrelevant features of attended items (cf. Marshall & Bays, 2013; Wheeler & Treisman, 2002; Xu, 2010). Instead, the effects of target detection on encoding extended beyond the information explicitly needed for task performance. Third, target detection boosted memory for the spatial relationship between items and the scene on which they appeared, permitting participants to more accurately report the location of a target than the location of a distractor. Finally, target detection facilitated relational memory for the perceptual features of items with enough detail to distinguish between individuals that vary along multiple dimensions. Therefore, target detection enhances memory for the features of items that appear with a scene even when they are not explicitly relevant.

These findings cannot be explained by better memory for the individual items in isolation. For example, in Experiment 3, better memory for items would help participants recognize old faces as well as old scenes, and both of these should be enhanced by target detection (Makovski et al., 2013; Swallow & Jiang, 2010). However, for the relational memory

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[1] The proportion of trials on which matched and foil faces were the same age, ethnicity, or both did not significantly differ across target and distractor trials, all t's < 1.40, p's > .171.

test, participants had to determine which of two old faces had been presented with a particular old scene. Better memory for the individual items – the scene, the old face that was paired with it, or the old face that was not paired with it – would not be sufficient to perform well on this task. Participants must be able to accurately pair the correct old face with that particular scene. The beneficial effects of target detection on encoding therefore include relational memory.

Current views of relational memory suggest that any effects of attention reflect the shaping of input into the hippocampus by goal-based or salience based orienting mechanisms, likely subserved by prefrontal cortex (Rubin, et al., 2017; Wang, et al., 2015). However, it is unclear whether similar mechanisms explain the effects of temporal selection on relational memory. An important feature of the tasks used to examine the attentional boost effect is that the background scenes (or words) are all intentionally encoded (or intentionally ignored, as in Swallow & Jiang, 2014a). Goal-based orienting mechanisms should prioritize all images during encoding, while also maintaining and implementing procedures for responding to targets. Because responding to targets demands attention (Duncan, 1980; Raymond, et al., 1992) the finding that divided attention impairs relational memory implies that it should be worse for target-paired scenes (e.g., Troyer & Craik, 2000). Yet, the opposite effect was observed in Experiments 1-3. The relational memory advantage for items presented on target trials represents a qualitatively different effect of attention on relational memory. Rather than the redistribution of limited processing resources, the data point to a mechanism that boosts the encoding of relational information encountered at behaviorally relevant moments.

The findings are consistent with prior studies that examined the effects of target detection on subjective judgments of remembering a scene (Leclerq et al., 2014) and on the ability to remember whether a scene was presented with a target or distractor (Swallow & Atir, 2018). Experiments 1-3 additionally establish a reliable effect of target detection on relational memory that extends to relevant and irrelevant features of detection task items. However, these data differ from two other studies that examined whether the attentional boost effect facilitates memory for the semantic or perceptual context in which words were encoded (Mulligan et al., 2016; Spataro et al., 2017). Though there are many ways in which these experiments differed from the ones presented here, we will focus on several factors that might explain differences in the results and warrant further investigation.

The first critical difference is the nature of the encoded item: words versus images. Whereas words were memorized in the experiments reported by Mulligan and colleagues (2016), pictures were encoded in Experiments 1-3 (and in Swallow & Atir, 2018). Source memory for words may be poorer than it is for scenes, even with the same participants, encoding conditions, and test conditions (e.g., Onyper, Zhang, & Howard, 2010). Differences in memory for words and pictures could arise as a consequence of how participants approach the encoding task (cf., Intraub & Nicklos, 1985; Paivio & Csapo, 1973; Weldon, Roediger, Beitel, & Johnston, 1995). For example, when visual features are seemingly irrelevant, participants may focus on the abstract, semantic content of words, improving later recall and recognition of the words but not explicit incidental memory for visual features (e.g., Rajaram, Srinivas, & Roediger, 1998; Graf

& Ryan, 1990; Smith & Vela, 2001; Weldon et al., 1995). For visual scenes, categorical information is rapidly assessed and persists in memory longer than visual features (Oliva, 2005; Potter et al., 2004). However, when participants memorize scenes from similar categories, they would do best by also focusing on information that distinguishes one scene from another, including subordinate categories and visual details (Anderson & Reder, 1999; Konkle, Brady, Alvarez, & Oliva, 2010; Nairne, 2002). Additional research is needed to evaluate the interaction between target detection and memory for different types of information, particularly as it relates to the ability to distinguish items from each other. Second, in Experiments 1-3, relational memory was examined by testing whether participants could report features of targets and distractors that appeared with a particular scene. Mulligan and colleagues (2016) tested memory for a word and its context by asking participants to indicate whether a given word was new, old and presented in one font/color combination, or old and presented in a different font/color combination. This procedure differs from that used in Experiments 1-3 in two potentially important ways. First, Experiments 1-3 tested memory for the perceptual features of the detection task items rather than the background items. It is possible that the beneficial effects of target detection are limited to the features of the detection targets or spatial locations, with little advantage for the perceptual details of the background item or the scene's temporal context. This may be particularly true for irrelevant perceptual features, which may not always be encoded and remembered (e.g., Marshall & Bays, 2013; Xu, 2010). Second, rather than simultaneously testing memory for the item and spatiotemporal context (as in Mulligan, et al. 2016), Experiments 1-3 first tested scene memory, then showed the old scene during the test of memory for the paired item's relevant and irrelevant features (providing feedback for each question). This may have reduced participants' uncertainty and allowed for a better match between the retrieval cue and the memory trace (Hollingworth, 2006; Nairne, 2002; Reder, Donavos, & Erickson, 2002). However, a relational memory benefit for target paired images also has been observed in experiments where participants first indicated whether an image was old or new, and then selected the color of the square it appeared with (e.g., blue, orange, or no-square) before receiving feedback on their response (Swallow & Atir, 2018). It is therefore unlikely that the availability of more reliable retrieval cues in Experiments 1-3 is the sole source of the difference in findings from those of Mulligan and colleagues (2016).

In Experiments 1-3, the items were presented multiple times rather than once (the attentional boost effect can occur with a single presentation, cf. Lin, et al., 2010; Makovski, Swallow, & Jiang, 2012; Mulligan, et al., 2016; Spataro, et al., 2013). Participants therefore had multiple opportunities to learn the association between a scene and the item it was paired with. With repeated presentations, participants could learn scenes that predict the presence of target features, or the need to generate a motor response. However, because images that precede targets by 100 or 500 ms are not better remembered than those that precede distractors, it is unlikely that the ability to use a scene to predict the presence of a target is enough to boost memory (Swallow & Jiang, 2010; 2011). The ability to use a scene to predict the presence of task-relevant features also cannot account for the relational memory advantage for irrelevant features. Another

possibility is that participants first encode the background items and then add in relational and visual detail in subsequent presentations. If so, memory for the perceptual features of an item (as tested in Mulligan et al., 2016) may be weaker and more susceptible to interference than memory for the item's meaning (Anderson & Reder, 1999; Potter et al., 2004). Alternatively, memory for relational information may strengthen with additional presentations, though this effect is stronger when the items are presented over multiple days (Litman & Davachi, 2008).

The use of multiple presentations in Experiments 1-3 limits their applicability to memory for a single episode (Tulving, 1972). Instead, these experiments may relate more directly to event memory: the mental construction of a scene that takes place at one time, but integrates information encountered across multiple encoding episodes (Rubin & Umanath, 2015). This information may be represented across multiple systems, including basal ganglia, neocortex, and hippocampus. Indeed, previous research has demonstrated that damage to the hippocampus impairs relational memory even when scene-face pairs have been presented multiple times (Hannula, Ryan, Tranel, & Cohen, 2007). Future research should consider how the attentional boost effect is affected by the repetition of events with overlapping constituents.

Finally, it is important to note that targets were rare in Mulligan, et al., (2016), but as frequent as distractors in Experiments 1-3 (and in Swallow & Atir, 2018). Several lines of evidence indicate that distinctiveness, resulting from either the frequency or perceptual salience of targets relative to distractors, has little if any effect on the attentional boost effect for background images (Swallow & Jiang, 2012; 2014a; 2014b). However, distinctiveness manipulations that increase item related processing may reduce memory for irrelevant item features (Hunt & McDaniel, 1993; Mulligan, 2011). Therefore, the role of distinctiveness in modulating the effects of target detection on relational memory, and context more broadly, will be important to explore.

A related concern comes from the fact that target trials always included a motor response, but distractor trials did not. Motor productions can facilitate memory. For example, participants better remember words they have read aloud than words they have read silently (MacLeod, Gopie, Hourihan, Neary, & Ozubko, 2010). However, this effect disappears when uniform responses are made to half the words (e.g., pressing the same button, rather than reading the word aloud; MacLeod, et al., 2010). In addition, other work has shown that faces paired with no motor response are sometimes better remembered than faces paired with a motor response (Makovski, et al., 2013). This suggests that uniform motor responses like the ones in Experiments 1-3 are not sufficient to boost memory in these tasks.

To accommodate the current data, it is necessary to modify views on the effects of attention on memory. Current understanding of the attentional boost effect suggests that it occurs during encoding. In addition, there is substantial evidence that target detection affects the processing of low-level visual or auditory item features (e.g., Pascucci & Turatto, 2013; Spataro et al., 2013; Swallow, Makovski, & Jiang, 2012). However, the attentional boost effect in explicit memory tests of words does not appear to depend on matching visual or auditory features (e.g., word modality, font, or color) of the word during encoding and test (Mulligan,

Spataro, & Picklesimer, 2014; Mulligan et al., 2016). This may mean that the attentional boost effect in explicit memory tests reflects a memory advantage for more abstract information, such as concepts and categories (Mulligan et al., 2016; Weldon, et al., 1995). One might also claim that the attentional boost effect in explicit visual long-term memory results from better conceptual encoding (Konkle, et al., 2010). However, data from Experiments 1-3 argue that, just as enhanced encoding of low-level perceptual features cannot be the whole story, neither can enhanced encoding of abstract, conceptual information.

A potential solution may be to extend an earlier account of the attentional boost effect, the dual-task interaction model, in two ways. The dual-task interaction model claims that well characterized mechanisms of attentional selection over space, objects, and features operate alongside a mechanism that globally boosts perceptual processing at behaviorally relevant moments (Swallow & Jiang, 2013). This model could readily incorporate effects of temporal selection on spatiotemporal context and abstract, amodal information, which were not explicitly considered when the account was first described. Indeed, the neurophysiological mechanism that was proposed to produce the attentional boost effect – the locus coeruleus norepinephrine system (LC-NE) – projects to nearly every region of the brain including the hippocampus (Sara, 2009). Because NE increases the signal-to-noise ratio of activity in afferent areas of the brain as well as long-term potentiation in the dentate gyrus of the hippocampus (Sara, 2009), phasic LC-NE activity in response to targets (Aston-Jones & Cohen, 2005) would have widespread facilitative effects on encoding such as the ones seen in this and similar studies.

The effects of goals and tasks on the way the current situation is processed should be more thoroughly considered in the dual-task interaction model. Independent effects of temporal selection (perhaps mediated by subcortical mechanisms) and the selection of task-relevant information, including features and locations (perhaps mediated by prefrontal cortex) might be sufficient to account for some data. For example, the attentional boost effect is present, but less reliable when background scenes are ignored during encoding (Swallow & Jiang, 2011; Swallow & Jiang, 2014a). In addition, expectations about the importance of distinguishing low-level perceptual features for a subsequent memory test may vary across scene and word encoding, changing the type of information that is facilitated by target detection (cf. Intraub & Nicklos, 1985). In a similar vein, the way a stimulus is processed during encoding could influence the conditions under which the attentional boost effect is best measured (as in transfer appropriate processing; Graf & Ryan, 1990; Weldon, et al., 1995).

Conclusion

Target detection can trigger the selection of a behaviorally relevant moment, boosting the encoding of concurrently presented items. It also enhances memory for the relationship between one item and relevant and irrelevant features of other items that appeared with it during encoding. As a result, increasing attention to behaviorally relevant moments, such as when a target appears in a stream of distractors, boosts memory for the event as a whole. Such a

mechanism is well positioned to influence what people remember about their experiences, how they represent that information in memory, and how they envision the future.

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