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The Yellow Light: Predictability Enhances Background Processing During Behaviorally Relevant Events

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The attentional boost effect refers to the observation that when simultaneously performing a scene memory task and a target detection task, participants better remember scenes that appear at the same time as the detection target than scenes that coincide with distractors. The attentional boost effect is thought to result from a transient increase in attention during an acute behaviorally relevant event, resulting from a temporal orienting response. But can endogenous orienting to predictable targets trigger this response in the same manner as exogenous orienting to unpredictable targets? Until now, the attentional boost effect has only been tested under conditions in which the target's appearance was unpredictable. Because of the distinction between exogenous and endogenous orienting, target predictability could attenuate the attentional boost effect, or it could increase temporal orienting efficiency and enhance the effect. To test the attentional boost effect under predictable conditions, participants memorized scenes while responding to a target digit, 0, among a stream of digits appearing in the center of those scenes. In some blocks, the 0 predictably followed the digit sequence 3–2–1. In these predictable blocks, participants showed a robust attentional boost effect. This shows that both endogenous orienting to temporally predictable targets and exogenous orienting to unpredictable targets enhance concurrent task processing.

Keywords: attentional boost effect, predictability, temporal attention, expectation, dual-task processing

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Driving a car is a common task that necessitates both divided and temporally sustained attention. Drivers must attend to the road ahead of them for long periods of time in order to respond to important events while simultaneously keeping track of speed, directions, road signs, and other vehicles. Events that require a response in these situations can be either unpredictable, such as a deer jumping into the road, or predictable, such as a stop light (a yellow light reliably predicts a red stop light). This example brings forth two questions about the human attentional system. First, when one responds to an acute event during a prolonged task, how does their attention to the environment surrounding the event change? Second, does the effect of this response differ between predictable and unpredictable events? This study seeks to answer these questions.

Our research stems from two somewhat contradictory traditions of research on attention. The first tradition describes performance on two concurrent tasks as a tradeoff: Increasing attention to one task reduces attention to the other (Kinchla, 1992). This is based on the observation that the attentional demand for detecting and responding to a target is higher than the demand for rejecting a nontarget, yielding well-known effects such as the two-target cost (Duncan, 1980) and the attentional blink (Raymond, Shapiro, & Arnell, 1992). This tradeoff frequently occurs in tasks involving discrete trials, the structure of which guarantees that participants are in a near optimal state before each trial. The second tradition focuses on the fluctuation of attention over time. This tradition typically uses continuous performance tasks and observes changes in performance across time. Internal factors, such as vigilance decrement or mind wandering, can drive this fluctuation. Experimental factors can also trigger fluctuations, as when the structure of the task changes (Swallow, Zacks, & Abrams, 2009). Research on this fluctuation has uncovered a paradoxical attentional boost effect, whereby target detection enhances perception and memory of surrounding information (Swallow & Jiang, 2010, 2013).

For example, in Swallow and Jiang (2010), participants encoded a stream of scenes to memory while concurrently monitoring a sequence of tones for the occurrence of high tones. Although the detection of target tones exerts greater attentional demand than the rejection of nontarget tones (as indexed by increased engagement of the frontoparietal attention network; Swallow, Makovski, & Jiang, 2012), participants remembered scenes presented concurrently with target tones better than scenes presented with nontarget tones (see also Leclercq & Seitz, 2012; Lin, Pype, Murray, & Boynton, 2010; Mulligan, Spataro, & Picklesimer, 2014; Schonberg et al., 2014; Swallow & Atir, 2018; Swallow, Jiang, & Riley, 2019; Turker & Swallow, 2019). In other words, increasing attention to one task sometimes facilitates processing in a secondary task, producing an attentional boost, rather than dual-task interference.

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One theoretical account, the temporal orienting account, attempts to explain these two seemingly contradictory patterns of results—dual-task interference (capacity sharing) and facilitation (momentary increases in capacity; Swallow & Jiang, 2013). According to this account, two concurrent tasks typically interfere with each other by competing for limited attentional resources, resulting in performance trade-off effects. However, the total pool of resources is not constant across time, and task demands can induce changes in the size of that resource pool. Under continuous dual-task conditions, where one task contains a stream of intermixed relevant and irrelevant stimuli, detecting a relevant stimulus in that task triggers a transient temporal orienting response to that behaviorally relevant event. This response is accompanied by the brief firing of neurons in the locus coeruleus (LC) and the release of norepinephrine to broad regions of the brain (Aston-Jones, Rajkowski, Kubiak, & Alexinsky, 1994; Aston-Jones & Cohen, 2005), resulting in a temporary increase in the pool of attentional resources available for both tasks. A recent study found that an LC-parahippocampal gyrus circuit is engaged in response to “Go” targets, resulting in an encoding boost for all concurrent stimuli (Yebra et al., 2019). As a result, the temporal orienting response facilitates not only processing of the primary task, but also processing of concurrently presented background stimuli. By considering both the competition for limited resources between tasks and the fluctuation of attention over time, this account explains why an increase in attention to one task sometimes boosts performance in another.

Mounting evidence supports the temporal orienting account. Detecting a target increases brain activity in early visual areas (Swallow et al., 2012), enhances tilt aftereffect from background stimuli (Pascucci & Turatto, 2013), improves memory for concurrently presented words (Spataro, Mulligan, & Rossi-Arnaud, 2013), facilitates long-term and short-term perceptual learning of background motion (Seitz & Watanabe, 2003), and increases the perceived value of concurrently presented food items (Schonberg et al., 2014). Manipulations of the attentional demand of background stimuli—such as increases in the duration of the presentation of background stimuli and the use of emotional stimuli—modulate the attentional boost effect, suggesting that the effect is driven by changes in attention (Mulligan & Spataro, 2015; Mulligan et al., 2014; Rossi-Arnaud, Spataro, Costanzi, Saraulli, & Cestari, 2018; Spataro, Mulligan, & Rossi-Arnaud, 2015; Yebra et al., 2019).

Despite its success, the temporal orienting account leaves one critical question unanswered: What triggers a temporal orienting response? Typically, researchers assert that behaviorally relevant events trigger the orienting response. The term “behaviorally relevant event” encompasses many possibilities, yet existing studies have only tested one kind of relevant event—the appearance of a detection target at an unpredictable moment. However, relevant events need not be unpredictable. Consider driving: The detection of a red traffic light is a highly relevant event requiring a response by the driver. Yet the moment when a light turns red is not unpredictable—the duration of the green light provides some information, and the onset of the yellow light predicts when the red light will appear.

Can both predictable and unpredictable events trigger a temporal orienting response, causing a transient attentional boost? Previous research suggests that temporal orienting may be either exogenous under unpredictable conditions or endogenous under predictable conditions (Coull, Frith, Büchel, & Nobre, 2000; Coull & Nobre, 1998). Exogenous temporal orienting is involuntary and occurs in response to a behaviorally relevant acute event, like orienting toward a suddenly appearing salient stimulus or the detection of an unpredictable target in a stream of distractors. Endogenous temporal orienting is voluntary and occurs when a cue indicates the temporal position of an upcoming behaviorally relevant event. Coull and Nobre (1998) demonstrated the existence of these two distinct forms of temporal orienting by extending the spatial Posner cueing task (Posner, 1980) to the temporal domain. Coull and Nobre (1998) cued the temporal position of an auditory target in a serial target detection task. These cues could be either valid, allowing endogenous orienting to the target, or invalid, requiring rapid exogenous orienting. They found that participants were faster responding to a stimulus if it occurred at a time predicted by a cue than if it occurred earlier than expected. Interestingly, invalid trials could also be divided into exogenous and endogenous orienting trials with distinct results. When the invalid cue predicted a late temporal position of the target, and the target appeared earlier than expected, participants were slow to respond to the target, reflecting exogenous orienting to the unexpected target. When the invalid cue predicted an early target appearance, and the target appeared later than expected, participants were able to voluntarily orient to the later time point once the early time point passed without the target’s appearance. They showed a smaller cost of invalid cueing in the latter type of invalid trial. These findings not only demonstrate that people can orient to moments in time, but they also reveal a distinction between exogenous and endogenous orienting.

Because temporal orienting may be either exogenous or endogenous, we may expect orienting to trigger a transient increase in attention in a continuous dual-task target detection paradigm, whether or not the orienting occurs exogenously in response to an unpredictable target or endogenously in response to a predictable target. That is, the attentional boost effect may be unaffected by the addition of predictive cues. This prediction aligns with the finding that the attentional boost effect is surprisingly robust in the face of several factors that may influence temporal orienting. For example, the attentional boost is equally strong for rare and frequent target events, even though rare events trigger the novelty P3 in ERP and may induce a stronger orienting response (Barry, Steiner, & De Blasio, 2016; Swallow & Jiang, 2012).

However, the behavioral and neural distinctions between exogenous and endogenous orienting (Coull et al., 2000; Coull & Nobre, 1998), in conjunction with the modulatory influence of predictability on many other processes (Agres, Abdallah, & Pearce, 2018; Fernández, Boccia, & Pedreira, 2016; Glautier & Shih, 2015; Hudson, Bach, & Nicholson, 2018; O’Callaghan, Kveraga, Shine, Adams, & Bar, 2017; Sali, Anderson, & Yantis, 2014; Seli et al., 2018; Summerfield & Egner, 2009), suggest that predictability may modulate the attentional boost effect. Predictability makes the anticipation of and preparation for the target’s appearance protracted, rather than transient. This may alter the time course of the attentional boost or eliminate it altogether. Thus, by examining how predictability affects the attentional boost, we can identify critical mechanisms that induce the attentional boost and elucidate the manner in which endogenous and exogenous orienting influence concurrent task processing.

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Experiment 1

To examine how predictability affects the attentional boost effect, we asked participants to monitor a stream of digits for the occurrence of the digit 0 (target digit). In some trial blocks, the occurrence of 0 was unpredictable. In other trial blocks, the countdown sequence 3, 2, 1 always led to 0, and participants were informed of the predictability. Photographs of scenes were presented in the background, and participants were instructed to memorize the scene images. A recognition test was administered later to determine whether scenes coinciding with the target digit were remembered better than scenes coinciding with the nontarget digits.

Trial blocks containing unpredictable targets were similar to prior studies on the attentional boost effect, leading us to predict better memory for scenes coinciding with the target digit than for scenes coinciding with other digits under unpredictable conditions. Several different predictions may be made about the predictable blocks. First, predictability may reduce the attentional demand of the digit monitoring task, leaving a larger pool of resources available for the scene task. This should yield better scene memory in predictable than unpredictable blocks, regardless of the temporal position and functional role of the concurrent digit (Lavie, 2011). Second, predictability may shift the timing of the temporal orienting response from the predicted (target) digit to the predictive digits. This shift may induce an attentional boost to scenes coinciding with the predictive digits and attenuate the enhancement of memory for scenes coinciding with the target digit. Third, the attentional boost effect may be protracted to include predictive stimuli, with participants showing enhanced memory both for scenes coinciding with predictive digits and for scenes coinciding with target digits. Fourth, the reduced acuteness of the target event in predictable blocks may attenuate or eliminate the attentional boost effect, with participants showing the same memory accuracy regardless of the functional role of the concurrent digit. Finally, predictability may have no effect on the attentional boost effect, given the effect's robustness to other manipulations, resulting in better memory for scenes coinciding with the target digit only.

Method

Participants. College students between the ages of 18–35 years participated in this study in exchange for extra course credit. All participants had normal or corrected-to-normal visual acuity and were naive to the purpose of the study. Each participant completed one experiment. The protocol was approved by the University of Minnesota institutional review board.

Sample size was guided by previous studies on the attentional boost effect, with typical sample sizes ranging from 12–20 participants (Swallow & Atir, 2018; Swallow & Jiang, 2010, 2013, 2014). Based on the effect size of $d = 0.74$ (Swallow & Jiang, 2010), G-power analysis suggests that a minimum of 17 participants was needed to reach a power of .80 with an alpha level of .05 (two-tailed)[1]. We therefore tested 20 participants in Experiment 1.

Participants in Experiment 1 included 16 women and four men with a mean age of 20.5 years. Three more participants were tested, but their data were excluded for chance-level memory performance.

Equipment. Stimuli were presented on a 17-in. CRT color monitor (1024x768 pixels, 75 Hz) using MATLAB and PsychToolBox (Brainard, 1997; Pelli, 1997). Viewing distance was unconstrained and was approximately 40 cm.

Materials. A set of 651 color scenes was obtained from online sources and a personal collection. Scenes subtended 11.5° × 11.5° over a gray background. For each participant, 210 scenes were randomly selected to be presented in the encoding phase, and 210 different scenes were randomly selected to be foils presented during the memory test. Forty additional scenes were shown during practice. During the encoding phase, numbers were presented in the center of each scene (font size 14, approximately 0.6°) in a green color (RBG values 0, 255, 0).

Design and procedure. Each experiment consisted of two phases: an encoding phase and a memory phase. First, participants completed an encoding phase. During this phase, participants viewed a stream of color scenes presented at a pace of 1s/image, with a number presented in the middle of each scene. The scene and the digit onset at the same time. The digit lasted 150 ms and the scene 500 ms, followed by a 500 ms masker composed of a scrambled version of the same scene. Participants were instructed to press the spacebar every time the number in the middle of the scene was 0 (Figure 1, left). They were told to also memorize all of the scenes that were presented behind the numbers for a later memory test.

Each scene/number presentation comprised one trial. The encoding phase consisted of 10 blocks of 105 trials each. Each block began with instructions telling the participant to press the spacebar for the digit 0 and to memorize the scenes. After each block, participants were shown the percent of correct responses on the digit task, where correct responses occurred each time participants refrained from pressing the spacebar for a digit other than 0 and each time participants pressed the spacebar in response to the 0. Participants chose when to begin each block using a mouse click.

There were two alternating block types: predictable and unpredictable. In predictable blocks, the number 0 occurred at predictable moments. Specifically, in predictable blocks, the number 3 was followed by 2, then 1, then 0. In other words, there was a countdown sequence of 3–2–1–0. To reduce temporal regularity, the numbers 7, 8, and 9 appeared between predictive sequences, comprising four to eight filler trials. They did not appear in order and were not predictive of the appearance of the 0 or of the countdown sequence. In unpredictable blocks, the same numbers appeared (0, 1, 2, 3, 7, 8, 9), but there was no sequence to predict the appearance of the target (0). In other words, the 0 could appear at any point throughout the block, with some constraints that decreased temporal distinctions between predictable and unpredictable blocks. The following constraints on the temporal position of the digit 0 applied to both predictable and unpredictable blocks. First, the 0 could not appear in any of the first three trials of a block. Second, the 0 had to occur once within the first seven trials of the block. Third, the 0 could not occur more often than once every seven trials.

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[1] Though the sample size of 20 should be adequate to assess the presence or absence of the basic attentional boost effect, some other experimental effects—such as differences among the digits 3, 2, and 1 in the predictive sequence—may be associated with a smaller effect size. To ensure adequate power, data were pooled across experiments in these analyses. In addition, Experiment 3 constituted a replication experiment with a larger sample size, allowing for better-powered and more fine-grained analyses.

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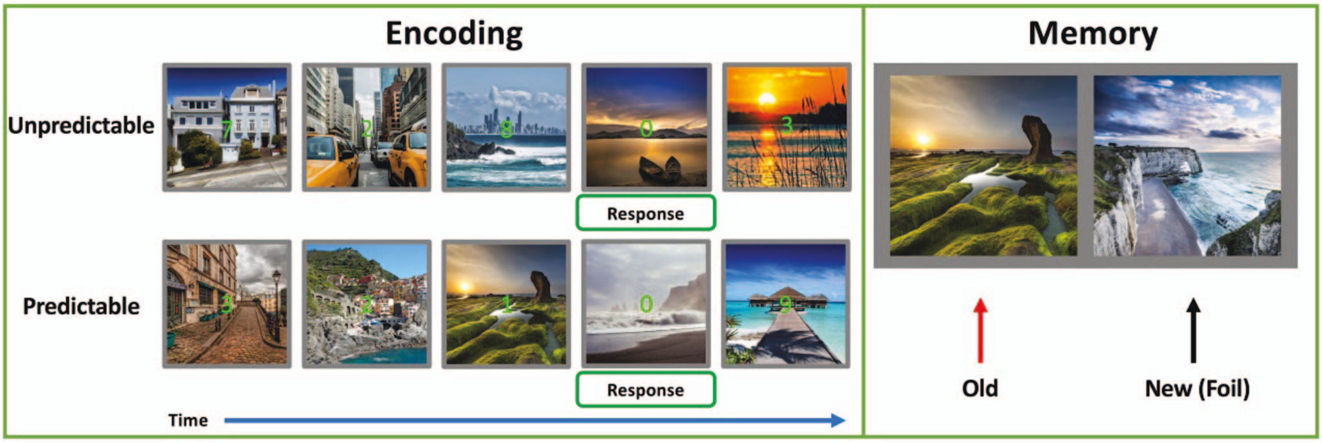

Figure 1. Experimental task. Participants viewed a stream of natural scenes, with each scene appearing for 500 ms followed by a 500 ms masker. In Experiment 1, all digits appeared in the color green (gray). The digits onset at the same time as the scenes and lasted 150 ms. Each scene was randomly paired with one block type and one digit within that block type. Predictable and unpredictable blocks alternated. The encoding phase (left) was followed by a memory test (right), in which two scenes were presented, one of which had been shown in the encoding phase and one of which had never been shown. Stimuli are not drawn to scale. Images displayed here are copyright-free images that are equivalent to those used in the experiment. These images were all sourced from Pixabay. See the online article for the color version of this figure.

Predictable and unpredictable blocks alternated, and the starting block type was counterbalanced across participants. At the beginning of each block, participants were given instructions depending on the block type of the upcoming block. Before predictable blocks, a computer voice read the on-screen instructions, "This is a predictable block. The sequence 3, 2, 1 will lead to 0." Before unpredictable blocks, the instructions read, "This is an unpredictable block. 0 can occur at any time."

Each scene was randomly paired with a specific block type and a specific number within that block type. For instance, if a particular scene appeared along with 0 in a predictable block, it would never appear in an unpredictable block or with a number other than 0. The 210 scenes were randomly and evenly divided across block types and numbers, resulting in each number in each condition being paired with 15 different scenes. The randomization was performed independently for each participant to prevent systematic differences in scene memorability across conditions. Participants saw each scene five times during the encoding phase. Because each number was paired with 15 different scenes, sequences of scenes were not predictive of the appearance of the 0.

A memory test followed the encoding phase (Figure 1, right). In the memory test, participants identified the scenes they had seen during the encoding phase. On each trial of the memory test, two scenes were presented next to each other (the center of each scene was 9° to the left or right of fixation; the scenes were $11.5° \times 11.5°$ in size). Participants used the mouse to click on the scene that they thought they had seen during the previous phase. One scene was always old (having been presented in the encoding phase), and one scene was always new (having not been presented in the encoding phase). The memory phase presented each scene from the encoding phase in a separate trial, for a total of 210 trials. Participants received auditory feedback in the form of a rising tone sequence (300 ms) if correct, or a short low tone (100 ms) if incorrect. The trial ended once participants made a response, and there was no time limit. Participants pressed the spacebar to progress from trial to trial.

Results

Digit task performance. In the encoding phase, accuracy on the number task was high in both predictable ($M = 99.2\%$, $SE = 0.1\%$) and unpredictable blocks ($M = 99.4\%$, $SE = 0.1\%$). Overall accuracy did not significantly differ between predictable and unpredictable blocks, $t(19) = 1.21$, $p = .24$, $d = 0.27$.

Reaction time for the spacebar press on 0-digit trials was faster in predictable ($M = 281$ ms, $SE = 12$ ms) than unpredictable blocks ($M = 467$ ms, $SE = 9$ ms), $t(19) = 15.79$, $p < .001$, $d = 3.53$. This demonstrated that participants relied on the predictive sequence to speed their responses to the target.

Scene memory. When considering effects of predictability, the numbers that appeared in the center of each image were divided into three-digit categories. Numbers 7, 8, and 9 comprised a category of digits that were not predictive, numbers 3, 2, and 1 comprised a category of digits that were predictive in the predictable blocks, and the number 0 comprised its own category as a target for which a response was required. Figure 2 shows scene memory accuracy across digit categories.

In the unpredictable blocks, digits 7–9 and 3–1 were functionally equivalent; both were nonpredictive nontargets. Scene memory associated with these two categories was comparable as well, $t(19) = 0.05$, $p > .95$. Scenes associated with the target 0 were better remembered than scenes associated with either of the nontarget categories: $t(19) = 4.95$, $p < .001$, $d = 1.11$ compared with 3-1, and $t(19) = 5.68$, $p < .001$, $d = 1.27$ compared with 7–9. This finding replicated the attentional boost effect under temporally unpredictable conditions.

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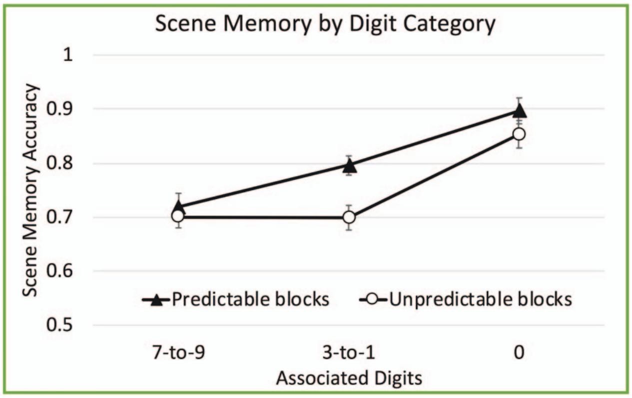

Figure 2. Scene memory from Experiment 1. Proportion of correctly recognized scenes is plotted across the digit category with which the scenes were associated. The digits 7–9 were unpredictive in both block types, the digits 3–1 were predictive in the predictable blocks only, and the digit 0 was the response target in both block types. Error bars show ± 1 *SE* of the mean. See the online article for the color version of this figure.

Making the occurrence of the target predictable did not attenuate the attentional boost effect. In the predictable blocks, scenes encoded with the target 0 were better remembered than scenes encoded with the nonpredictive nontarget category 7–9, $t(19) = 6.39$, $p < .001$, $d = 1.43$, or with the predictive nontarget category 3-1, $t(19) = 4.49$, $p < .001$, $d = 1.00$. The predictive digits also conveyed an advantage, with better memory for scenes encoded with the predictive category 3–1 than the nonpredictive category 7–9, $t(19) = 2.97$, $p = .01$, $d = 0.66$. Statistical significance reported above remained with Bonferroni correction for multiple comparisons.

An ANOVA on scene memory accuracy with block type (predictable vs. unpredictable) and digit category (0, 3-1, or 7–9) as factors revealed a significant main effect of block type, $F(1, 19) = 12.95$, $p = .002$, $\eta_p^2 = .41$, digit category, $F(2, 38) = 33.78$, $p < .001$, $\eta_p^2 = .64$, and a significant interaction between the two, $F(2, 38) = 3.63$, $p = .04$, $\eta_p^2 = .16$. Nonpredictive nontargets 7–9 were associated with comparable levels of scene memory in the two block types, $t(19) = 1.01$, $p = .33$, $d = 0.23$, suggesting that predictability did not simply make the digit task easier overall. Instead, the effects of predictability depended on the digit category, as demonstrated in the interaction between block type and digit category. This interaction, as well as the main effect of predictability, was mainly driven by better memory for digits 3-1, but not digits 7–9, in predictable blocks, compared with unpredictable blocks, $t(19) = 4.13$, $p < .001$, $d = 0.92$. Scenes coinciding with the target digit were remembered marginally better in predictable than unpredictable blocks, $t(19) = 1.90$, $p = .07$, $d = 0.42$. There were minor differences among predictive digits 3, 2, and 1. The analysis of these distinctions will be reported in a later section of the article (“Effects of predictive digits 3, 2, and 1 on scene processing”) after we have described all of the experiments and can pool data to increase statistical power.

Discussion

This experiment represents the first exploration of the influence of temporal predictability on the attentional boost effect and the potential distinction between the effects of exogenous and endogenous orienting to target events on background processing. Our results showed that the attentional boost effect—better memory for background scenes coinciding with a detection target than a nontarget—was observed both when the timing of the target was predictable and when it was unpredictable. That is, both exogenous and endogenous orienting enhanced concurrent task processing.

Although the attentional boost effect was robust in both predictable and unpredictable blocks, the mechanisms underlying endogenous and exogenous orienting appear to differ. In unpredictable blocks, memory benefits were confined to scenes coinciding with the target digit. In predictable blocks, however, participants additionally showed a memory benefit for scenes coinciding with nontarget digits that predicted the appearance of the target, albeit a smaller benefit than for scenes coinciding with the target digit itself. This benefit could not be attributed to a general reduction in task demands in predictable blocks. A reduction in task demands should enhance memory for scenes coinciding with both the unpredictive digits 7–9 and the predictive digits 3-1, yet memory accuracy was higher only in the latter condition.

One of two mechanisms may explain the higher accuracy for scenes coinciding with predictive digits 3–1 relative to unpredictive digits 7–9 in the predictable blocks. First, because the predictive digits reliably cue the target event, they may also be categorized as behaviorally relevant moments and induce a temporal orienting response. That is, the attentional boost becomes temporally protracted to include the predictive cues. If orienting to the appearance of the predictive digits led to this effect, the smaller magnitude of memory advantage for predictive digits than for the predicted target digit may result from distinctions in the efficiency of orienting between predictable and unpredictable moments.

The second, alternative explanation centers on the role of predictability in affecting task control. Because the timing of the occurrence of the 0 is fully determined from the moment the number 3 occurs, the need for identifying the digit is reduced during the predictive sequence leading to 0. This may have allowed participants to quickly shift resources toward scene processing upon the appearance of the predictive sequence, even though a transient increase in attentional resources did not occur until the target’s appearance. Digit monitoring is still needed before the detection of the predictive sequence, explaining why there is not a general benefit to all scenes in the predictive blocks. This second explanation suggests that if the task continues to require digit monitoring until the target’s appearance, such as when the predictive sequence does not fully determine the target’s temporal position, the benefit conveyed by predictive nontargets should also dissipate. In other words, the effects of endogenous orienting in predictable blocks should be observed only at the moment to which participants orient and not at the moment in which participants receive the endogenous cue and decide to orient to the target event. The next experiment tests this prediction by necessitating digit monitoring even in predictable blocks.

Experiment 2

In this second experiment, participants were again asked to press the spacebar in response to the 0, but only when it appeared in one assigned target color. All digits could appear in either the color red or the color green, and each participant was assigned one color as

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their target color. They were to respond with a spacebar press to 0 digits only when they occurred in that target color. Thus, in predictable blocks, although the target only appeared at predictable moments, a 0 digit in the nontarget color could also appear following the sequence 3–2–1, so participants had to attend to the digit before making a response and could not disengage from the digit task after seeing the predictive digits.

This experiment achieved three goals. First, we aimed to replicate the observation of the attentional boost effect in predictable blocks, demonstrating that the effect can be triggered by either exogenous or endogenous temporal orienting. Second, we examined whether the memory benefit extended to the predictive digits 3–1 under conditions that did not allow participants to completely disengage from the digit task. This would determine whether the benefit observed for predictive digits in Experiment 1 resulted from a distinction between the effects of exogenous and endogenous orienting on background processing or simply task management. Third, we tested whether the attentional boost effect occurred only when the digit 0 appeared in the target color or whether it also occurred when the digit 0 appeared in the distractor color.

The experimental condition tested in the unpredictable blocks was reminiscent of Swallow and Jiang (2014), in which the detection target was defined by the conjunction of color and shape. Despite perceptual similarity between some of the nontargets and the target, memory benefits were restricted to background images encoded with the target. This finding suggested that the attentional boost effect was triggered by the categorization of and response to the detection target, rather than the detection of features that matched the target template. In the present experiment, the nontarget color 0 is perceptually similar to the target color 0 but does not warrant a response. Thus, in unpredictable blocks, we would expect a boost only for scenes coinciding with the target color 0.

Data from the predictable blocks can yield important new insights into mechanisms of temporal orienting and the attentional boost. First, a replication of the memory benefit to scenes encoded with the target color 0 would confirm, once again, that the attentional boost is not confined to instances of exogenous orienting to temporally unpredictable targets. Second, the presence of a benefit to scenes encoded with predictive digits 3–1 would suggest that orienting to predictive cues can facilitate memory in the moments leading up to the target event. The absence of this effect would suggest that predictive cues do not reliably influence background processing before a target event. This would also indicate that the attentional boost effect occurs at the moment to which one orients, rather than the moment at which one detects the predictive cue and decides to orient to a future event. Finally, participants' response to the nontarget-color 0 can inform us as to whether the attentional boost depends on the categorization of a stimulus as a target or whether it may also occur when people preemptively orient attention to a temporal moment, even though the stimulus occurring at that moment is eventually categorized as a nontarget. If the attentional boost effect is observed for nontarget-color 0 digits, this would suggest that the transient increase in attentional resources can be supported solely by endogenous temporal orienting to the expected target event.

Method

Participants. Twenty new participants completed Experiment 2. The participants included 17 women and three men with a mean age of 20.1 years. Three more participants were tested, but two were excluded for chance-level memory performance, and one was excluded for failing to consistently respond to the target digit in the digit task.

Materials and procedure. Experiment 2 was nearly identical to Experiment 1 with one crucial modification. Digits were either red or green (color was randomly selected on each trial), and participants were instructed to respond with a spacebar press to the digit 0 only when it appeared in one specific target color. Each participant was assigned either red or green as their target color, and this target color was maintained for that participant throughout the experiment. Target color was counterbalanced between participants. In predictable blocks, the digit 0 occurred at a predictable moment, but the color was not predictable (50% of 0 digits were red, and 50% were green, appearing in random order within each block). As in Experiment 1, each scene was randomly paired with a specific block type and a specific number within that block type, and randomization was performed independently for each participant. Scenes paired with a 0 were consistently paired with either the target color or the nontarget color. The manipulation of color meant dividing 0-digit trials into target color trials and nontarget color trials, resulting in a smaller number of scenes coinciding with target trials. To counteract this reduction, we increased the number of scenes associated with each digit from 15 to 20 (each digit appeared 10 times in red and 10 times in green per block), which resulted in 140-trial blocks instead of 105-trial blocks. As a result, the number of scenes to remember increased from 210 to 280, so the memory test included 280 trials.

Results

Digit task performance. Accuracy on the digit task was high in both predictable ($M = 99.5\%$, $SE = 0.1\%$) and unpredictable blocks ($M = 99.5\%$, $SE = 0.1\%$). Accuracy did not significantly differ between predictable and unpredictable blocks, $t(19) = 0.22$, $p = .83$, $d = 0.05$. Reaction time to the target-colored 0 was significantly faster in predictable blocks ($M = 451$ ms, $SE = 14$ ms) than in unpredictable blocks ($M = 541$ ms, $SE = 7$ ms), $t(19) = 9.84$, $p < .001$, $d = 2.20$. This demonstrates an advantage in anticipating the timing of the target's likely appearance. In addition, this shows that participants attended to and used the predictive sequence to their advantage, even though it was followed by a nontarget-color 0 half of the time.

Because Experiment 2 included trials in which a distractor-colored 0 appeared after the predictive sequence, it is important to consider the rate of false alarm responses in order to contextualize scene memory effects on 0-distractor trials. False alarms were rare. Participants incorrectly responded to 0 distractors on 0.14% of trials in predictable blocks and 0.14% of trials in unpredictable blocks. Participants incorrectly responded to non-0 digits on 0.19% of trials in predictable blocks and 0.17% of trials in unpredictable blocks. Neither of these false alarm rates differed between predictable and unpredictable blocks (lowest $p = .73$).

Scene memory. The numbers that appeared in the center of each image were divided into four digit categories: nonpredictive digits 7–9, predictive digits 3-1, the digit 0 in the target color

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(0-target), and the digit 0 in the nontarget color (0-distractor). Scene memory accuracy across digit categories can be seen in Figure 3, left. An ANOVA on scene memory accuracy with block type (predictable vs. unpredictable) and digit category (0-target, 0-distractor, 1-to-3, or 7-to-9) as factors revealed a significant main effect of block type, $F(1, 19) = 16.16$, $p = .001$, $\eta_p^2 = .46$, with higher accuracy in predictable blocks and digit category, $F(3, 57) = 13.46$, $p < .001$, $\eta_p^2 = .42$, with better accuracy for 0-target than for the other digits, and a significant interaction between the two, $F(3, 57) = 6.69$, $p = .001$, $\eta_p^2 = .26$. As the follow-up tests reported next show, the attentional boost effect appeared to be more robust in the predictable blocks.

Data from the unpredictable blocks were consistent with previous findings in which the target was defined as the conjunction of color and shape (Swallow & Jiang, 2014). Specifically, memory for scenes coinciding with the target 0 was numerically better than for scenes coinciding with nontarget digits 7–9, $t(19) = 1.19$, $p = .25$, $d = 0.26$, and marginally better than for scenes coinciding with nontarget digits 3-1, $t(19) = 1.86$, $p = .08$, $d = 0.42$. In contrast, memory for scenes coinciding with the distractor 0 was numerically worse than for scenes coinciding with digits 7–9, $t(19) = 2.01$, $p = .06$, $d = 0.45$, and digits 3-1, $t(19) = 1.16$, $p = .26$, $d = 0.26$. As in Swallow and Jiang (2014), any benefit in scene memory was restricted to the digit in the target color and did not apply to the digit in the distractor color. A direct comparison between 0-target and 0-distractor conditions showed better memory for scenes coinciding with 0-targets, $t(19) = 2.18$, $p = .04$, $d = 0.49$, though this effect would not be significant with Bonferroni correction.

Results changed when the timing of the 0 was predictable, with several notable findings. First, when the 0 appeared in the target color, scene memory was significantly better than for scenes coinciding with either the nonpredictive digits 7–9, $t(19) = 8.03$, $p < .001$, $d = 1.80$, or the predictive digits 3-1, $t(19) = 7.13$, $p < .001$, $d = 1.59$. This finding confirmed the presence of an attentional boost effect in predictable blocks. Second, even when the digit 0 appeared in the distractor color, its associated scene memory was better than for scenes coinciding with either the nonpredictive digits 7–9, $t(19) = 4.37$, $p < .001$, $d = 0.98$, or the predictive digits 3-1, $t(19) = 3.19$, $p = .01$, $d = 0.71$. These statistical effects remained significant with Bonferroni correction for multiple comparisons. The effect was greater for 0-targets than 0-distractors, $t(19) = 2.33$, $p = .03$, $d = 0.52$, though this effect was not significant with Bonferroni correction. Thus, contrary to the findings from the unpredictable blocks, when the timing of the 0 was predictable, the appearance of the 0 resulted in a memory benefit, even when the 0 appeared in the distractor color. Third, the memory benefit did not extend to predictive digits. Unlike Experiment 1, memory for scenes coinciding with predictive digits 3–1 did not differ significantly from memory for scenes coinciding with nonpredictive digits 7–9, $t(19) = 0.09$, $p = .93$, $d = 0.02$.

There was not strong evidence for a general advantage of predictability, as there were no differences between the block types for the digit categories of 7–9, $t(19) = 0.34$, $p = .74$, $d = 0.08$, or 3-1, $t(19) = 0.94$, $p = .36$, $d = 0.21$. There was however a significantly larger advantage for scenes coinciding with the target-colored 0 in predictable blocks compared with unpredictable blocks, $t(19) = 2.94$, $p = .008$, $d = 0.66$. As expected given the advantage for 0-distractors in predictable blocks only, there was also a significant difference between 0-distractors between the two block types, $t(19) = 3.97$, $p = .001$, $d = .89$.

Discussion

When the target was defined by the combination of digit identity and color, the attentional boost effect in the unpredictable blocks was restricted to the target 0, excluding the perceptually similar distractor 0. Consistent with Swallow and Jiang (2014), this find-

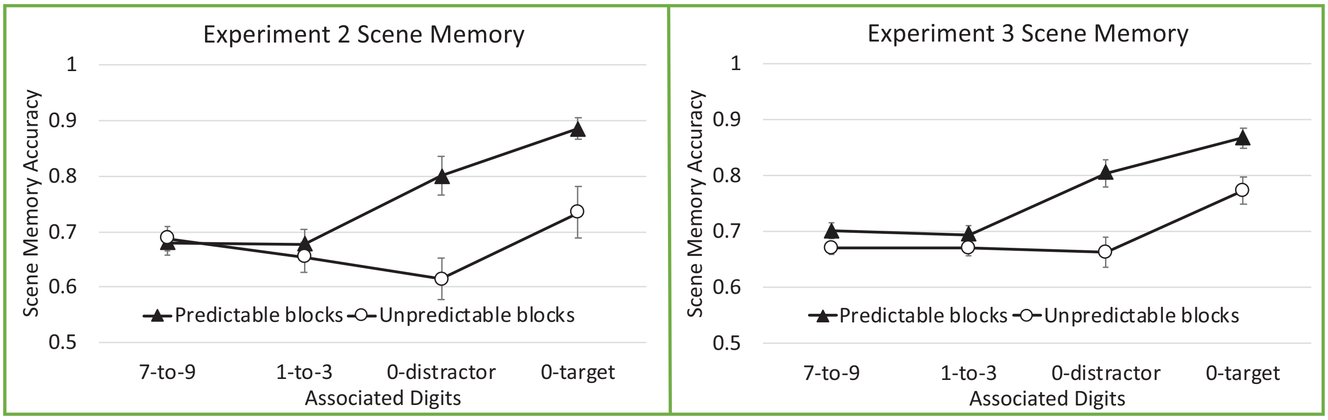

Figure 3. Scene memory from Experiments 2 (left) and 3 (right). Proportion of correctly recognized scenes is plotted across the digit categories with which the scenes were associated. The digits 7–9 were unpredictive in both block types, the digits 3–1 were predictive in the predictable blocks only, the 0-distractor category includes scenes coinciding with the digit 0 when it appeared in the nontarget color, and the 0-target category includes scenes coinciding with the digit 0 when it appeared in the target color as the response target in both block types. Data from Experiment 2 (N = 20) are plotted on the left, and data from Experiment 3 (N = 48) are plotted on the right. Experimental conditions were identical between Experiments 2 and 3. Error bars represent ± 1 *SE* of the mean. See the online article for the color version of this figure.

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ing shows that when the timing of the target could not be predicted, the attentional boost effect may be confined to stimuli categorized as targets. The attentional boost for the target 0 was weaker than that observed in Experiment 1. This may be due to increased dual-task interference from a color–digit conjunction search task relative to a simpler digit search task. The weaker effect may also be attributed to the reduction in the number of target trials following the division of 0-digit trials into target-color trials and nontarget-color trials—instead of 15 target trials per block, there were 10. We will address this possibility by replicating Experiment 2 with a larger sample size in the next experiment.

The key contribution of Experiment 2 is its novel combination of conjunction targets and blocks in which the timing of the target digit 0 was predictable. Confirming the results in Experiment 1, we observed better memory for scenes coinciding with the target digit, even when participants could predict when the target would occur. Thus, like exogenous temporal orienting toward unpredictable targets, endogenous temporal orienting toward predictable targets triggers an attentional boost effect. Experiment 2 also provides evidence that endogenous temporal orienting enhances concurrent task performance even when the detection stimulus (0-distractor) is not categorized as a target. This cannot be explained by high rates of erroneous responses to 0-distractors because the false alarm rates for 0-distractor trials were very low and did not differ between predictable and unpredictable blocks. To our knowledge, this is the first observation that temporal orienting alone, in the absence of target detection, can enhance concurrent task performance.

Experiment 2, which differed from Experiment 1 in its use of a discrimination task for the digit 0, did not observe the protracted attentional boost effect in response to the predictive digits 3-1. That is, when participants could not disengage from the digit task after the appearance of the predictive digits, the memory benefit became confined to the oriented moment and did not extend to the predictive digits. Thus, even though predictive cues may ease the task demand in the moments leading up to target detection under some circumstances, they do not reliably facilitate concurrent task performance.

The results from Experiment 2 suggest that it may be underpowered to answer several questions related to subtler experimental effects. Because half of the 0 digits appear in a nontarget color in Experiment 2, there are many fewer target trials than in Experiment 1, even after increasing the number of scenes coinciding with each digit. This decreased statistical power and limited fine-grained analyses. To achieve higher statistical power in this paradigm involving both a conjunction target and predictability, we conducted a third experiment that more than doubled the sample size of Experiment 2.

Experiment 3

Experiment 3 was a replication attempt of Experiment 2 with a larger sample size that would allow for better powered analyses. First, we aimed to replicate the attentional boost effect for both target and nontarget 0s in predictable blocks. Second, we aimed to determine whether ample power would allow for detection of a significant attentional boost effect for target 0s in unpredictable blocks. Third, we intended to determine whether or not the apparent memory disadvantage for scenes coinciding with the distractor 0 observed in unpredictable blocks in Experiment 2 was spurious. We also further investigated the pattern of memory behavior observed in predictable blocks for scenes coinciding with predictive digits 3, 2, and 1.

Method

Participants. We aimed to obtain data from at least 45 participants or as many as we could test in one semester of data collection. The sample size was chosen to detect an experimental effect that is moderate in effect size (Cohen's $d = 0.5$). G-power analysis suggests that a sample size of 45 affords a power of 0.91 in detecting a moderate effect at an alpha level of 0.05 (two-tailed). Forty-eight new participants completed Experiment 3. The participants included 28 women and 20 men with a mean age of 19.9 years. Twelve more participants were tested, but seven were excluded for chance-level memory performance, and five were excluded due a to computer malfunction that prevented completion of the experiment.

Materials and procedure. Experiment 3 was identical to Experiment 2.

Results

Digit task performance. Accuracy on the digit task was high in both predictable ($M = 99.5\%$, $SE = 0.07\%$) and unpredictable blocks ($M = 99.3\%$, $SE = 0.06\%$). Accuracy was significantly higher in predictable blocks, $t(47) = 2.38$, $p = .02$, $d = 0.34$. Reaction time to the target-colored 0 was also significantly faster in predictable blocks ($M = 426$ ms, $SE = 8$ ms) than in unpredictable blocks ($M = 535$ ms, $SE = 6$ ms), $t(47) = 18.75$, $p < .001$, $d = 2.71$. This demonstrates that participants used predictive cues to prepare for the appearance of the target, even when a nontarget 0 followed the 3–2–1 sequence half of the time.

As in Experiment 2, it is important to consider the rate of false alarm responses to ensure that participants did not respond to 0-distractors at a disproportionately high rate in predictable blocks. False alarms were rare in both block types. Participants incorrectly responded to 0-distractors on 0.17% of trials in predictable blocks and 0.21% of trials in unpredictable blocks. Participants incorrectly responded to non-0 digits on 0.18% of trials in predictable blocks and 0.17% of trials in unpredictable blocks. Neither of these false alarm rates differed between predictable and unpredictable blocks (lowest $p = .22$).

Scene memory. The numbers that appeared in the center of each image were divided into the same four digit categories as in Experiment 2: nonpredictive digits 7–9, predictive digits 3-1, the digit 0 in the target color (0-target), and the digit 0 in the nontarget color (0-distractor). Figure 3 (right) shows scene memory accuracy across digit categories. Overall, the results in Experiment 3 were remarkably consistent with those observed in Experiment 2. An ANOVA on scene memory accuracy with block type (predictable vs. unpredictable) and digit category (0-target, 0-distractor, 1–3, or 7–9) as factors revealed a significant main effect of block type, $F(1, 47) = 38.84$, $p = .001$, $\eta_p^2 = .45$, with higher accuracy in predictable blocks and digit category, $F(3, 141) = 31.87$, $p < .001$, $\eta_p^2 = .40$, with better accuracy for 0-target than for the other digits, and a significant interaction between the two, $F(3, 141) = 6.37$, $p < .001$, $\eta_p^2 = .12$.

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Data from the unpredictable blocks clarified and strengthened the findings of Experiment 2. As in Experiment 2, memory for scenes coinciding with the target 0 was better than for scenes coinciding with nontarget digits 7–9 and 3-1, and this attentional boost effect did reach significance in this better-powered experiment: $t(47) = 4.35$, $p < .001$, $d = 0.63$ when compared with 7–9, and $t(47) = 4.28$, $p < .001$, $d = 0.62$ when compared with 3-1. The attentional boost effect was restricted to the target-color 0. Memory for scenes coinciding with the distractor 0 did not differ from memory for scenes coinciding with digits 7–9, $t(47) = 0.29$, $p = .77$, $d = 0.04$, or 3-1, $t(47) = 0.30$, $p = .77$, $d = 0.04$. Consistent with Swallow and Jiang (2014), scene memory was restricted to the digit in the target color and did not apply to the digit in the distractor color. A direct comparison between 0-target and 0-distractor conditions showed better memory for scenes coinciding with 0-targets, $t(47) = 3.34$, $p = .002$, $d = 0.48$.

In Experiment 2, memory for scenes coinciding with the distractor 0 was slightly worse than for scenes coinciding with digits 7–9 or digits 3-1. In Experiment 3, memory for scenes coinciding with the distractor 0 did not differ from memory for scenes coinciding with digits 7–9 or digits 3-1. Thus, the worse memory for scenes coinciding with the distractor 0 observed in Experiment 2 may be spurious.

When the timing of the 0 was predictable, results again aligned with those found in Experiment 2. First, when the 0 appeared in the target color, scene memory was again significantly better than for scenes coinciding with either the nonpredictive digits 7–9, $t(47) = 9.97$, $p < .001$, $d = 1.44$, or the predictive digits 3-1, $t(47) = 8.90$, $p < .001$, $d = 1.28$. This finding confirmed the presence of an attentional boost effect in predictable blocks observed in Experiments 1 and 2. Second, when the digit 0 appeared in the distractor color, its associated scene memory was again better than for scenes coinciding with both the nonpredictive digits 7–9, $t(47) = 4.82$, $p < .001$, $d = 0.70$, and the predictive digits 3-1, $t(47) = 5.04$, $p < .001$, $d = 0.73$. Thus, the memory advantage for scenes coinciding with 0, regardless of whether the 0 appeared in the target or distractor color, held with the increased power in Experiment 3. Again, like Experiment 2, the effect was greater for 0-targets than 0-distractors, $t(47) = 2.46$, $p = .02$, $d = 0.36$, though this effect was not significant with Bonferroni correction.

Encoding benefits of predictability were strongest for scenes coinciding with digit 0. *T* tests revealed a significant difference between the two block types for 0 in the target color, $t(47) = 3.35$, $p = .002$, $d = 0.48$, and 0 in the distractor color, $t(47) = 4.81$, $p < .001$, $d = 0.69$. Predictability may also have a small, general effect for non-0 scenes. Memory accuracy was significantly better for digits 7–9 in predictable than unpredictable blocks, $t(47) = 2.56$, $p = .014$, $d = 0.37$, though it did not differ for digits 1–3 between the two block types, $t(47) = 1.68$, $p = .10$, $d = 0.24$.

Discussion

Experiment 3 confirmed many of the findings in Experiment 2 and provided some new insights as well. First, the memory advantage for scenes coinciding with both target and nontarget 0s in predictable blocks was replicated. Second, the attentional boost effect, where scenes coinciding with the target 0 were better remembered than scenes coinciding with nonpredictive digits 7–9, reached significance when power was added. Third, the inhibition of scenes coinciding with the nontarget 0 in unpredictable blocks was not replicated, suggesting that the attentional boost effect is more likely driven by a transient increase in attention at the moment to which one orients than by a dip in attention or memory inhibition in response to distractor rejection.

Before diving deeper into the implications of the findings, we conducted a fourth experiment to address a potential stimulus confound. Specifically, could the effects observed in the first three experiments be a result of some prelearned automatic responses to the numbers 3, 2, 1, and 0 or 7, 8, and 9? After all, 0 was always the target digit, and the predictive sequence was always 3–2–1. Given that people are more sensitive to smaller digits than to larger digits (Dehaene, 2011), it is important to rule out the possibility that the memory advantage observed in Experiments 1, 2, and 3 was driven in part by a “small number” effect or some other preexisting bias toward these digits or digit sequences. Experiment 4 addressed this concern by eliminating the task relevance of the digits and the countdown sequence.

Experiment 4

To rule out the possibility that small numbers are intrinsically salient and may yield a memory advantage, participants in Experiment 4 were asked to encode the scenes and ignore the digits. The digits were still presented in the center of the scenes that participants were instructed to memorize. If smaller digits are intrinsically salient, we might expect the same memory enhancement for scenes encoded with 0 or 3, 2, and 1. A lack of a memory advantage to scenes coinciding with 0 and other digits would demonstrate, instead, that the target detection task modulated scene memory in the first three experiments.

Method

Participants. Experiment 4 tested 15 women and 5 men with a mean age of 19.5 years. One further participant was tested but was excluded for chance-level memory performance.

Materials and procedure. All procedures and stimuli were identical to Experiment 1, besides a change in instructions. Experiment 4’s instructions presented participants with only one task: to memorize the scenes. Participants were told to ignore the digits that appeared in the center of each scene, and they did not see the score on the digit task between blocks because they did not perform the digit task. Because the digits were irrelevant to the task, the predictable and unpredictable blocks did not differ in terms of task demands, and the instructions did not mention any difference between the two block types. Thus, in the analysis presented below, “predictable” refers to blocks in which the task-irrelevant digits 3, 2, 1, and 0 appeared in sequence, and “unpredictable” refers to blocks in which the task-irrelevant digits appeared in random order.

Results and Discussion

As seen in Figure 4, scene memory was similar across digit categories, regardless of whether the block included predictable or unpredictable sequences.

An ANOVA on scene memory accuracy with block type (predictable vs. unpredictable) and digit category (0, 1-to-3, or 7-to-9)

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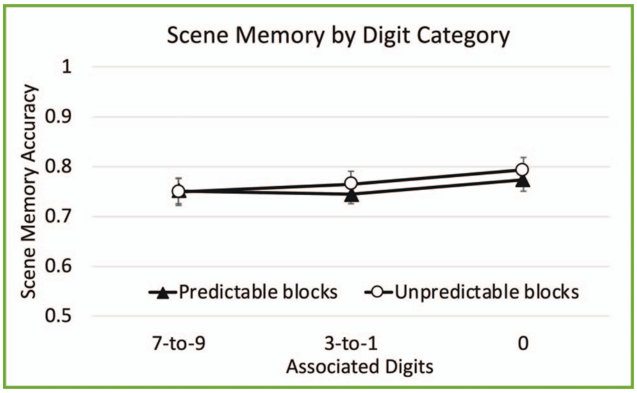

Figure 4. Data from Experiment 4. Proportion of correctly recognized scenes is plotted across the digit categories with which the scenes were associated. Proportion of correctly remembered scenes was plotted separately for scenes appearing in "predictable" and "unpredictable" blocks. Because the digits were irrelevant in this experiment, "predictable" blocks are those in which the sequence 3, 2, 1, 0 occurred in the task-irrelevant digit stream, and "unpredictable" blocks are those in which all task-irrelevant digits appeared in random order. The two block types did not differ in task demands. Error bars represent ± 1 *SE* of the mean. See the online article for the color version of this figure.

as factors found no main effect of block type, *F*(1, 19) = 0.46, *p* = .51, η_p^2 = .02, no effect of digit category, *F*(2, 38) = 2.11, *p* = .14, η_p^2 = .10, and no interaction between the two, *F*(2, 38) = 0.22, *p* = .81, η_p^2 = .01. This suggests that the effects observed in Experiments 1, 2, and 3 were not artifacts of a prelearned, automatic response to any digit or digit category.

Effects of Predictive Digits 3, 2, and 1 on Background Processing

Because the digits 3, 2, and 1 were presented in a fixed order in the predictable blocks in Experiments 1–3, the three digits may serve different roles, with 3 being indicative of the onset of the sequence, and 1 being indicative of the impending target. Did scene memory differ for these three digits? Table 1 shows memory accuracy for scenes encoded in predictable blocks across different digits.

In Experiment 1, scene memory was slightly worse for digits 3 and 1 than for digit 2. The effect size was small, however, and did not reach statistical significance, *F*(2, 38) = 1.53, *p* = .23, η_p^2 = .07. In Experiment 2, as in Experiment 1, memory was numerically better for scenes associated with digit 2, rather than digits 3 or 1. This effect did not reach statistical significance, *F*(2, 38) = 2.82, *p* = .07, η_p^2 = .13, perhaps owning to the small number of participants.

As the sample size increased in Experiment 3, greater statistical power allowed us to replicate the pattern of behavior seen in Experiments 1 and 2. In predictable blocks, when the digits 3, 2, and 1 were compared in an ANOVA, there was a significant main effect of digit, *F*(2, 94) = 3.53, *p* = .03, η_p^2 = .07. Planned comparisons showed that in predictable blocks, memory for scenes coinciding with the digit 2 was significantly better than scenes coinciding with the digit 1, *t*(47) = 2.43, *p* = .02, *d* = 0.35, and marginally better than scenes coinciding with the digit 3, *t*(47) = 1.75, *p* = .09, *d* = 0.25. Memory for scenes coinciding with the digit 1 was not significantly different than memory for scenes coinciding with the digit 3, *t*(47) = 0.98, *p* = .33, *d* = 0.14.

The greatest statistical power was achieved when we combined data across Experiments 1–3 (*N* = 88). This combination is justified because participants in all three experiments were tested using the same predictive sequence, and there are no between-experiment comparisons. First, an ANOVA tested the difference among digits 3, 2, and 1 in predictable blocks, finding a significant effect of digit value, *F*(2, 174) = 7.72, *p* = .001, η_p^2 = .08. Next, we compared each of the three predictive digits with the baseline (digits 7–9) in predictable blocks. There was a significant memory advantage for scenes coinciding with the digit 2 compared with scenes coinciding with the nonpredictive digits 7–9, *t*(87) = 3.36, *p* = .001, *d* = 0.36. There was not a significant difference between the baseline and the digit 1, *t*(87) = 0.03, *p* = .97, *d* = 0.004, or the baseline and the digit 3, *t*(87) = 0.74, *p* = .46, *d* = 0.08.

The advantage for the digit 2 could not attributed to intrinsic differences in how digits were processed. When participants ignored the digit task in Experiment 4, there was no difference in accuracy between the predictive digits 1, 2, and 3 in predictable blocks, *F*(2, 38) = 0.67, *p* = .52, η_p^2 = .03. Furthermore, the apparent advantage for the digit 2 was confined to predictable blocks in Experiments 1–3. In these experiments, an ANOVA with block type (predictable vs. unpredictable) and digit (digit 2 vs. baseline digits 7–9) as factors revealed a main effect of predictability, *F*(1, 87) = 23.73, *p* < .001, η_p^2 = .21, a main effect of digit, *F*(1, 87) = 4.06, *p* = .047, η_p^2 = .05, and an interaction between the two, *F*(1, 87) = 7.81, *p* = .006, η_p^2 = .08. Supporting this interaction, in unpredictable blocks, there was no difference among the digits 3, 2, and 1, *F*(2, 174) = 0.18, *p* = .84, η_p^2 = .002, and there was no difference between any of the digits 3, 2, or 1 and the baseline digits 7–9, lowest *p* = .41.

Thus, in predictable blocks, there was no memory advantage for scenes coinciding with the lead digit 3. This, in conjunction with

Table 1
Memory Accuracy for Scenes Encoded in Predictable Blocks Across Digits

Experiment	7–9	3	2	1	0-distractor	0-target
1 (*N* = 20)	71.9%	78.3%	83.0%	77.3%	N/A	89.7%
2 (*N* = 20)	68.0%	64.8%	73.3%	65.3%	80.0%	88.5%
3 (*N* = 48)	70.1%	68.9%	72.5%	66.9%	80.4%	86.7%
4 (*N* = 20)	75.1%	75.0%	72.7%	75.7%	77.3%	N/A
Mean Exp 1–3 (*N* = 88)	70.0%	70.1%	75.1%	68.9%	80.3%[a]	87.8%

[a] Including only data from Experiments 2 and 3 because there were no 0-distractor trials in Experiment 1.

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the observation of an attentional boost for 0-distractors in predictable blocks only suggests that the memory benefit from endogenous orienting occurs at the moment to which one orients, rather than at the moment of the predictive cue. However, there was a small but significant memory advantage for scenes coinciding with the digit 2. As discussed below, this advantage may reflect the same task management that appears to have driven the advantage for the predictive digits as a category in Experiment 1.

General Discussion

The temporal orienting account of the attentional boost effect holds that the pool of attentional resources available at a given moment can increase or decrease over the course of an extended task and that detection of a behaviorally relevant event within a task spurs a temporary increase in the size of this resource pool (Swallow & Jiang, 2010, 2013; Swallow et al., 2019). When multitasking, this leads to an increase in resources available for both tasks, thus paradoxically increasing performance on a secondary task during the moments that require increased attention to the primary task.

This account, however, does not consider the potentially distinct roles of endogenous temporal orienting to predictable behaviorally relevant events and exogenous temporal orienting to unpredictable events. Because temporal orienting can occur in response to either endogenous or exogenous cues, the two forms of temporal orienting may have the same effect on background processing. However, exogenous and endogenous temporal orienting are supported by distinct mechanisms and have distinct behavioral effects (Coull et al., 2000; Coull & Nobre, 1998), so we may expect predictive, endogenous cues to modulate the attentional boost effect. This modulation could occur in one of two directions. On the one hand, the presence of stimuli that are predictive of an upcoming event may attenuate the transient increase in the attentional pool by reducing the acuteness of the event, meaning that endogenous temporal orienting would not support the attentional boost effect. On the other hand, endogenous orienting to the moment a target is expected to appear may result in an increase in the resource pool at the predicted time-point, even when a nontarget appears at that moment. Which effect did the introduction of predictability have on temporal orienting of attention?

The experiments presented here provide converging support for the latter prediction. Experiment 1 shows preservation of the attentional boost effect in predictable blocks. Experiments 2 and 3 expand on these findings by showing that the attentional boost effect occurs for both targets and nontargets if they occur at the moment at which a target was predicted to appear. This suggests that the attentional boost effect reflects selection of a moment in time, which can result from either endogenous or exogenous temporal orienting (Coull et al., 2000; Coull & Nobre, 1998).

Previous studies have observed the attentional boost effect only for targets that require a response and not for distractors that are highly similar to the target (Swallow & Jiang, 2014). These studies therefore concluded that the temporal orienting that supports the attentional boost effect is triggered by target categorization. Here, in the predictable blocks of our second and third experiments, we observed an attentional boost effect for 0-digit trials, both when the digit appeared in a color that required a response and when it appeared in a nontarget color. This seems to contradict previous studies, but it is crucial that this effect only appeared in predictable blocks. In predictable blocks, participants can endogenously orient attention to the anticipated temporal position of the target before target categorization, whereas in unpredictable blocks, participants can only orient to the temporal position of a target once the target has been categorized.

Our study also has implications for understanding mechanisms of temporal orienting. Using single-task conditions, Coull and Nobre (1998) asked participants to respond to a target whose timing may either be validly predicted by a cue or be invalidly predicted. In Coull and Nobre (1998), the cue was a symbol that indicated whether the target would appear after a short (300 ms) or a long (1500 ms) interval. Response time was facilitated when the target appeared at the validly predicted moment. An invalid cue was particularly detrimental when the target appeared earlier than the cue indicated. Its negative effect was smaller if the target appeared later than the cue indicated. The distinction between the two kinds of invalid trials presumably occurred because when the target did not appear at the predicted (early) moment, participants could voluntarily reorient to the later moment. These findings support two types of temporal orienting. Temporal orienting may be endogenous, as when participants either orient to the validly cued moment or orient to the later time point after the target does not appear at the early time point. Alternatively, temporal orienting may be exogenous, as when participants orient toward a target appearing earlier than the cue indicated.

Using fMRI, Coull et al. (2000) showed dissociable neural mechanisms underlying endogenous and exogenous temporal orienting. Exogenous temporal orienting, occurring in response to a target appearing earlier than cued, was associated with increased activation in the visual cortex. In contrast, endogenous temporal orienting, occurring in anticipation of a target appearing later than cued, was associated with right frontal cortex activation, including activation in the ventrolateral and dorsolateral prefrontal areas and the left superior parietal lobule. This suggests that the two kinds of temporal orienting have distinct neural mechanisms, with exogenous orienting representing a more stimulus-based bottom-up processing and endogenous orienting representing more voluntary top-down processing. Our observation of an attentional boost for 0-distractors in predictable blocks but not in unpredictable blocks supports this distinction between stimulus-driven exogenous orienting and strategic, anticipatory endogenous orienting. Nonetheless, much as exogenous and endogenous spatial orienting play complementary roles, the combined influences of endogenous and exogenous temporal orienting enable people to both actively anticipate an important moment in the future and to react to the unexpected occurrence of important stimuli.

Temporal orienting in the unpredictable blocks of our study is analogous to the exogenous temporal orienting system studied by Coull and Nobre (1998). An important difference between the current paradigm and Coull and Nobre's work is that participants were tested under dual-task conditions in our study, in contrast with the single-task conditions used in Coull and Nobre (1998). Enhanced target processing following temporal orienting does not necessarily imply that the benefit would extend to concurrent tasks. The enhanced scene memory in the current study, as well as in many previous findings of the attentional boost effect (Leclercq & Seitz, 2012; Lin et al., 2010; Mulligan et al., 2014; Schonberg et al., 2014; Swallow & Atir, 2018; Swallow & Jiang, 2010, 2013,

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2014; Swallow et al., 2019; Turker & Swallow, 2019), indicates that temporal orienting to an unexpected target moment enhances global processing that encompasses both the target stimulus and the concurrently presented stimuli.

The key contribution of the present study is the finding that the global enhancement of temporal orienting is not limited to exogenous temporal orienting. It also extends to endogenous temporal orienting. In fact, when temporal orienting is endogenous, the attentional boost to the concurrent stimuli is not confined to situations in which the anticipated stimulus is eventually categorized as the target. When participants actively anticipate a target but a distractor appears, scenes appearing at that moment are also better remembered than scenes appearing at moments in which a target is not expected and does not appear. This finding shows that the benefit of temporal orienting in concurrent task processing is a general phenomenon that is not contingent on target detection. Furthermore, it shows that the effects of endogenous orienting on background processing occur at the moment to which one orients, rather than at the moment at which the predictive cue occurs.

Endogenous temporal orienting could reduce the acuteness of the orienting response, yet the attentional boost for the concurrent scenes was not reduced. To the contrary, in Experiments 2 and 3, scene memory was better when accompanied by target detection in the predictable blocks, relative to target detection in the unpredictable blocks. This finding may be attributed to the greater effectiveness of temporal orienting under endogenous, rather than exogenous, control. This is congruent with the findings of Coull and Nobre (1998). They found that participants responded more quickly to targets appearing at predictable moments or occurring later than predicted (allowing endogenous orienting) than to targets appearing earlier than expected (requiring exogenous orienting). In the present study, we similarly observed an advantage for endogenous, anticipatory orienting to the target.

Predictability may also alter the task demand, allowing participants to more effectively allocate resources to the two tasks at hand, as evidenced by the memory advantage for scenes coinciding with the digit 2 in predictable blocks. When the digit 3 occurs, participants do not have time to allocate attention to the background scenes, but they can more effectively allocate resources while the digit 2 is present. Although the same task management applies to digit 1, memory for scenes coinciding with the digit 1 did not show the same advantage. This difference may result from response anticipation. Previous research has found that words immediately preceding a word that was spoken aloud were poorly remembered (Forrin, Ralph, Dhaliwal, Smilek, & MacLeod, 2019). This anticipatory effect on recognition memory could result in poorer recognition of scenes appearing just before the target digit, which, in predictable blocks, would be the digit 1. The cost associated with the anticipatory effect may have offset the benefit of task management[2].

Our study adds to increasing evidence that temporal expectation alters attentional processing. Seli et al. (2018) found that temporal predictability alters the pattern of mind wandering. They asked participants to press the spacebar every time the hand on a virtual clock reached the 12:00 position, which occurred predictably every 20 s. Participants engaged in more intentional and unintentional mind wandering in moments temporally far from the target bar-press event than in the moments just before that predictable event. Because mind wandering may reflect an adaptive use of leftover resources to engage in planning or problem-solving, this increase in mind wandering in the moments long before the target event is an effective allocation of resources. Based on these findings, Seli et al. (2018) predicted that predictability would improve multitasking performance. The present results support and extend this prediction—not only did predictability in a dual-task scenario improve performance on both tasks on average, as the significant main effect of predictability in each experiment demonstrated, but it enhanced the attentional boost effect, as shown by the significantly better memory for scenes coinciding with 0-targets in predictable blocks compared with unpredictable blocks in Experiments 2 and 3.

The findings of the present study are also consistent with the observation that predictability allows for better cognitive control in dual-task conditions. Whitehead and Egner (2018) showed that in a Stroop-like task, task-set interference in incongruent trials can be overcome if a high proportion of incongruent trials allows participants to adopt a strategic selective cognitive state in anticipation of upcoming incongruent trials. Similarly, pairing two images and making one reliably predictive of subsequent incongruent trials reduces congruency effects for incongruent trials following either member of the image pair (Bejjani, Zhang, & Egner, 2018). In both cases, making incongruent trials predictable allows participants to strategically adopt a transient cognitive state that is highly selective for target information. In the present study, we show that predictability similarly allows participants to allocate attention to an upcoming relevant time point, increasing the resources available for both tasks under dual-task conditions at that important time point.

As a behavioral study, the present set of experiments cannot directly assess how the neural mechanisms underlying the attentional boost effect differ between endogenous cueing in predictable blocks and exogenous cueing in unpredictable blocks. Future studies may use pupillometry, EEG, or fMRI to more directly compare the neural responses between the two block types. In previous studies, target detection in a serial detection task like that in the present study was associated with a larger pupil response than was distractor rejection (Swallow et al., 2019). This provided evidence for increased LC activation at the moment of target categorization. If the attentional boost effect observed in predictable blocks here is also a result of a transient release of norepinephrine in the LC, a similar pupillary response should be observed at the moment of the target's appearance (and at the expected moment of the target's appearance) in both predictable and unpredictable blocks.

Attention researchers have long appreciated the power of the influence of expectation and predictability, and it has been a decade since the first report of the paradoxical but robust attentional boost effect. Nonetheless, researchers have never considered

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[2] Although the anticipation effect may explain the disadvantage for scenes coinciding with digit 1 relative to scenes coinciding with digit 2, it likely does not explain the attentional boost effect. Memory for scenes coinciding with the target digit 0 was not only better than memory for scenes coinciding with digit 1, it was also better than memory for scenes coinciding with non-predictive digits 7–9. The non-predictive digits and their background scenes were always at least four digits away from the digit 0 in predictable blocks, and an anticipation effect is not likely to inhibit memory for such distant scenes.

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the interaction between the two. Because the attentional boost effect is thought to result from a transient increase in attentional capacity at the moment of an acute behaviorally relevant event, predictability may have been expected to attenuate the attentional boost effect by reducing the acuteness of target events. Instead, predictability enhanced and extended the attentional boost effect. Not only does this finding have important theoretical implications for our understanding of the shared and distinct behavioral effects of endogenous and exogenous temporal orienting and dual-task interaction, but it also has important practical implications. The attentional boost effect reflects better performance on both tasks under dual-task conditions during the most relevant moment of one task. In extending this effect, predictability makes multitasking more efficient. When driving, the appearance of a yellow light not only warns the driver of the upcoming red light, it also allows the driver to better process their entire visual environment as they bring their car to a stop at the intersection. Further research testing the limits of the extension of the attentional boost via predictive cues could provide insights into methods for improving dual-task performance in many domains.

References

Agres, K., Abdallah, S., & Pearce, M. (2018). Information-theoretic properties of auditory sequences dynamically influence expectation and memory. *Cognitive Science, 42,* 43–76. http://dx.doi.org/10.1111/cogs.12477

Aston-Jones, G., & Cohen, J. D. (2005). An integrative theory of locus coeruleus-norepinephrine function: Adaptive gain and optimal performance. *Annual Review of Neuroscience, 28,* 403–450. http://dx.doi.org/10.1146/annurev.neuro.28.061604.135709

Aston-Jones, G., Rajkowski, J., Kubiak, P., & Alexinsky, T. (1994). Locus coeruleus neurons in monkey are selectively activated by attended cues in a vigilance task. *The Journal of Neuroscience, 14,* 4467–4480. http://dx.doi.org/10.1523/JNEUROSCI.14-07-04467.1994

Barry, R. J., Steiner, G. Z., & De Blasio, F. M. (2016). Reinstating the Novelty P3. *Scientific Reports, 6,* 31200. http://dx.doi.org/10.1038/srep31200

Bejjani, C., Zhang, Z., & Egner, T. (2018). Control by association: Transfer of implicitly primed attentional states across linked stimuli. *Psychonomic Bulletin & Review, 25,* 617–626. http://dx.doi.org/10.3758/s13423-018-1445-6

Brainard, D. H. (1997). The psychophysics toolbox. *Spatial Vision, 10,* 433–436. http://dx.doi.org/10.1163/156856897X00357

Coull, J. T., Frith, C. D., Büchel, C., & Nobre, A. C. (2000). Orienting attention in time: Behavioural and neuroanatomical distinction between exogenous and endogenous shifts. *Neuropsychologia, 38,* 808–819. http://dx.doi.org/10.1016/S0028-3932(99)00132-3

Coull, J. T., & Nobre, A. C. (1998). Where and when to pay attention: The neural systems for directing attention to spatial locations and to time intervals as revealed by both PET and fMRI. *The Journal of Neuroscience, 18,* 7426–7435. http://dx.doi.org/10.1523/JNEUROSCI.18-18-07426.1998

Dehaene, S. (2011). *The number dense: How the mind creates mathematics, revised and updated edition*. New York, NY: Oxford University Press.

Duncan, J. (1980). The locus of interference in the perception of simultaneous stimuli. *Psychological Review, 87,* 272–300. http://dx.doi.org/10.1037/0033-295X.87.3.272

Fernández, R. S., Boccia, M. M., & Pedreira, M. E. (2016). The fate of memory: Reconsolidation and the case of prediction error. *Neuroscience and Biobehavioral Reviews, 68,* 423–441. http://dx.doi.org/10.1016/j.neubiorev.2016.06.004

Forrin, N. D., Ralph, B. C. W., Dhaliwal, N. K., Smilek, D., & MacLeod, C. M. (2019). Wait for it . . . performance anticipation reduces recognition memory. *Journal of Memory and Language, 109,* 104050. http://dx.doi.org/10.1016/j.jml.2019.104050

Glautier, S., & Shih, S.-L. (2015). Relative prediction error and protection from attentional blink in human associative learning. *Quarterly Journal of Experimental Psychology, 68,* 442–458. http://dx.doi.org/10.1080/17470218.2014.943250

Hudson, M., Bach, P., & Nicholson, T. (2018). You said you would! The predictability of other's behavior from their intentions determines predictive biases in action perception. *Journal of Experimental Psychology: Human Perception and Performance, 44,* 320–335. http://dx.doi.org/10.1037/xhp0000451

Kinchla, R. A. (1992). Attention. *Annual Review of Psychology, 43,* 711–742. http://dx.doi.org/10.1146/annurev.ps.43.020192.003431

Lavie, N. (2011). Nilli Lavie. *Current Biology, 21,* R645–R647. http://dx.doi.org/10.1016/j.cub.2011.05.051

Leclercq, V., & Seitz, A. R. (2012). The impact of orienting attention in fast task-irrelevant perceptual learning. *Attention, Perception, & Psychophysics, 74,* 648–660. http://dx.doi.org/10.3758/s13414-012-0270-7

Lin, J. Y., Pype, A. D., Murray, S. O., & Boynton, G. M. (2010). Enhanced memory for scenes presented at behaviorally relevant points in time. *PLoS Biology, 8,* e1000337. http://dx.doi.org/10.1371/journal.pbio.1000337

Mulligan, N. W., & Spataro, P. (2015). Divided attention can enhance early-phase memory encoding: The attentional boost effect and study trial duration. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 41,* 1223–1228. http://dx.doi.org/10.1037/xlm0000055

Mulligan, N. W., Spataro, P., & Picklesimer, M. (2014). The attentional boost effect with verbal materials. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 40,* 1049–1063. http://dx.doi.org/10.1037/a0036163

O'Callaghan, C., Kveraga, K., Shine, J. M., Adams, R. B., Jr., & Bar, M. (2017). Predictions penetrate perception: Converging insights from brain, behaviour and disorder. *Consciousness and Cognition, 47,* 63–74. http://dx.doi.org/10.1016/j.concog.2016.05.003

Pascucci, D., & Turatto, M. (2013). Immediate effect of internal reward on visual adaptation. *Psychological Science, 24,* 1317–1322. http://dx.doi.org/10.1177/0956797612469211

Pelli, D. G. (1997). The VideoToolbox software for visual psychophysics: Transforming numbers into movies. *Spatial Vision, 10,* 437–442. http://dx.doi.org/10.1163/156856897X00366

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology, 32,* 3–25. http://dx.doi.org/10.1080/00335558008248231

Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1992). Temporary suppression of visual processing in an RSVP task: An attentional blink? *Journal of Experimental Psychology: Human Perception and Performance, 18,* 849–860. http://dx.doi.org/10.1037/0096-1523.18.3.849

Rossi-Arnaud, C., Spataro, P., Costanzi, M., Saraulli, D., & Cestari, V. (2018). Divided attention enhances the recognition of emotional stimuli: Evidence from the attentional boost effect. *Memory, 26,* 42–52. http://dx.doi.org/10.1080/09658211.2017.1319489

Sali, A. W., Anderson, B. A., & Yantis, S. (2014). The role of reward prediction in the control of attention. *Journal of Experimental Psychology: Human Perception and Performance, 40,* 1654–1664. http://dx.doi.org/10.1037/a0037267

Schonberg, T., Bakkour, A., Hover, A. M., Mumford, J. A., Nagar, L., Perez, J., & Poldrack, R. A. (2014). Changing value through cued approach: An automatic mechanism of behavior change. *Nature Neuroscience, 17,* 625–630. http://dx.doi.org/10.1038/nn.3673

Seitz, A. R., & Watanabe, T. (2003). Is subliminal learning really passive? *Nature, 422,* 36. http://dx.doi.org/10.1038/422036a

Seli, P., Carriere, J. S. A., Wammes, J. D., Risko, E. F., Schacter, D. L., & Smilek, D. (2018). On the clock: Evidence for the rapid and strategic modulation of mind wandering. *Psychological Science, 29,* 1247–1256. http://dx.doi.org/10.1177/0956797618761039

Spataro, P., Mulligan, N. W., & Rossi-Arnaud, C. (2013). Divided attention can enhance memory encoding: The attentional boost effect in implicit memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 39,* 1223–1231. http://dx.doi.org/10.1037/a0030907

Spataro, P., Mulligan, N. W., & Rossi-Arnaud, C. (2015). Limits to the attentional boost effect: The moderating influence of orthographic distinctiveness. *Psychonomic Bulletin & Review, 22,* 987–992. http://dx.doi.org/10.3758/s13423-014-0767-2

Summerfield, C., & Egner, T. (2009). Expectation (and attention) in visual cognition. *Trends in Cognitive Sciences, 13,* 403–409. http://dx.doi.org/10.1016/j.tics.2009.06.003

Swallow, K. M., & Atir, S. (2018). The role of value in the attentional boost effect. *Quarterly Journal of Experimental Psychology, 72,* 523–542. http://dx.doi.org/10.1177/1747021818760791

Swallow, K. M., & Jiang, Y. V. (2010). The attentional boost effect: Transient increases in attention to one task enhance performance in a second task. *Cognition, 115,* 118–132. http://dx.doi.org/10.1016/j.cognition.2009.12.003

Swallow, K. M., & Jiang, Y. V. (2012). Goal-relevant events need not be rare to boost memory for concurrent images. *Attention, Perception, & Psychophysics, 74,* 70–82. http://dx.doi.org/10.3758/s13414-011-0227-2

Swallow, K. M., & Jiang, Y. V. (2013). Attentional load and attentional boost: A review of data and theory. *Frontiers in Psychology, 4,* 274. http://dx.doi.org/10.3389/fpsyg.2013.00274

Swallow, K. M., & Jiang, Y. V. (2014). The attentional boost effect really is a boost: Evidence from a new baseline. *Attention, Perception, & Psychophysics, 76,* 1298–1307. http://dx.doi.org/10.3758/s13414-014-0677-4

Swallow, K. M., Jiang, Y. V., & Riley, E. B. (2019). Target detection increases pupil diameter and enhances memory for background scenes during multi-tasking. *Scientific Reports, 9,* 5255. http://dx.doi.org/10.1038/s41598-019-41658-4

Swallow, K. M., Makovski, T., & Jiang, Y. V. (2012). Selection of events in time enhances activity throughout early visual cortex. *Journal of Neurophysiology, 108,* 3239–3252. http://dx.doi.org/10.1152/jn.00472.2012

Swallow, K. M., Zacks, J. M., & Abrams, R. A. (2009). Event boundaries in perception affect memory encoding and updating. *Journal of Experimental Psychology: General, 138,* 236–257. http://dx.doi.org/10.1037/a0015631

Turker, H. B., & Swallow, K. M. (2019). Attending to behaviorally relevant moments enhances incidental relational memory. *Memory & Cognition, 47,* 1–16. http://dx.doi.org/10.3758/s13421-018-0846-0

Whitehead, P. S., & Egner, T. (2018). Cognitive control over prospective task-set interference. *Journal of Experimental Psychology: Human Perception and Performance, 44,* 741–755. http://dx.doi.org/10.1037/xhp0000493

Yebra, M., Galarza-Vallejo, A., Soto-Leon, V., Gonzalez-Rosa, J. J., de Berker, A. O., Bestmann, S., . . . Strange, B. A. (2019). Action boosts episodic memory encoding in humans via engagement of a noradrenergic system. *Nature Communications, 10,* 3534. http://dx.doi.org/10.1038/s41467-019-11358-8

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