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Santa Barbara

Characterizing the Neural and Behavioral Consequences of
Attentional Priority over Space and Time

A dissertation submitted in partial satisfaction of the
requirements for the degree Doctor of Philosophy
in Psychological and Brain Sciences

by

Carlene Ann Chak

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June 2026

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Publications

- Chak, C.**, Machniak, E., Giesbrecht, B. (2025). Task-irrelevant abrupt onsets differentially impact value-related orienting and maintenance. *Attention, Perception, & Psychophysics*, 87(7), 2048-2058.
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ABSTRACT

Characterizing the Neural and Behavioral Consequences of Attentional Priority over Space and Time

by

Carlene Ann Chak

At any given moment, we are presented with far more information in the environment than we can consciously perceive. To combat this limitation, the attentional system prioritizes specific stimuli at the expense of others; however, failures in prioritization can lead to increased distraction and missed goal-related opportunities. Existing research on this topic is dominated by spatial attention tasks, even though attention is also constrained in the temporal domain. My dissertation research is focused on better understanding the spatiotemporal dynamics of attentional priority by exploring how the prioritization process unfolds across features commonly favored in the selection process and as a function of task relevance. In Chapters 2 and 3, I use both behavioral and neural measures to reveal the rapid allocation and delayed disengagement of attention toward stimuli associated with previous experience, facilitating performance when task-relevant and delaying the consolidation of subsequent information when task-irrelevant. Physically salient stimuli result in a similar consolidation delay, but only when temporal attention is constrained. Crucially, neither salient nor experience-associated stimuli delay processing when temporal attention is unconstrained.

In Chapter 4, I report how motivational salience is powerful enough to insulate information from abrupt onsets (i.e. transient flashes). Abrupt onsets were most disruptive during divided attention and when presented late in the cue-target interval (appearing after value-related cues but just prior to the target display). This interference can be attributed to our failure to rapidly disengage attention from the most potent distractors, abrupt onsets. In addition, abrupt onsets only impacted performance for individuals with low working memory capacity when presented during the retention interval. Although abrupt onsets are particularly distracting, when these distractors appeared in the location of a previously presented target, low-capacity individuals were able to treat the abrupt onset distractor as a cue, ultimately refreshing their memory of target information. Across these studies, the spatiotemporal profile of attentional priority suggests that 1) the influence of history-driven information is exceptionally strong and long-lasting, and 2) abrupt onsets presented prior to and after the encoding of value-related information differentially impact the processes of attentional orienting and maintenance.

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I. Introduction

The attentional system promptly assigns priority to incoming information; a trait typically viewed as adaptive, resulting in behavioral benefits when successful and costs when unsuccessful. Information related to a current goal guides attention voluntarily, providing a perceptual filter that allocates attentional resources toward goal-relevant features in our environment (Gazzaley & Nobre, 2012; Stankevich & Geng, 2015). This is demonstrated by our ability to detect a friend amongst a crowd with relative ease, leveraging their known facial features to guide attention accordingly. Our failure to attend to task-relevant information can result in significant consequences, ranging from missed opportunities, academic underachievement, and even automobile accidents. Though these costs suggest a flawed attentional system, there are biological benefits associated with the involuntary capture of attention (Anderson, 2021). For example, rapidly orienting our attention toward physically salient stimuli allows us to readily identify sources of nourishment as well as impending danger, highlighting the evolutionary importance of the involuntary allocation of stimulus-driven attention. Classic accounts of attentional control suggest that attention is predominantly biased toward goal-driven and stimulus-driven factors, with goal-driven factors associated with the internal goals of the observer and stimulus-driven factors associated with the external physical salience of a stimulus (Jonides, 1981). However, this binary interpretation was challenged by evidence suggesting *previous* goal-driven information can exert an influence on *current* stimulus-driven attention (Awh et al., 2012).

Stimuli that acquire associations through exposure such as those previously selected or associated with a reward, are unique in their ability to involuntarily capture attention

(Anderson et al., 2021; Failing & Theeuwes, 2018). The influence of our prior experience on the rapid deployment of attention is referred to as *selection history*. Research suggests that targets are more readily detected when their features are repeated, indicating a perceptual advantage for items previously selected (Theeuwes & Van der Burg, 2011). Similarly, previously rewarded stimuli are provided this same advantage, even when their reward is no longer relevant or directly interferes with the present goal (Anderson et al., 2011b; Le Pelley et al., 2017). Crucially, these biases operate without conscious awareness (Anderson & Yantis, 2013; Maljkovic & Nakayama, 2000). Together, these findings have contributed to an updated view of attentional control, highlighting the collective contribution of *goal-driven*, *stimulus-driven*, and *history-driven* ‘priority signals’ on the selection process.

While the literature on selective attention has provided a wealth of knowledge regarding the prioritization of attention spatially, there is a lack of empirical investigation into how priority signals uniquely influence the allocation of attention in the temporal domain. Of note, one of the most widely known hypotheses in the field is the *priority map hypothesis*, a representation of the cortical contributions to prioritized information across visual space (Serences & Yantis, 2007). Whereas spatial attention has significantly advanced to map the combined influence of priority signals, we have yet to establish a sophisticated framework identifying the unique impact of these priority signals on the temporal limitations of attention. The limits of temporal attention are clearly underexamined, however, they are paramount to comprehensively understand an attentional control system that prioritizes information both spatially and temporally. To resolve this, chapter two incorporates multiple priority signals within a nonspatial paradigm to directly compare their independent effects on temporal attention. Existing paradigms within temporal attention typically present these priority signals

as either targets or distractors, rarely measuring their influence across these contexts. Consequently, interpreting the influence of priority signals as a function of task relevance is often confounded with different experimental designs. For this reason, chapter two employs a nonspatial rapid serial visual presentation (RSVP) task across all three experiments. RSVP tasks are effective in inducing a temporal bottleneck of attention. Specifically, when two targets are presented in rapid succession, we often fail to identify the second target, a phenomenon termed the *attentional blink* (Raymond et al., 1992). Across all three experiments in chapter two, the experimental paradigm is consistent; only manipulating whether the priority signal is associated with a target or distractor. This series of experiments provides a comprehensive understanding of priority control in the temporal domain by elucidating the unique dynamics of each priority signal and their influence across contexts of relevance.

Chapter three extends the previous work by measuring the underlying neural mechanisms associated with the costs of prioritizing distracting information. While task-irrelevant priority typically enhances target processing in RSVP tasks (Le Pelley et al., 2016; Raymond & O'Brien, 2009; Rutherford et al., 2010), the evidence regarding their influence on distraction remains ambiguous. To address this ambiguity, intervening distractors presented between two targets are coupled with either selection history or physical salience. Critically, to determine whether these priority signals accelerate or delay attentional disengagement, the temporal precision afforded by electroencephalography (EEG) will be utilized to quantify delays in consolidating post-distractor information into working memory (Vogel et al., 1998; Vogel & Luck, 2002).

While the preceding chapters focus on *history-driven* and *stimulus-driven* priority signals, Chapter four completes a thorough analysis on the various mechanisms of attentional

control by examining the protective role of *goal-driven* attention on *stimulus-driven* distraction. This final chapter incorporates both temporal and spatial attention, manipulating the spatial allocation of attention while simultaneously presenting task-irrelevant salient stimuli at varying intervals throughout the information processing stream. Previously, stimulus features associated with selection history and reward imbued these traits through prior experience, with their associations made in implicit learning tasks preceding the main experiments. The salient stimuli used in chapter two and three were no more physically salient than the other priority signals; only unique in their absence of a previously learned association. The motivation behind this methodological choice was to ensure any effects provided by selection history or previously rewarded information were not merely the result of their distinct physical characteristics in relation to surrounding stimuli. With this in mind, our last chapter employs arguably the most potent salient distractor in visual attention, an abrupt onset, or transient flash (Yantis & Jonides, 1984). Though these distractors are particularly powerful in capturing attention, there is evidence of their suppression in the presence of *goal-driven* attention (Yantis & Jonides, 1990). Reward is a powerful motivator of goal-driven attention, often enhancing proactive control for information leading to its procurement (Frömer et al., 2021). Taking advantage of this strong motivational bias, this chapter directly probes whether reward-related cues can insulate information from stimulus-driven interference. This specific project provides a significant contribution to our understanding regarding the spatial and temporal dynamics of goal-driven and stimulus-driven attention by further exploring how this relationship unfolds during encoding and retention.

Together, chapters two through four provide a comprehensive framework of attentional priority, offering insights into the independent contributions of history- and stimulus-driven

factors as well as the combined influence of goal-driven and stimulus-driven priority signals. This document extends previous findings by characterizing how attentional priority unfolds across both spatial and temporal domains.

The structure of this document is organized such that each chapter functions as its own independent empirical investigation into attentional priority. Accordingly, there will be an introduction, methods, results, and discussion section present for each specific chapter. References will similarly follow their corresponding chapter. In addition, chapter four has been published in its exact form in the peer-reviewed journal, *Attention, Perception, and Psychophysics* under the title *Task-irrelevant abrupt onsets differentially impact value-related orienting and maintenance*.

II. Behavioral dynamics of attentional priority across time

Introduction

Completing any task effectively depends on our ability to appropriately prioritize information. The prioritization process is responsible for promoting the most relevant stimuli for further processing along the information processing stream. Attention is known to be biased toward physically salient, goal relevant, and previously selected information. In other words, these attributes serve as *priority signals*, indicating their importance to the attentional system and are rooted in the origins of human behavior, providing benefits for the rapid detection of threats and rewards in the environment, and costs for distractions that lead to missed opportunities (Anderson, 2021). The preferential processing of information provided by priority signals is demonstrated by their ability to guide spatial attention in their favor (Bisley, 2011). While there is a wealth of visual search literature dedicated to understanding how attention is prioritized spatially (for review, see Luck et al., 2021), how this prioritization process unfolds in the temporal domain is not as well understood.

Just as attention is limited in the amount of information one can process at a given *location* (Vecera & Rizzo, 2003), it is also limited in the amount of information one can process at a given *moment*. A prime illustration of this temporal bottleneck is the *attentional blink* (AB) phenomenon typically seen in rapid serial visual presentation (RSVP) tasks (Raymond et al., 1992). In these tasks, two targets are presented within a stream of distractors displayed at a rate of approximately 10 items per second. When participants are asked to report both targets, the classic finding is the failure to identify the second target when it is presented within 200 to 500 ms of the first target. Many theories attribute this failure to limited resources being available

for the second target while the first target is actively consolidated into working memory (Chun & Potter, 1995; Jolicoeur, 1998). The attentional blink is a robust finding that has been extensively replicated and provides a strong baseline for measuring the constraints of temporal attention (Martens & Wyble, 2010; Olivers & Meeter, 2008; Zivony & Lamy, 2020). For this reason, it is perfectly suited to determine how the priority signals of physical salience, selection history, and reward modulate this bottleneck of attention.

A wealth of literature has identified the unique effects of reward and selection history on the attentional system, as both consist of goal-driven and stimulus-driven properties. Selection history, the association made between a stimulus and an observer's prior experience with that stimulus, has a strong attentional bias that can even override physical salience. Theeuwes and Van der Burg (2011) cleverly observed the effects of selection history when investigating the impact of an irrelevant singleton on the interference of correctly identifying a target. Subjects could only ignore the irrelevant singleton when the color of the target remained identical to the target color from the previous trial, suggesting that the previously selected feature of target color permitted a strong attentional bias capable of overriding the salience of the irrelevant singleton. Similar benefits are observed in the temporal domain. Repeating a color from one trial to the next in an RSVP task facilitates target identification when the color is associated with a target item and degrades distractor interference when associated with a distractor item (Yashar & Lamy, 2010), suggesting that selection history amplifies target enhancement *and* distractor suppression. However, it has also been shown that when a previous target is presented as a distractor alongside a present target, our sensitivity to the present target stimulus decreases (Kyllingsbæk et al., 2001). Together, these findings point

to an involuntary capture of attention toward previous stimulus information that is difficult to ignore in both temporal and spatial selective attention.

A subset of research has focused on a specific type of selection history affiliated with reward. Anderson and colleagues (2011) observed an increase in visual search times when distractors presented in a visual search display were associated with a high-value reward compared to when they were associated with a low-value reward. Critically, the reward value itself was irrelevant to the visual search task, as the association between the reward and stimulus was made in a prior task. This phenomenon has been coined with the term *value-driven attentional capture* to characterize the attentional bias toward task-irrelevant rewarding stimuli. Previously rewarded information similarly modulates attention as observed in RSVP tasks. Faces previously associated with monetary value are able to “break through” the attentional blink (Raymond & O’Brien, 2009), challenging the traditional view of an impenetrable and rigid central bottleneck of temporal attention (Broadbent & Broadbent, 1987; Jolicoeur, 1998).

While we typically combine the influence of priority signals to decide where and at what moment to selectively attend to information in our environment, it is imperative to elucidate the unique contribution of each of the priority signals of physical salience, selection history, and previously rewarded information, on the temporal constraints of attention. To investigate their independent biases on attention, the current study will incorporate these priority signals within the same paradigm and across task-relevant (associated with a target) as well as task-irrelevant (associated with a distractor) contexts. Across three experiments, these priority signals will be associated with a particular color that will be placed around the first

target (Exp 1), second target (Exp 2), or a distractor (Exp 3) in an RSVP task to measure how they modulate the central bottleneck of attention.

Foundational theories assert that identifying a second target within the attentional blink window is dependent upon our ability to efficiently suppress the distractors trailing the first target (Olivers & Meeter, 2008; Raymond et al., 1992). Importantly, working memory capacity is directly correlated to one's filtering efficiency, suggesting that high-capacity individuals are more proficient in removing irrelevant information from the visual field (Vogel et al., 2005). Working memory is critical for both the storage and filtering of information (Baddeley, 1996), and RSVP tasks investigating the attentional blink require both components. Previous work has shown that working memory capacity correlates with overall target accuracy in the attentional blink (Akyürek & Hommel, 2005), while filtering efficiency correlates with the magnitude of the attentional blink itself (Arnell & Stubitz, 2010). Given the extensive relationship observed between working memory and attentional control, the present study will incorporate working memory capacity as a factor in all analyses.

The following experiments aim to disentangle the independent contributions of the priority signals of physical salience, selection history, and reward, highlighting the extent to which their influence on temporal attention is driven by enhanced target processing, impaired disengagement, or the failure to suppress distracting information. To complement these findings, we will assess how these mechanisms are further explained by working memory capacity.

Experiment 1

While it is presumed that all priority signals will capture attention, the relative influence of each signal and the temporal dynamics of their capture remains an open empirical question. Experiment 1 will test two competing hypotheses while placing the priority manipulation on the first target. If the first target is presented within a color demanding attentional priority, it is possible that the processing of this target may accelerate consolidation, freeing up valuable attentional resources to process the second target at shorter lags, manifesting as a reduced attentional blink. This hypothesis is referred to as the ‘capture and release’ hypothesis (Blakely et al., 2012). In contrast, it is possible that the first target in this scenario might protract the duration of processing, occupying attentional resources for a longer duration, manifesting as an increased attentional blink. This hypothesis is referred to as the ‘capture and hold’ hypothesis (Parks et al., 2014).

Methods

Participants

Thirty-three adult students aged 18 - 22 years old ($M = 19.52 \pm 1.21$; 7 males, 26 females; 32 right-handed, 1 left-handed) from the University of California, Santa Barbara volunteered to participate in the current study. Participants received 1 credit/hour plus an additional 0.5 credits for travel time (2 total credits) for their participation. All procedures were approved by the University of California, Santa Barbara Human Subjects Committee.

Materials

All stimuli were generated using MATLAB with custom scripts and extensions from PsychToolbox (Brainard, 1997) and were presented on an LED monitor with a refresh rate of

60Hz and running on Linux. Subjects were seated approximately 136 cm away from the computer screen and used a standard keyboard to type their response.

Stimuli

Change detection task. The change detection task was generated to directly replicate the change detection task created by Adam and colleagues (2018). The set sizes used in this task include three, six, and eight. Nine unique colors were used for the square stimuli ($RGB = 0, 0, 255; 0, 255, 0; 255, 0, 0; 255, 255, 0; 255, 0, 255; 0, 255, 255; 255, 128, 0; 255, 255, 255; 1, 1, 1$) and the background was gray ($RGB = 127.5, 127.5, 127.5$). All stimuli were presented within a background display size of $7^\circ \times 5.2^\circ$ with at least 1.8° of space between each item. The squares measured $1.2^\circ \times 1.2^\circ$, and the fixation measured $0.12^\circ \times 0.12^\circ$.

Training task. The training task was a modified version of the training task used by Anderson and colleagues (2011). Our modification replaced the ‘low reward’ condition with a ‘no reward’ condition to associate one of the colors with selection history. A white fixation cross ($0.5^\circ \times 0.5^\circ$) was presented in the middle of the screen against a black background. Six shapes ($2.3^\circ \times 2.3^\circ$) were presented as circles and drawn at equal distances along an imaginary circle measuring 5.0° in radius. For each subject, two randomly selected colors from a total of eight colors ($RGB: 0\ 255\ 0; 0\ 255\ 255; 255\ 0\ 255; 255\ 128\ 0; 255\ 255\ 0; 255\ 255\ 255; 255, 0, 0; 0, 0, 255$) were chosen as target colors. On each trial, one of the six circle shapes was outlined in one of the target colors and the remaining five circle shapes were each outlined in a randomly chosen color from the remaining list of non-target colors. A horizontal or vertical oriented white line was drawn inside of the target-colored circle, and a 45° white line randomly tilted to the left or right was drawn inside the remaining circles.

Main experiment. In each RSVP stream, distractors were always digits 2-9 and targets were always letters A-Z excluding letters 'I' and 'O' due to their similarity to digits '1' and '0'. The two target letters were chosen randomly and never the same on any given trial. All distractors were chosen randomly and replaced accordingly to ensure no distractors were repeated within four items of each other. The first target (T1) was randomly presented in position 3-10 of the stream with the second target (T2) appearing either 2, 3, or 8 items after the first target. Each RSVP stream ended with T2+1 items. All items in the stream were black and presented within a circle. Surrounding circles were also black, however, the color of the circle surrounding T1 was dependent upon the priority manipulation. T1 was encompassed within a circle that either matched the rewarding color from the training task (reward), matched the non-rewarding color from the training task (selection history), was a randomly chosen color from the remaining colors in the training task (salience), or was black (no priority). All letters and digits were centered within each circle measuring 1.2 x 1.2. All stimuli were presented against a gray (*RGB: 171, 171, 171*) background.

Procedure

Change detection task. Each trial began with a 1000 ms fixation period followed by the presentation of either three, six, or eight different colored squares (see Figure 1). The colored squares were displayed for 250 ms prior to a 1000 ms delay period. One of the squares reappeared in either the same color (no change trial) or a different color (change trial) than the square previously presented in that location and remained on the screen until a response was made. Subjects were instructed to remain fixated on the center of the screen until it was time to make a response. For their response, subjects pressed the 's' key if the color was the *same* and pressed the 'd' key if the color was *different*. There were 48 trials per set size and three

blocks. Half of all the trials were a ‘change’ trial and the other half a ‘no change’ trial. On ‘change’ trials, the square displayed in the response period was a different color than the square presented in that location during the encoding period. Capacity, as measured by ‘ K ’, was computed as follows: $N \times (H - FA)$, where N represents set size, H refers to the hit rate, and FA refers to the false alarm rate (Cowan, 2011). Each subject was then given an overall working memory capacity score, calculated as the average K across all set sizes ($Median = 2.89$, $Min = 1.44$, $Max = 4.38$).

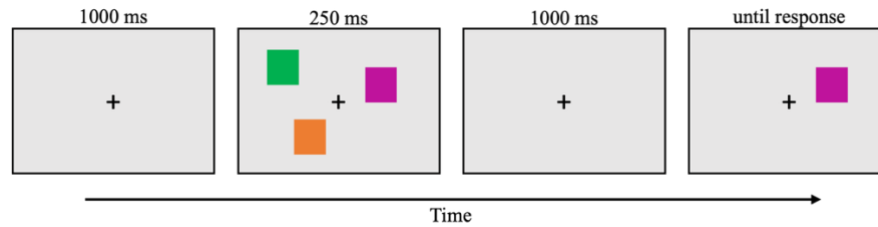


Figure 1. Trial schematic of a ‘same’ trial in the change detection task.

Training task. At the start of the experiment, participants were shown two target colors and instructed to respond to the oriented line presented within the target-colored circle as quickly as and accurately as possible. Participants were to respond with the ‘z’ key if the line inside of the target color was oriented horizontally and the ‘m’ key if the line was oriented vertically. Each trial began with a fixation cross displayed for a randomly jittered interval of 400 – 600 ms prior to the onset of the six colored circles. The circles were presented until a response was made; however, responses were marked as incorrect and the display terminated after 800 ms. Following the main display, there was an interstimulus interval of 1000 ms followed by feedback presented for 1500 ms. One of the target colors resulted in a 10-point reward 80% of the time and only when correct responses were made, while the other target never resulted in

any reward regardless of accuracy. Critically, this was not told to the participants, as they were expected to learn this association throughout the task. Feedback consisted of the total points earned for a particular trial as well as the cumulative total of points earned. The training task consisted of two blocks of 120 trials, perfectly counterbalanced across target color (rewarding and not rewarding) and line orientation (horizontal and vertical) (see Figure 2).

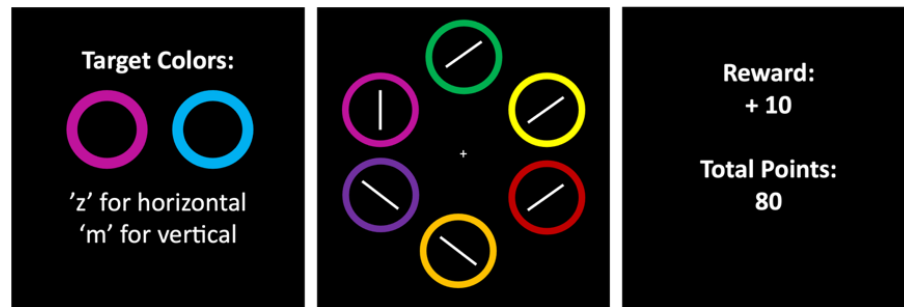


Figure 2. **Left panel:** Initial display shown to participants in the training task. **Middle panel:** An example of the display presented on a given trial. **Right panel:** An example of the feedback display provided at the end of each trial.

Main experiment. A black fixation cross was presented in the center of the screen until a keypress was made. After the subject initiated the trial with a keypress, the black fixation cross remained on the screen for a randomly jittered duration of 1000 – 1050 ms. Each item and its corresponding circle were then presented for 50 ms with a 33 ms interstimulus interval, totaling 83 ms per item in the stream (see Figure 3). After all items were presented, participants were prompted to report the first letter in the stream followed by the second letter of the stream. A blank period was presented for 33 ms following their last response and prior to the start of the next trial. There was a total of 5 blocks with 72 trials each for the main experiment, and 1 block of ten trials for the practice. Feedback regarding accuracy was only provided in the practice block. Each block was counterbalanced across the conditions of lag (2, 3, 8) and priority (none, salience, selection history, reward).

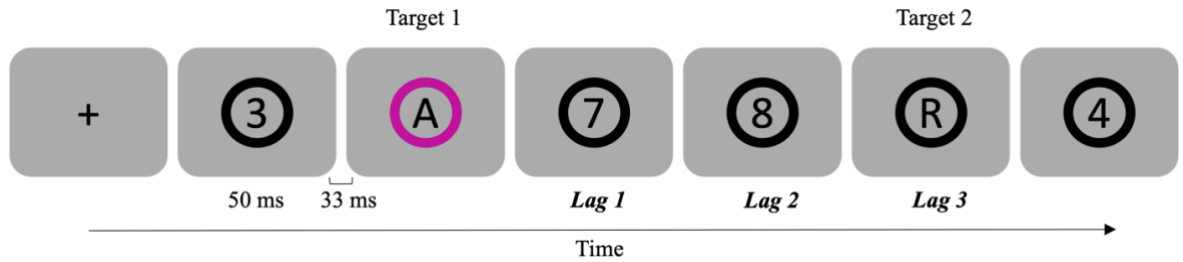


Figure 3. Schematic of a trial in the RSVP task for Experiment 1 with the priority manipulation placed on T1 and the presentation of T2 in lag 3.

Analysis

T2 accuracy. The conventional measure of performance in an attentional blink task is the accuracy of identifying the second target, contingent on the first target being correctly identified ($T2|T1$). However, the current series of experiments will instead be measuring raw T2 accuracy, or T2 accuracy across *all* trials regardless of T1 accuracy. There are several critical reasons for doing so, one being that the manipulation of each task is a direct manipulation of the priority signals on the targets themselves. If one priority condition were to always result in an easier identification of T1, our sample would be biased towards this specific priority signal. In addition, measuring T2 across all trials allows the following question to be investigated: *what is the total capacity of the attentional system to handle interference and use priority signals?* The present study is theoretically motivated to unpack how the prioritization process unfolds across an entire attentional episode, including when a first target is missed. Furthermore, in the context of working memory capacity, it is crucial to include all trials in our analysis for the simple reason that those with higher working memory capacity could be generally more accurate in identifying the first target of an RSVP stream. Because of this, the classic measure of a conditional $T2|T1$ has the potential of misrepresenting our data and skewing results toward those with higher working memory capacity. After all, inaccurate T1

trials are a perfect demonstration of the attentional system at its limit, which could impact the utility of prioritized information.

Modeling. All RSVP data were analyzed using a Generalized Linear Mixed Model (GLMM) with a binomial distribution and logit link function from the *afex* and *lme4* packages in R. The categorical predictors of *lag* and *priority* as well as the continuous and mean-centered predictor of *working memory capacity* were entered as fixed effects, with *subject* entered as the random effect. A full factorial model allowed us to evaluate the main effects of our predictors while simultaneously accounting for any possible two-way and three-way interactions. All post-hoc comparisons were Holm-Bonferroni corrected. Importantly, ‘no priority’ was the reference level for *priority* and ‘lag 3’ was the reference level for *lag*. We chose the priority reference level given it demonstrates the absence of a priority signal and thus serves as an appropriate baseline for the other priority signals. We chose ‘lag 3’ as our reference level for *lag* to emphasize how priority modulates the bottleneck of attention. Due to the rapid duration of our RSVP stream (83 ms per item), ‘lag 2’ is presented just prior to the 200 – 500 ms bottleneck window, justifying ‘lag 3’ as our temporal window of constrained attention.

Results and Discussion

Training Task

Reaction time

A paired-samples t-test indicated no significant difference in reaction time for trials with a rewarding target color ($M = 529.42$, $SE = 10.35$) compared to trials with a non-rewarding target color ($M = 536.87$, $SE = 10.70$), $t(32) = 1.78$, $p = .084$, $d = 0.31$. However, the results

were trending in the expected direction, with faster reaction times associated with the rewarded target color (Figure 4).

Accuracy

A paired-samples t-test indicated that accuracy was significantly greater in trials with a rewarding target color ($M = 0.79$, $SE = 0.02$) compared to trials with a non-rewarding target color ($M = 0.76$, $SE = 0.03$), $t(32) = -3.63$, $p < .001$, $d = -0.63$ (Figure 4).

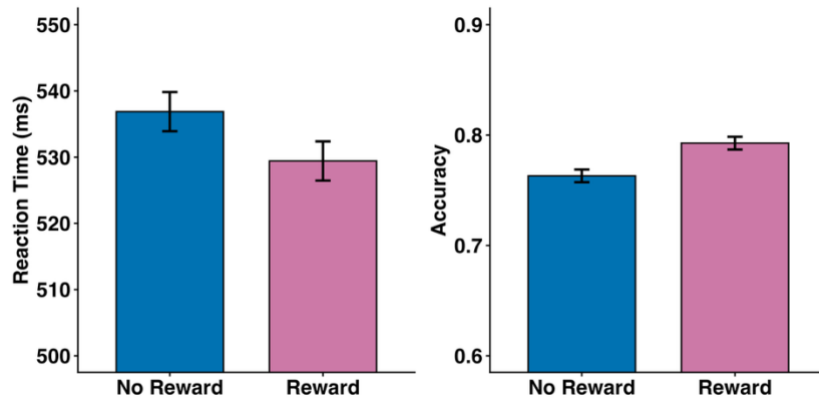


Figure 4. Reaction time and Accuracy as a function of target condition in the training task in Experiment 1. Error bars are Cousineau-Morey (Morey, 2008) corrected standard errors of the mean.

RSVP Task

T1 Accuracy

A generalized linear mixed model (GLMM) was used to assess the effect of Lag, Priority, and Working Memory Capacity on T1 performance. There were significant main effects of Priority ($\chi^2(3) = 32.37$, $p < .001$) and Lag ($\chi^2(2) = 109.40$, $p < .001$) qualified by a significant Priority x Lag interaction, ($\chi^2(6) = 17.97$, $p = .006$). To better understand this interaction, the simple effects of Priority were examined at each level of Lag. At Lag 2, all priority signals resulted in increased T1 accuracy compared to no priority signal (all $ps < .05$), however, none of these differences remained in Lag 3. Interestingly, the priority signals of

reward and selection history substantially improved performance in Lag 8 (all $ps < .01$) (see Figure 5).

These findings suggest that when T1 is most susceptible to interference from T2 at the shortest lag, all priority signals significantly facilitate the maintenance and consolidation of T1 information. However, this advantage disappears by the subsequent lag, reflecting a temporal recovery of T1 processing regardless of priority. At the longest lag, the influence of the priority signals associated with reward and selection history resurfaced, highlighting the lingering bias of these priority signals well after temporal constraints are removed.

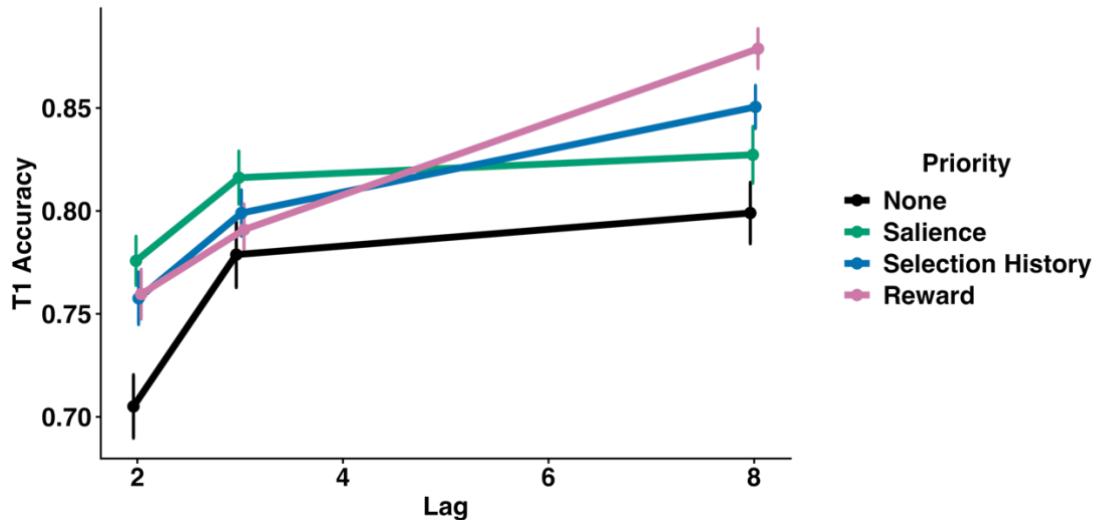


Figure 5. T1 accuracy as a function of priority signal and lag in Experiment 1. Error bars are presented as Cousineau-Morey (Morey, 2008) corrected standard errors of the mean.

T2 Accuracy

The same predictors of Priority, Lag, and Working Memory Capacity were entered into a GLMM to assess their effects on T2 accuracy. Our results yielded a main effect of Lag, ($\chi^2(2) = 850.17, p < .001$). Post-hoc comparisons confirmed that all lags differed significantly

from each other (all $ps < .001$), demonstrating the classic ‘checkmark’ pattern characteristic of the attentional blink (Figure 6).

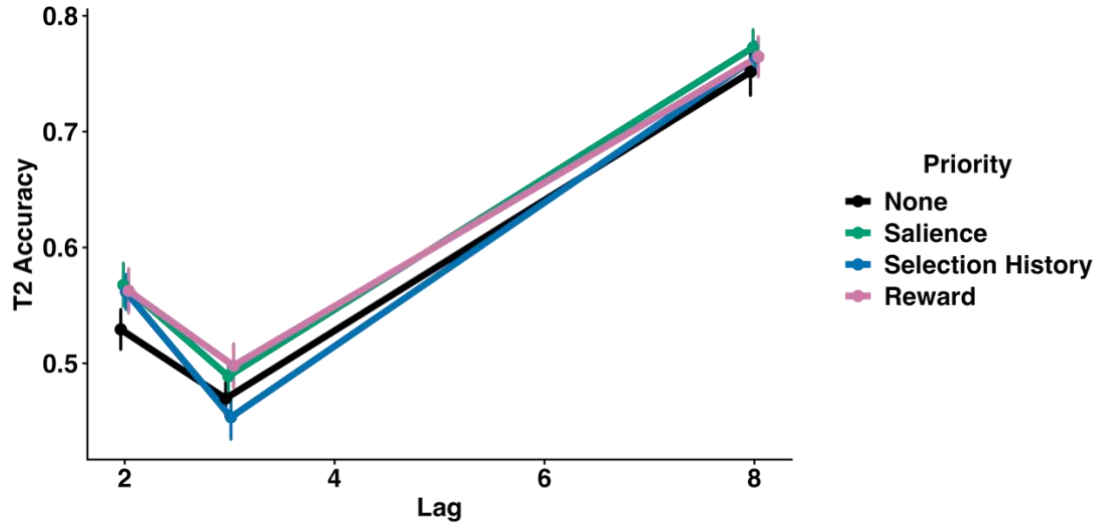


Figure 6. T2 accuracy as a function of priority signal and lag in Experiment 1. Error bars are presented as Cousineau-Morey (Morey, 2008) corrected standard errors of the mean.

Our original hypotheses presumed there would be an effect of T1 priority on T2 performance, either via a capture and hold mechanism resulting in degraded T2 identification or via the accelerated resolution of T1 processing, facilitating a more rapid identification of T2. Unexpectedly, priority signals placed on T1 only influenced T1 performance, implying that priority signals may selectively modulate the gain or representation of the very item they are associated with.

Experiment 2

The current study will shift the manipulation of priority from the first target to the second target of the RSVP stream. We expect to observe enhanced performance for targets associated with prioritized stimuli; however, we have no apriori hypothesis related to the influence of any specific priority signal. Prioritized targets may ‘break through’ the attentional

blink due to their enhanced involuntary capture, resulting in an attenuated attentional blink. Therefore, the present study will investigate the presence of a ‘capture-related enhancement’ (Gibson & Kelsey, 1998) associated with the unique priority signals of selection history, reward, and physical salience.

Methods

Participants

The final sample consisted of thirty-three adult students aged 18 - 23 years old ($M = 19.30 \pm 1.38$; 4 males, 29 females; 32 right-handed, 1 left-handed) from the University of California, Santa Barbara who volunteered to participate in the current study. Participants received 1 credit/hour plus an additional 0.5 credits for travel time (2 total credits) for their participation. All procedures were approved by the University of California, Santa Barbara Human Subjects Committee. Two participants were excluded from the original sample ($N = 35$) given their working memory capacity (K) scores fell more than 2.5 standard deviations below the mean.

Materials

Materials remained identical from Experiment 1, with all stimuli generated using custom scripts in MATLAB and extensions from PsychToolbox. All displays were presented on an LED monitor with a refresh rate of 60Hz and running on Linux. Subjects were seated approximately 136 cm away from the computer screen and used a standard keyboard to type their response.

Stimuli

All stimuli are identical to Experiment 1 except for the main experiment. In the main experiment, the manipulation of priority is moved to the second target. Specifically, the colored circle surrounding T1 in Experiment 1 has moved to T2 in Experiment 2 (see Figure 7).

Procedure

All procedures are identical to Experiment 1 for all tasks, including the main experiment. The instructions remain the same across both main experiments; participants were tasked with monitoring the RSVP stream for two target letters, both of which were to be reported at the end of stream.

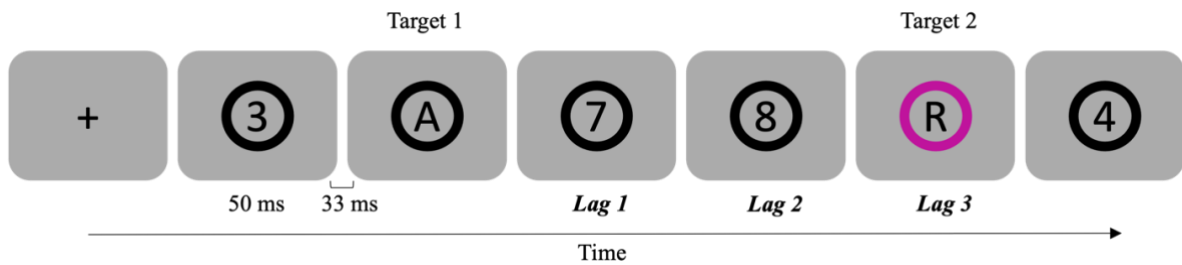


Figure 7. Schematic of a trial in Experiment 2 with the priority manipulation placed on T2 and the presentation of T2 in lag 3.

Results and Discussion

Training Task

Reaction Time

A paired-samples t-test revealed a significant difference in reaction time for trials presented with a rewarding target color ($M = 541.45$, $SE = 10.19$) compared to trials with a non-rewarding target color ($M = 552.17$, $SE = 11.62$), $t(32) = 2.46$, $p = .019$, $d = 0.43$ (Figure 8).

Accuracy

A paired-samples t-test indicated no significant difference in accuracy for trials presented with a rewarding target color ($M = 0.82$, $SE = 0.02$) compared to trials with a non-rewarding target color ($M = 0.81$, $SE = 0.02$), $t(32) = -1.23$, $p = .229$, $d = -0.21$ (Figure 8).

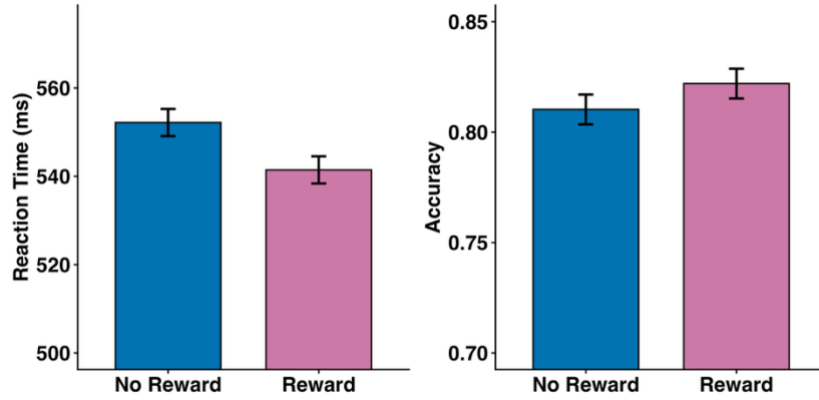


Figure 8. Reaction time and Accuracy as a function of target condition in the training task in Experiment 2. Error bars represent standard errors of the mean.

RSVP Task

T1 Accuracy

A generalized linear mixed model (GLMM) was used to assess the effect of Lag, Priority, and Working Memory Capacity on T1 performance. Our results revealed a single main effect of Lag ($\chi^2(2) = 215.83$, $p < .001$), with T1 performance significantly increasing as a function of Lag (all $ps < .001$). This pattern was also observed in Experiment 1, however, as expected, the influence of Priority on T1 is no longer present (Figure 9).

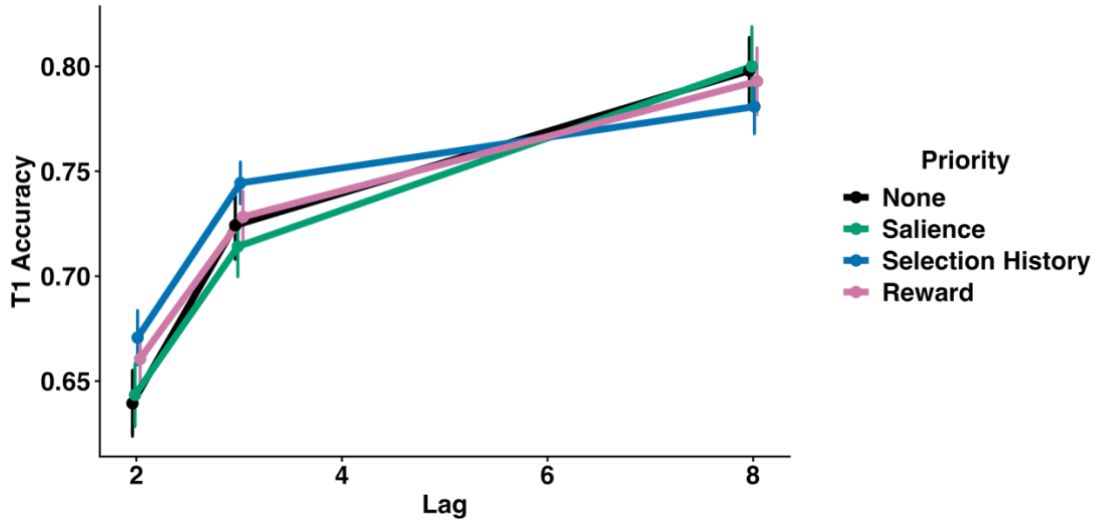


Figure 9. T1 accuracy as a function of priority signal and lag in Experiment 2. *Note.* Error bars are presented as Cousineau-Morey (Morey, 2008) corrected standard errors of the mean.

T2 Accuracy

The same predictors of Priority, Lag, and Working Memory Capacity were entered into a GLMM to assess their effects on T2 accuracy. There were significant main effects of Priority ($\chi^2(3) = 11.81, p = .008$) and Lag ($\chi^2(2) = 662.89, p < .001$) (see Figure 10). T2 performance was significantly enhanced for items associated with selection history compared to items unassociated with priority, ($z = -3.251, p = .007$). Both reward ($z = -2.474, p = .070$) and physical salience ($z = -2.355, p = .074$) exerted a marginal positive influence on performance relative to the no priority baseline. This finding further emphasizes that priority signals selectively modulate the consolidation of the specific item they are associated with. Regarding the main effect of Lag, all lags were significantly different from one another (all $ps < .001$). As expected, performance was most impaired at Lag 3 ($M = .51, SE = .18$) and reached its peak at Lag 8 ($M = .76, SE = .19$), following the classic recovery pattern of the attentional blink.

While the interaction between Priority and Lag remains non-significant, ($\chi^2(6) = 4.27, p < .640$), the numerical differences between our priority conditions and the baseline were most

pronounced when attention was limited. Exploratory pairwise comparisons within Lag 3 and Lag 8 were conducted given our *a priori* hypotheses regarding the attentional bottleneck. These comparisons were used to assess the impact of priority specifically on the bottleneck of attention (Lag 3) compared to when the bottleneck is resolved (Lag 8). Priority reliably modulated performance during the attentional blink window itself, with selection history enhancing performance significantly more than baseline for Lag 3 ($z = -.311, p = .007$) only. Reward revealed a similar trend that was only present in Lag 3 ($z = -2.34, p = .069$) as well, while physical salience did not influence performance compared to baseline in any Lag (all $ps > .10$). These findings, though exploratory, provide the necessary context needed to unveil when priority signals are most helpful, suggesting that history-driven signals are most effective during the attentional bottleneck.

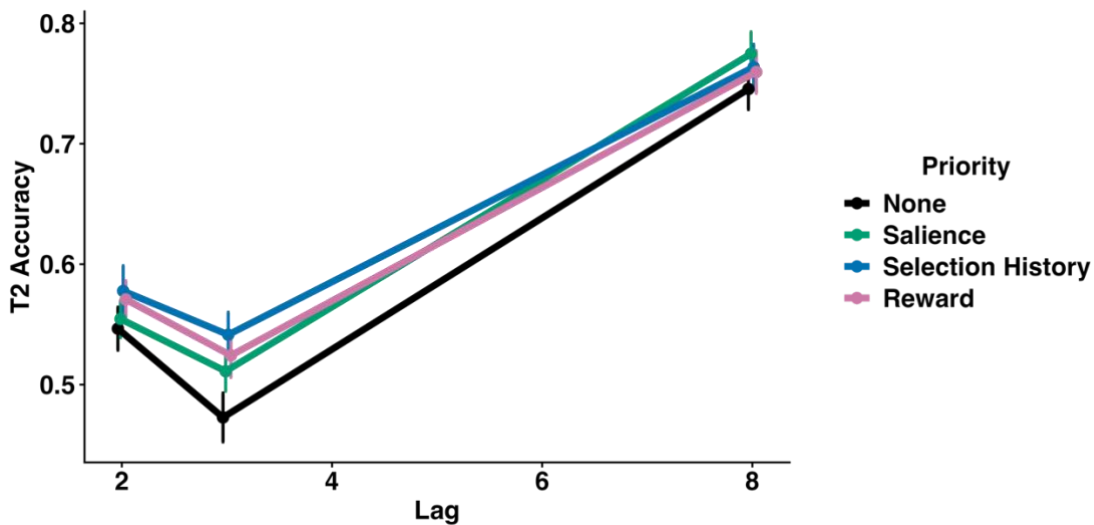


Figure 10. T2 accuracy as a function of priority signal and lag in Experiment 2. Error bars are presented as Cousineau-Morey (Morey, 2008) corrected standard errors of the mean.

Our model also revealed a significant interaction between Priority and Working Memory Capacity, ($\chi^2(3) = 11.24, p = .010$). A simple slopes analysis confirmed that the benefit afforded by physical salience increased as working memory capacity increased ($z = -3.235, SE$

= 0.11, $p = .007$) (Figure 11). Though it may seem counterintuitive for those with high working memory capacity to experience the benefit from bottom-up priority signals as opposed to those with lower working memory capacity, it is important to note that our priority signals do not perfectly align with the classic top-down and bottom-up dichotomy of attention (Awh et al., 2012). Notably, our reward and selection history priority signals only differ from our priority signal of salience due to their prior relevance in the training task. In other words, both selection history and reward are equally as physically salient as our salient signal, with their distinction solely due to the added association they contain. With this frame of reference, it seems plausible that history-driven signals can act as a ‘prime’ for all capacity types, while the mere physical distinction of a stimulus is only helpful for those with leftover capacity.

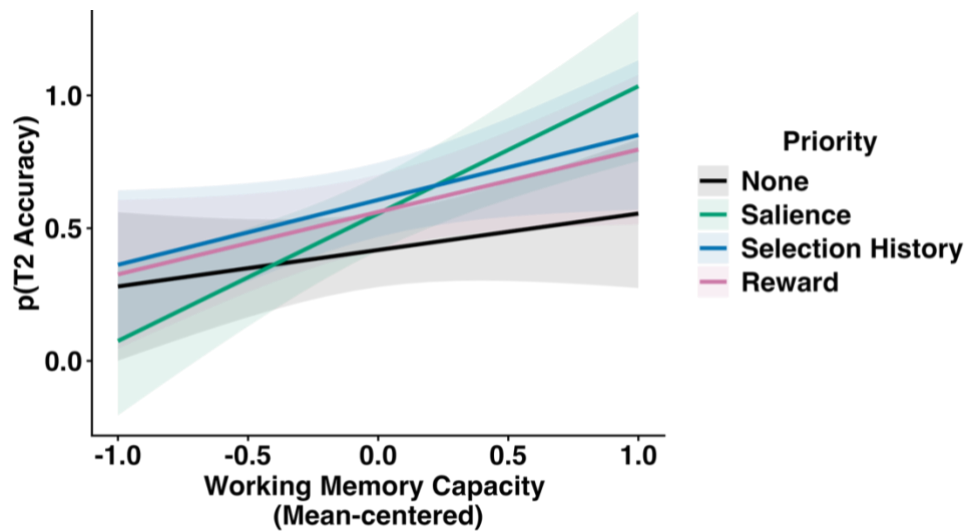


Figure 11. Predicted T2 accuracy as a function of priority signal working memory capacity in Experiment 2. Shaded ribbons represent standard errors of the mean.

Experiment 3

While Experiments 1 and 2 investigate how priority signals shift our attention to target information, Experiment 3 examines how priority signals influence the suppression and

filtering of distracting information. To investigate this, the priority manipulation is placed on an intervening distractor presented between the two targets. If a target is more likely to be identified following a prioritized distractor, this would suggest a failure in suppressing these distractors due to capture-related enhancement (Gibson & Kelsey, 1998). Furthermore, if a target appears within 200 to 500 ms of the prioritized distractor, improved target accuracy would provide evidence for a ‘capture and release’ (Blakely et al., 2012) account while degraded accuracy would support the ‘capture and hold’ (Parks et al., 2014) account of priority.

Methods

Participants

The final sample consisted of thirty-seven adult students aged 18 - 27 years old ($M = 19.38 \pm 1.71$; 9 males, 27 females, 1 non-binary; 34 right-handed, 3 left-handed) from the University of California, Santa Barbara who volunteered to participate in the current study. Participants received 1 credit/hour plus an additional 0.5 credits for travel time (2 total credits) for their participation. All procedures were approved by the University of California, Santa Barbara Human Subjects Committee. One participant was excluded from the original sample ($N = 38$) given their working memory capacity (K) score fell more than 2.5 standard deviations below the mean.

Materials

Materials remained identical to Experiments 1 and 2, with all stimuli generated using custom scripts in MATLAB and extensions from PsychToolbox. All displays were presented on an LED monitor with a refresh rate of 60Hz and running on Linux. Subjects were seated

approximately 136 cm away from the computer screen and used a standard keyboard to type their response.

Stimuli

All stimuli remained identical to Experiments 1 and 2 except for the main experiment. In the main experiment there are two key differences. The first difference is the manipulation of priority is moved to one of the distractors, referred to as the *critical distractor*. The critical distractor always appeared in Lag 2. Specifically, the colored circle surrounding T2 in Experiment 2 has moved to the critical distractor in Experiment 3 (see Figure 12). Due to the critical distractor appearing in Lag 2, our levels within the condition of Lag have changed. Therefore, the second key difference in Experiment 3 is that T2 now appears at either Lag 3, Lag 4, or Lag 8. This means that when T2 appears in Lag 3, it not only appears within attentional blink window of T1, but it also appears immediately following the critical distractor. As alluded to in the introduction, should there be any capture-related enhancement of the distractor, we should observe increased performance for target items following this distractor.

Procedure

All procedures are identical to those in Experiments 1 and 2 for all tasks, including the main experiment. The instructions remain the same across all main experiments; participants were tasked with monitoring the RSVP stream for two target letters, both of which were to be reported at the end of stream.

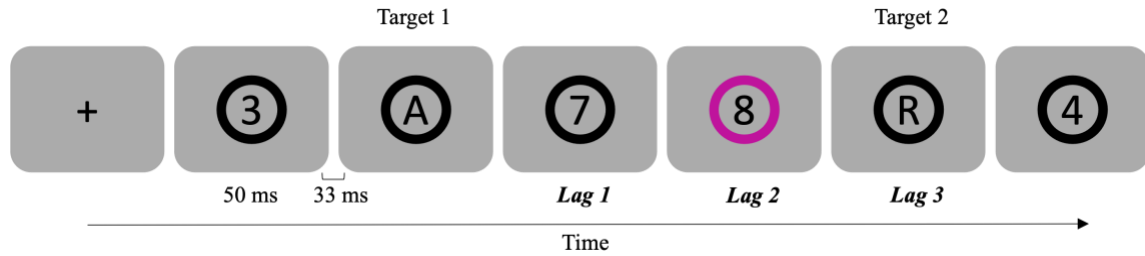


Figure 12. Schematic of a trial in Experiment 3 with the priority manipulation placed on a critical distractor in lag 2 and the presentation of T2 in lag 3.

Results and Discussion

Training Task

Reaction Time

A paired-samples t-test confirmed a significant effect of target condition on reaction time, $t(36) = 2.87, p = .007, d = 0.47$. Participants were faster in responding to targets associated with a reward ($M = 559.41, SE = 8.69$) compared to those that were unassociated with a reward ($M = 572.22, SE = 8.88$) (Figure 13).

Accuracy

We conducted another paired-samples t-test to assess the influence of target condition on accuracy; however, participants were no more accurate in the rewarding target condition compared to the unrewarding target condition, $t(36) = -0.78, p = .439, d = -0.13$ (Figure 13).

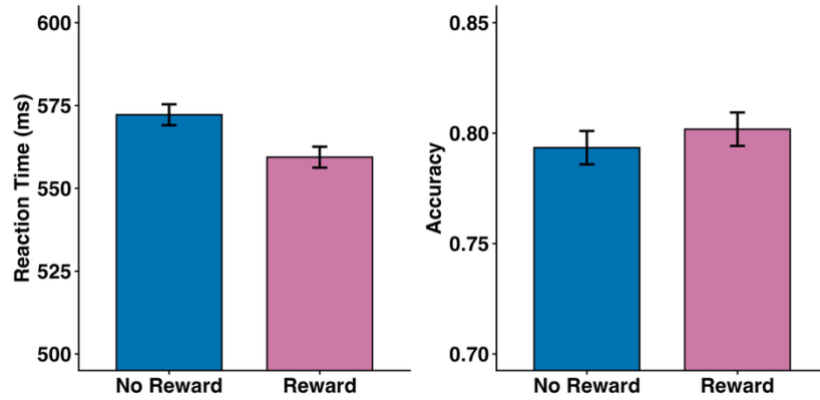


Figure 13. Reaction time and Accuracy as a function of target condition in the training task in Experiment 3. Error bars are presented as Cousineau-Morey (Morey, 2008) corrected standard errors of the mean.

RSVP Task

T1 Accuracy

A generalized linear mixed model (GLMM) was used to assess the effect of Lag, Priority, and Working Memory Capacity on T1 performance. Our results revealed a single main effect of Lag ($\chi^2(2) = 128.53, p < .001$), with T1 performance significantly increasing as a function of Lag (all $ps < .001$) (Figure 14). The effect of Lag has been consistent across all experiments, highlighting the increase in target consolidation as more time passes through the bottleneck. Of note, the effect of Priority on T1 performance is only observed when T1 itself contains a priority signal (Experiment 1).

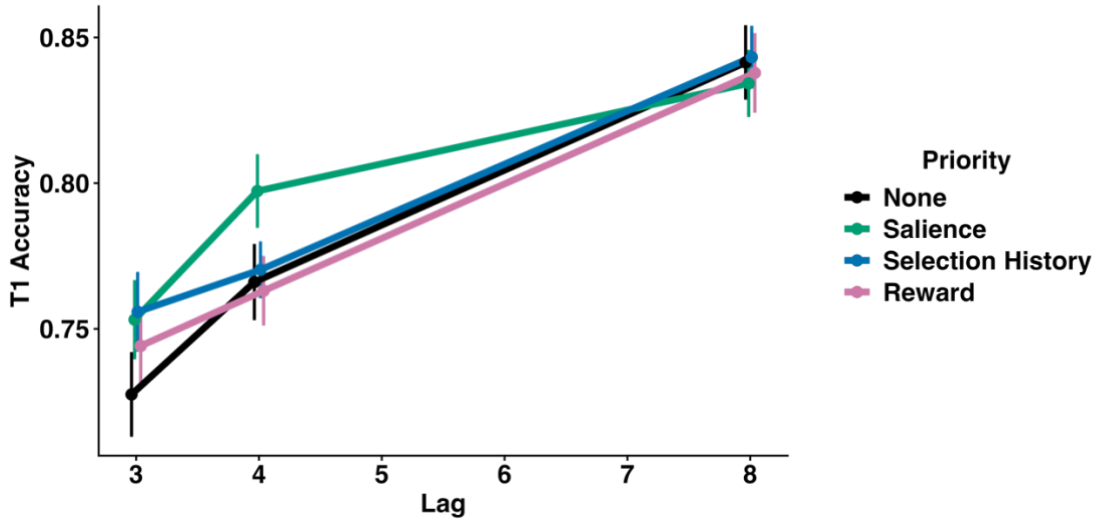


Figure 14. T1 accuracy as a function of priority signal and lag in Experiment 3. Error bars are presented as Cousineau-Morey (Morey, 2008) corrected standard errors of the mean.

T2 Accuracy

A GLMM was conducted with the same predictors of Lag, Priority, and Working Memory Capacity to assess their impacts on T2 performance. Our results yielded main effects of Lag ($\chi^2(2) = 992.39, p < .001$) and Working Memory Capacity ($\chi^2(1) = 5.27, p = .022$), qualified by their interaction ($\chi^2(2) = 24.27, p < .001$). A simple slopes analysis demonstrated that working memory capacity was a strong predictor of T2 performance during the attentional blink window, such as in Lag 3 ($z = 3.19, p = .001$) and Lag 4 ($z = 2.70, p = .007$). However, this relationship was no longer significant by Lag 8 ($z = 1.06, p = .288$). These findings suggest that when distractors must be suppressed during the bottleneck of attention, working memory capacity dictates how successful one is in identifying subsequent target information (Figure 15).

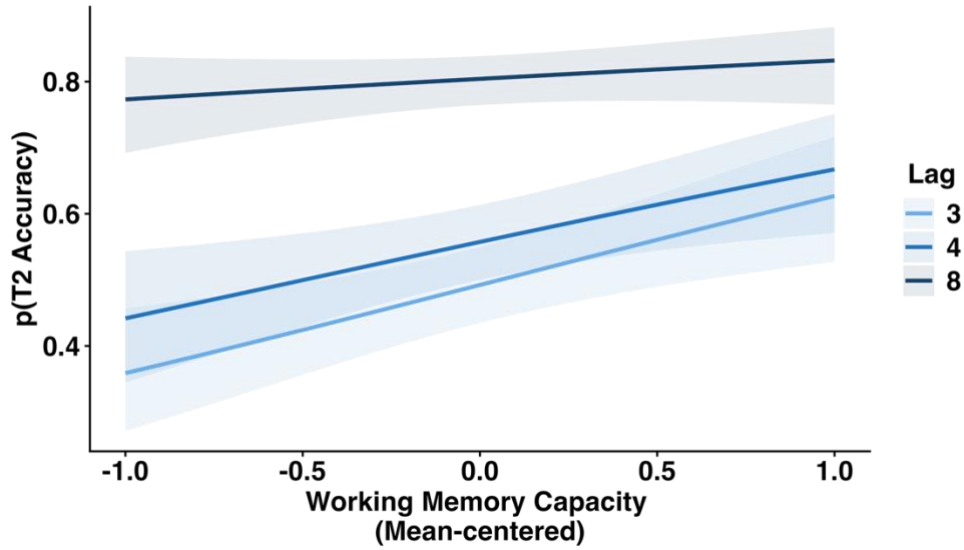


Figure 15. Predicted T2 accuracy as a function of Lag and Working Memory Capacity in Experiment 3. Shaded ribbons represent 95% confidence intervals.

General Discussion

Prioritizing information is critical for the survival of all organisms. Failing to appropriately allocate attention to rapidly presented information can lead to car accidents, disruptions in air traffic operations, and decreased awareness in general. To further understand the underlying mechanisms of temporal attention, we investigated how different priority signals, such as physical salience, selection history, and reward influence information processing when presented at varying temporal intervals and across shifting contexts of task relevance. In the first two experiments, we employed an RSVP task with distractors presented as digits and targets presented as letters either two, three, or eight items away from each other. We manipulated priority by surrounding target stimuli with colors associated with our unique priority signals. The priority signals of selection history and reward were generated from their corresponding colors presented in a previous task, while the priority signal of salience was a randomly selected color on each trial. It should be noted that across all experiments,

participants successfully made the association between the priority signals of selection history and reward and their corresponding colors from the learning task. For the main experimental task, the priority manipulation was placed on the first target (T1) in Experiment 1, the second target (T2) in Experiment 2, and on a distractor in Experiment 3. Importantly, the distractor associated with priority was always the distractor presented in Lag two, resulting in the presentation of T2 in Experiment 3 at lags three, four, and eight. We hypothesized that each priority signal would capture attention, however, it was unclear whether this would result in enhanced processing and rapid consolidation or a delayed disengagement of attention.

The purpose of Experiment 1 was to investigate how prioritized information influences the processing of subsequent information when attention is limited temporally. We found that when T2 is presented less than 200 ms after T1, priority in general boosts the consolidation of T1 information. Though most attentional blink studies focus on the effect of T1 consolidation on T2 accuracy, it is important to highlight that T1 itself is subject to significant interference from the presence of T2 as well. The presentation of T2 in lag two is arguably when interference is highest for T1, with our results suggesting that any priority signal improves target consolidation above baseline during this period. This finding was not present in lag three, indicating that once enough time has passed following the presentation of T1, it is more protected from interference generally, and thus no longer benefits from associated priority. Surprisingly, selection history and reward associated priority signals significantly enhanced T1 consolidation at the longest lag. These two priority signals are the only priority signals associated with the previous learning task, and thus together represent ‘history-driven’ priority. Knowing that responses to T1 were made following the presentation of all items in the stream, it appears that history-driven priority may exert a more protracted influence on T1, preventing

the decay of this information over longer durations. The influence of previously selected information, rewarding or not, appears to carry a lingering bias of attention. There is converging evidence for this in spatial attention tasks, with previously encountered information often strengthening target identification (Failing & Theeuwes, 2018) however, this is the first demonstration of this bias as it relates to the attentional blink and RSVP tasks. Though prior investigation of previously rewarded information has resulted in enhanced sensitivity for both T1 and T2 items (Raymond & O'Brien, 2009), it has not been shown to interact with lag. Our results maintain that history-driven information has a prolonged influence on target processing in the temporal domain.

Interestingly, we found no influence of T1 priority on subsequent T2 performance. This unexpected finding underscores the important assertion that priority signals only impact the item they are directly associated with. The lack of evidence for a 'capture and hold' or 'capture and release' account of attention clearly suggests that priority does not modulate the time course associated with processing upcoming stimulus information. This implies that priority signals instead may 'tag' information as it is presented, influencing only the likelihood of consolidating that specific tagged item. The idea of a 'priority tag' is not new; in fact, it has been suggested previously that such priority tags experience decay over time (Yantis & Jones, 1991). With this context, Experiment 1 implies that the priority tags associated with history-driven information are shielded from temporal decay.

Experiment 2 was conducted to assess the impact of priority on current target information as evidenced by capture-related enhancement. The results point toward a nuanced prioritization process that fluctuates across individuals. Selection history dominated the priority effect of T2, resulting in improved T2 accuracy while the other history-driven priority

signal of reward only showed a marginal positive influence on performance. Previous research has shown that while the biases of attention toward previously selected information is rather universal, the bias toward previously rewarded information is modulated by individual differences related to reward processing, such as those with depressive symptoms who are significantly less influenced by previously rewarding stimuli (Anderson et al., 2017). Provided that individuals with depressive symptoms exhibit a degraded response to rewarding stimuli, it is plausible that other individual differences related to reward processing could uniquely impact the history-driven signal of reward as well. Bearing this in mind, while our results strengthen existing research showcasing the universal impact of selection history on attention, our findings on the influence of previously rewarded information are not particularly surprising given that this priority signal is sensitive to individual differences related to reward processing.

Furthermore, the marginal influence of physical salience on T2 processing was qualified by an interaction with working memory capacity, indicating that the behavioral enhancement driven by salience increases as a function of capacity. As alluded to previously, the priority signals of selection history and reward are both tied to the ‘history’ of previously selected information whereas the priority signal of salience in the present task functions as a control to ensure any effects of history are not due to the salient nature of the stimulus itself. Observing a difference in target processing for history driven priority and pure physical salience further supports our previous findings that the influence of history is indeed unique and unassociated with the physical nature of the priority signal. With this framework in mind, it is reasonable to conclude that history-driven priority signals enhance target processing for all individuals while only those with residual capacity can wield the full benefit of purely bottom-up signals.

Exploratory analyses confirmed that the influence of priority on T2 processing was driven by the bottleneck of attention. This provides crucial support that priority signals facilitate attentional selection when the system is under temporal strain and limited in resources. This supports our related finding in Experiment 1, where all priority signals strengthened target consolidation during maximal interference.

The goal of Experiment 3 was to elucidate the effects of priority when associated with task-irrelevant information, such as distractors. When priority was placed on a critical distractor placed between two letter targets in our RSVP task, we failed to observe any influence of priority on the processing of either target. While we anticipated distractor interference to be greatest in trials that consisted of a priority signal, we instead found working memory capacity to be the main predictor of performance. Working memory capacity only predicted T2 performance when attentional resources were limited. This was a surprising finding given that this pattern of results was not present in either of the previous experiments. The lack of an effect of working memory capacity on T2 processing in the previous experiments coupled with its presence in the current experiment is likely driven by the unique suppression that is required to process T2 when priority is placed on an intervening distractor. In Experiment 3, any distractor item associated with a priority signal must be adequately suppressed to attend to subsequent target information and consequently, three-fourths of the trials require suppression. Therefore, working memory capacity plays a vital role in protecting information from interference when resources are limited. This finding resonates with those reported by Arnell and Stubitz (2009) who discovered that the attentional blink magnitude is dependent upon our ability to filter out irrelevant information.

Across three experiments we found that the relevance of the item associated with priority matters; with priority signals only facilitating performance when presented on targets (Experiments 1 and 2) and not when presented on a distractor (Experiment 3). It is possible that priority signals do in fact attach a ‘tag’ to the information they are presented with. If this were true and color was always the feature to be suppressed in Experiment 3, the distractor could have been filtered out before it was properly tagged for priority. While a future version of this experiment that controls for attentional set across experiments could rule out this potential explanation, there is neural evidence that already points to a mechanistic link between task relevance and priority. Specifically, activity in the superior colliculus increases substantially for reward-related targets compared to reward-related distractors (Conroy et al., 2023). Given that neurons within the superior colliculus are known to contribute to spatial priority maps, one could interpret this as evidence for the increased importance of targets for priority in general.

We also observed that history-driven effects are particularly strong, exerting their influence for longer durations. The enhancement of target information from priority signals has been shown to decay over time in spatial attention tasks, however, we observed no such decay in a temporal attention task. In the previous demonstration of this decay, the manipulated priority signal was an abrupt visual onset, a unique stimulus attribute that has been associated with transient shifts in attention (Yantis & Jones, 1991). Interestingly, priority signals derived from learned value or selection history can both rapidly deploy as well as sustain attention over time, uniquely contributing to the attentional control system (Anderson, 2021; Awh et al., 2012; MacLean & Giesbrecht, 2015; Stankevich & Geng, 2014). Considering this, our finding of a prolonged influence of history-driven signals on attention is reinforced by existing literature.

In summary, temporal prioritization of information is nuanced and shaped by our experience with previous information and individual differences in cognitive control. Associating information with a prior experience increases the likelihood of that information being consolidated into working memory, however, it does not increase the likelihood of consolidating subsequent information into memory. Strikingly, there are also no consequences for downstream target processing resulting from priority-related capture either, suggesting that priority signals are strictly tied to their associated items. When priority is associated with an item that is not a target, it fails to uniquely modulate attention. Our findings suggest that priority signals have a supportive role in attention, bolstering selectivity when the attentional system is most taxed. This series of experiments contributes to a wider prioritization framework of temporal attention, underscoring the broad implications of priority signals across varying contexts of relevance.

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III. Neural dynamics of attentional priority over time

Introduction

Our visual environment contains far more information than we can perceive, requiring selective attention to determine which stimuli to prioritize at the expense of others. This prioritization favors stimulus attributes that have aided our survival over many years, including those related to physical salience, novelty, and prior experience (Anderson, 2021; Awh et al., 2012). These favored attributes can guide attention voluntarily when related to a current task or goal and involuntarily when task-irrelevant (Jonides, 1981; Muller & Rabbitt, 1989). The involuntary capture of task-irrelevant information functions as a biological alarm system, alerting us to important changes in the environment, such as impending threats or fleeting opportunities (Anderson, 2021; Corbetta & Shulman, 2002). This capture of attention is costly when it draws upon resources intended for other visual information, delaying reactions and reducing recall for task-relevant information (see review Luck et al., 2021). A significant portion of our current understanding of attentional capture is grounded in visual search tasks that investigate shifts of covert and overt attention in space to task-irrelevant stimuli. However, stimuli compete for attention across time as well as across space (Martens & Wyble, 2010). This highlights the need to incorporate temporal attention into existing frameworks to provide a multifaceted understanding of the costs associated with attentional capture.

The relative salience of an item compared to its surroundings is known to bias spatial attention involuntarily, as demonstrated by increased visual search times for targets presented alongside singleton distractors (Theeuwes, 1992; Yantis & Jonides, 1990). This stimulus-driven account of attentional capture was initially theorized to be largely devoid of top-down

influence; automatically orienting attention to the most unique features in our visual field (Itti & Koch, 2001; Jonides & Yantis, 1988; Luck et al., 2021; Theeuwes, 1992, 1994). However, although the allocation of attention is often driven by physical salience, it can also be driven by experience, a phenomenon known as *selection history* (Awh et al., 2012). While much of the foundational literature suggests a clear dichotomy between ‘top-down’ and ‘bottom-up’ attentional control, selection history provides strong evidence that previous top-down goals can exert a substantial influence on current bottom-up processes (Awh et al., 2012). Studies on intertrial priming have shown that repeating stimulus information facilitates target detection (Le Pelley et al., 2017; Raymond & O’Brien, 2009; Rutherford et al., 2010) and enhances target salience (Theeuwes & Van der Burg, 2011), even without conscious awareness of the observer (Maljkovic & Nakayama, 2000). Additionally, stimulus features associated with an entirely separate task similarly benefit from history effects when they reappear as task-irrelevant distractors (Anderson et al., 2011a).

Previous work maintains that stimuli are most likely to induce capture when presented within the focus of attention, and that capture-related effects can be attenuated with a narrow attentional focus (Gibson & Kelsey, 1998; Ruthruff & Gaspelin, 2018). If our ability to resist task-irrelevant stimuli is partly contingent upon the successful spatial filtering of attention, then nonspatial tasks are the perfect candidate for evaluating the implications of attentional capture. For this reason, nonspatial tasks can provide significant insight into the consequences of attentional capture over time. Several studies have incorporated both salience and selection history into rapid serial visual presentation (RSVP) tasks as either targets or distractors to explore how they modulate the temporal bottleneck of attention (Folk et al., 2008; Lagroix et al., 2016; Nieuwenstein et al., 2005; Visser et al., 2004). This bottleneck of attention is reliably

observed by the failure to accurately report a masked target when it follows a previous target in close temporal proximity; also known as the *attentional blink* (AB) (Raymond et al., 1992). Several theories of attention credit this failure to a central bottleneck that is all consumed by the detection and consolidation of a previous target, only capable of processing incoming information when the bottleneck is cleared and resources become available (Chun & Potter, 1995; Jolicoeur, 1998). There is wide consensus that salience and selection history enhance performance when placed on targets (Lagroix et al., 2016; Le Pelley et al., 2016; Raymond & O'Brien, 2009); however, their influence when presented as distractors is less clear. One perspective suggests that repeated features expedite attentional engagement through priming, whereas salient features delay disengagement by capturing and holding our attention (Lagroix et al., 2016; Nieuwenstein, 2006; Nieuwenstein et al., 2005). Conversely, others argue that repeated features delay disengagement due to the observer having to compare these features against an existing attentional template, while purely salient distractors are appropriately and rapidly filtered out (Folk et al., 2008; Visser et al., 2004). Critically, all of these theories are predicated upon behavioral performance measures such as accuracy and reaction time. Given that electrophysiological recordings from RSVP tasks provide strong evidence of a neural delay in processing targets presented within the blink (Dell'Acqua et al., 2015; Vogel et al., 1998; Vogel & Luck, 2002), electroencephalography (EEG) provides the ideal temporal precision needed to resolve the debate surrounding the temporal consequences of capture.

The current study

Leveraging RSVP paradigms known to induce an attentional blink, the present study incorporates salience and selection history as distractors presented between two targets. By simultaneously recording neural activity, we can characterize the temporal influence of

priority-driven distractors on upcoming targets. Prior to the initiation of each RSVP stream, a simple discrimination task will present a shape in a color that either matches the color of the upcoming distractor (selection history) or is a unique color (salience), forming our two experimental conditions of capture. A positive going event-related potential (ERP) occurring approximately 300 – 500 ms post stimulus onset, known as the P3 component, is considered to reflect the active consolidation of information into working memory (Donchin & Coles, 1988). Previous studies have observed a delayed P3 component for unmasked targets presented during the blink period, suggesting that attentional blink failures arise from an occupied postperceptual bottleneck responsible for transferring information into working memory (Vogel & Luck, 2002). Consequently, the current study will measure P3 latency for the second target following distractors associated with salience and selection history compared to a neutral baseline. Should either distractor accelerate attentional engagement, we expect a reduced delay of the corresponding P3 latency to the second target, or at a minimum, a delay that is comparable to a neutral baseline. By contrast, if either distractor results in delayed disengagement of attention, we should observe a prolonged delay of the P3 latency in comparison to a neutral baseline condition. The present study intends to resolve a long standing debate on the temporal consequences of prioritized and distracting information through classic behavioral measurements associated with the attentional blink as well as measurements related to neural activity associated with information processing.

Methods

Participants

Thirty-nine adult students aged 18 - 24 years old ($M = 19.85 \pm 1.80$; 8 males, 27 females, 4 non-binary; 35 right-handed, 4 left-handed) from the University of California, Santa

Barbara volunteered to participate in the current study. Participants received a compensation of \$20 per hour for their time. All participants had normal color vision and normal or corrected-to-normal general vision. All procedures were approved by the University of California, Santa Barbara Human Subjects Committee.

Materials

All stimuli were generated using MATLAB with custom scripts and extensions from PsychToolbox (Brainard, 1997) and were presented on an LED monitor with a refresh rate of 60Hz and running on Linux. Subjects were seated approximately 130 cm away from the computer screen and used a standard keyboard to type their response. All participants used a chinrest adjusted to their specific height to maintain stable perception.

Eye tracking

An Eyelink 1000 (SR Research Ltd., Mississauga, Ontario, Canada) sampled at 500 Hz was used to ensure participants were actively maintaining central fixation and not blinking during critical periods in the trial, such as during the RSVP stream. This was assessed by calculating the gaze position and defining a window of tolerance. In the current study, the fixation tolerance used for participants was 150 pixels, except for several participants who experienced imperfect tracking due to reflective glasses or difficult calibration, in which the tolerance was increased. For these subjects, we also used eye activity recorded from the scalp to confirm the presence of eye blinks (see EEG preprocessing).

EEG

EEG data were recorded from 64 electrodes placed according to the 10-20 layout system using an ActiveTwo Amplifier (BioSemi) sampled at 2048 Hz. Four external electrodes

(VEOG) were placed above and below each eye to record vertical eye movements and two external electrodes were placed between the eye and the temple (HEOG) to record horizontal eye movements. Finally, one electrode was placed behind each ear and directly on the mastoid to serve as the reference signal.

Stimuli

Change detection task. The change detection task was generated to directly replicate the change detection task created by Adam and colleagues (2018). The set sizes used in this task include three, six, and eight. Nine unique colors were used for the square stimuli ($RGB = 0, 0, 255; 0, 255, 0; 255, 0, 0; 255, 255, 0; 255, 0, 255; 0, 255, 255; 255, 128, 0; 255, 255, 255; 1, 1, 1$) and the background was gray ($RGB = 127.5, 127.5, 127.5$). All stimuli were presented within a background display size of $7^\circ \times 5.2^\circ$ with at least 1.8° of space between each item. The squares measured $1.2^\circ \times 1.2^\circ$, and the fixation measured $0.12^\circ \times 0.12^\circ$ (Figure 1).

RSVP task. In each RSVP stream, distractors were always digits 2-9 and targets were always letters. The first target in the stream was randomly chosen from A-Z excluding letters 'I' and 'O' due to their similarity to digits '1' and '0'. The second target letter was an 'E' on 30% of the trials and another randomly chosen letter using the same criteria as above on 70% of the trials. All distractors were chosen randomly and replaced accordingly to ensure no distractors were repeated within four items of each other. The first target (T1) was randomly presented in position 3-5 of the stream with the second target (T2) appearing either 3 or 8 items after the first target. The critical distractor was always presented two items away from the first target. The first target was always black, and the second target was always white. Half of all trials ended with T2+1 items (masked) while the other half ended with T2 (unmasked). A randomly chosen shape (circle or square) was presented prior to each RSVP stream and presented in a

randomly chosen color (*RGB*: 0, 255, 0; 0, 255, 255; 255, 0, 255; 255, 128, 0; 255, 255, 0; 255, 0, 0; 0, 0, 255). For half of the subjects (selection history condition), the critical distractor was the same color as the shape preceding the RSVP stream. For the other half of the subjects (salience condition) the critical distractor was a different color from the shape preceding the stream. The critical distractor was only colored on half of all the trials and was presented in black for the remaining trials. All other distractors in the stream were black. All items were presented at central fixation. The circle and square shapes presented prior to the RSVP stream measured $0.8^\circ \times 0.8^\circ$ degrees of visual angle and all letters presented in the RSVP stream were centered in the same space. Stimuli were presented against a medium gray background (*RGB*: 127, 127, 127). All conditions of lag, distractor, mask were equally counterbalanced and the frequency manipulation for the second target was consistent across all conditions.

Procedure

Change detection task. Each trial began with a 1000 ms fixation period followed by the presentation of either three, six, or eight different colored squares (see Figure 1). The colored squares were displayed for 250 ms prior to a 1000 ms delay period. One of the squares reappeared in either the same color (no change trial) or a different color (change trial) than the square previously presented in that location and remained on the screen until a response was made. Subjects were instructed to remain fixated on the center of the screen until it was time to make a response. For their response, subjects pressed the 's' key if the color was the *same* and pressed the 'd' key if the color was *different*. There were 48 trials per set size and three blocks. Half of all the trials were a 'change' trial and the other half a 'no change' trial. On 'change' trials, the square displayed in the response period was a different color than the square presented in that location during the encoding period. Capacity, as measured by 'K', was

computed as follows: $N \times (H - FA)$, where N represents set size, H refers to the hit rate, and FA refers to the false alarm rate (Cowan, 2011). Each subject was then given an overall working memory capacity score, calculated as the average K across all set sizes ($Median = 2.83$, $Min = 1.15$, $Max = 4.51$).

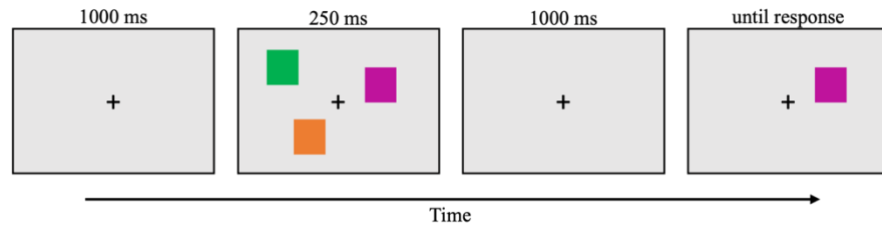


Figure 1. Trial schematic of the change detection task.

RSVP task. A black fixation cross was presented in the center of the screen until the space bar was pressed to initiate the start of each trial. Upon trial initiation, the black fixation remained on the screen for randomly jittered interval of 600 – 800 ms. Following the fixation, the shape stimulus was presented for 250 ms. Participants responded by pressing ‘z’ for circle shapes and ‘m’ for square shapes. Responses to these shapes were not analyzed, as they were only included in the task to serve as a previously selected stimulus feature (necessary for the selection history condition). After responding to the shape stimulus, participants pressed the spacebar to begin the next part of the trial. A black fixation cross appeared again for a jittered interval of 1000-1050 ms followed by the RSVP stream. Each item in the RSVP stream was presented for 50 ms followed by a 33 ms interstimulus interval. Participants were instructed to maintain fixated at the center of the screen until a probe appeared for a jittered interval of 1000 – 1050 ms to ensure event-related potentials epoched to the last target were not contaminated with eye movements. An untimed response screen instructed the participant to type the letter corresponding to the first target. After their response, a second response screen instructed

participants to respond whether the second letter was an ‘E’ or not. If the second target was an ‘E’, they typed that letter, but if it was any other letter they were instructed to type ‘O’. There were three blocks of 320 trials split across two sessions. Participants completed the change detection task followed by one block of the RSVP task in one session and returned within a week to complete the final two blocks in a second session. Participants were given a minimum sixty-second break every sixty trials and an extended break that lasted approximately ten minutes between blocks (Figure 2).

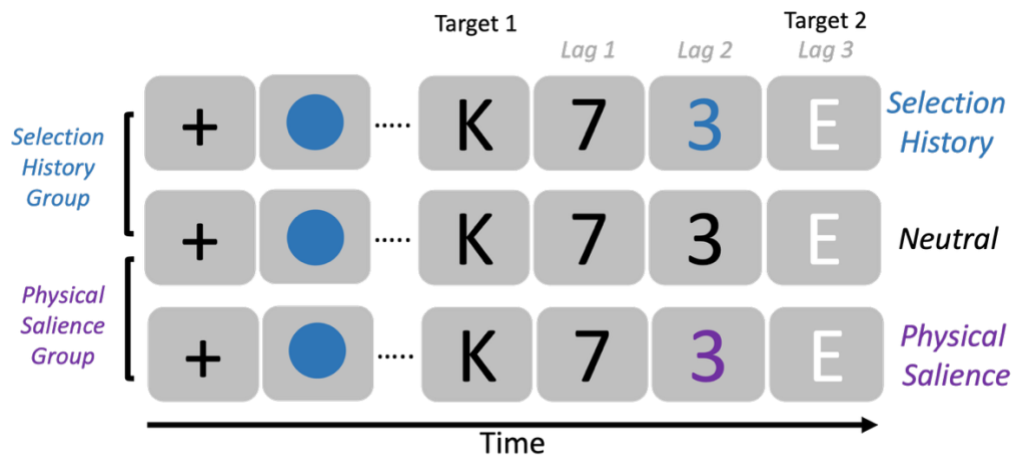


Figure 2. An example of an unmasked trial across conditions in the RSVP task displaying the infrequent T2 stimulus presented in lag 3.

EEG preprocessing

Data were processed from custom scripts generated in MATLAB along with preprocessing functions provided by the EEGLAB plugin (Delorme & Makeig, 2004). The signal was referenced to the mastoids and resampled to 256 Hz. We filtered the signal with a high-pass filter of .1 Hz and a low-pass filter of 30 Hz. The data were then epoched around the first target (-200 ms to 800 ms) to measure event-related activity in response to the second target and again to the critical distractor (-200 ms to 1000 ms) to measure differences in

distractor processing separately for each lag. The reason we chose to epoch to the first target is due to significant differences observed in processing the preceding distractor in lag 3 trials. This activity biased T2 activity when removed with baseline activity. All EEG data were then matched with their behavioral data and merged into one data frame per lag. This methodological choice was driven by the uneven number of time points across lags, preventing the use of single data frame for all lags. Baseline activity 200 ms prior to stimulus onset was removed. Trials were rejected if the amplitude deviated more than $\pm 100\mu\text{V}$ in any of the VEOG and HEOG channels. For the P3, trials were also rejected following the previous threshold for the electrodes of *Cz*, *Fz*, *Pz*, *POz*, *P1*, *P2*, *P3*, and *P4*. We then performed a linear detrend and removed baseline activity from 100 ms prior to stimulus onset a second time to further clean the signal. We decided to take these additional steps given the significant noise presented to the data due to the 12Hz visual presentation of our stimulus. For analyses of the P2 and N2 amplitudes, we rejected trials deviating from the previously mentioned threshold as well for electrodes *Cz*, *Fz*, *Pz*, and *Oz* and did not perform additional cleaning as there was an ample amount of trials given these components were not subject to the frequency manipulation of T2.

Analysis

Behavior. Only masked trials were included in the behavioral analysis. We applied a correction to our behavioral dependent measure of accuracy due to ceiling effects observed. All subjects performed above 70% and therefore we chose to treat 70% as our floor for by converting accuracy in reporting the second target given correct performance on the first target. We subtracted 0.7 from mean T2|T1 accuracy and divided this by $(1 - 0.7)$ to obtain our corrected values.

Modeling. Behavioral data were analyzed using a Generalized Linear Mixed Model (GLMM) with a binomial distribution and logit link function from the *afex* and *lme4* packages in R, while latency and amplitudes were measuring using a Linear Mixed Model (LMM) from the same packages. Type III omnibus tests determined significance using the maximum likelihood ratio tests for our binomial data and Kenward-Roger approximations for our continuous data. The categorical predictors of *lag*, *distractor type*, and *experimental condition* as well as the continuous and mean-centered predictor of *working memory capacity* were entered as fixed effects, with *subject* entered as the random effect. A full factorial model allowed us to evaluate the main effects of our predictors while simultaneously accounting for any possible two-way and three-way interactions. All post-hoc comparisons for simple effects and simple slopes analyses were Holm-Bonferroni corrected.

P3 latency. Only unmasked trials were used in the analysis. Activity was averaged across electrodes *P1*, *P2*, *P3*, *P4*, *Pz*, and *POz* before calculating a difference wave by subtracting activity in trials presenting a frequent T2 from trials presenting an infrequent T2 to isolate the P300 to rare events. The P3 onset and offset for each condition was based on their grand averaged waveforms and visual inspection of the positive event-related potential occurring after T2. The time windows chosen for each condition are in respect to T1 (all trials are epoched to T1) and as follows: Selection History: *Neutral Distractor (ND)*, *Lag 3*: 562 – 1007 ms; *Critical Distractor (CD)*, *Lag 3*: 650 – 1065 ms; *ND*, *Lag 8*: 970 – 1511 ms; *CD*, *Lag 8*: 917 - 1511 ms. Physical Salience: *ND*, *Lag 3*: 650 – 1150 ms; *CD*, *Lag 3*: 675 – 1226 ms; *ND*, *Lag 8*: 980 – 1420 ms; *CD*, *Lag 8*: 980 – 1420 ms. Within each window, we calculated the 50% fractional area latency by first setting negative values within this time window to zero and subsequently identifying the point corresponding to 50% of the total cumulative area (Luck,

2022). Finally, we subtracted the time associated with the T2 display (lag 3: 249 ms; lag 8: 664 ms) from the latency to make sure zero represented T2 onset.

P2 / N2 amplitude. Data were analyzed from the Cz electrode as this electrode was responsible for a significant portion of activity within the 100 – 300 ms time window following visual inspection of topographic plots. Activity in neutral distractor trials were subtracted from trials that presented a critical distractor to visualize the specific activity associated with the manipulation of priority. Time windows used for our analysis of each component were chosen through visual inspection of grand average waveforms. The following time windows were chosen for the P2 component: Lag 3 (156 ms – 200 ms) and Lag 8 (164 ms – 210 ms). We chose the following time windows for our analysis of the N2 component: Lag 3 (200 ms – 260 ms) and Lag 8 (207 ms – 260 ms). Average amplitude was then calculated within each time window for each lag and component.

Results

Accuracy

A linear mixed effects model was used to assess the effect of Lag, Condition, Distractor Type and Working Memory Capacity on T2|T1 performance. There were main effects for both Lag ($F(1,105) = 58.92, p < .001$) and Working Memory Capacity ($F(1,35) = 6.84, p < .001$). Accuracy significantly improved from lag 3 ($M = .83, SE = .015$) to lag 8 ($M = .92, SE = .015$), confirming participants did experience a blink in the shortest lag (Figure 3). A simple slopes analysis indicated that overall performance increased as a function of working memory capacity ($\beta = .043, SE = .012$; Figure 4). We believe a ceiling effect may have contributed to

our lack of distractor or condition effects on performance, as the average overall accuracy (87%) was well above chance.

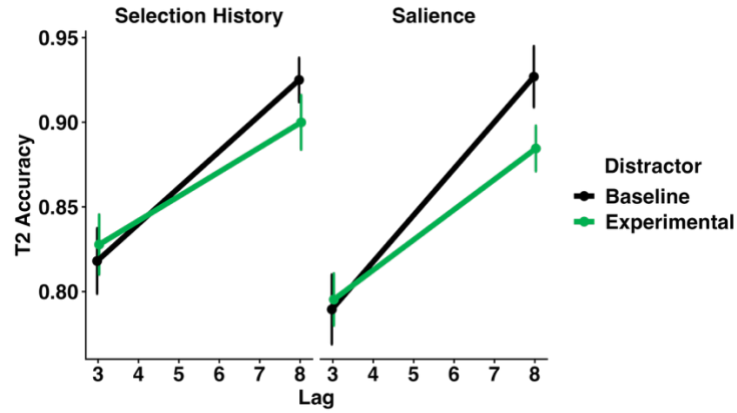


Figure 3. T2/T1 accuracy as a function of lag, working memory capacity, and distractor type. Error bars are presented as Cousineau-Morey (Morey, 2008) corrected standard errors of the mean.

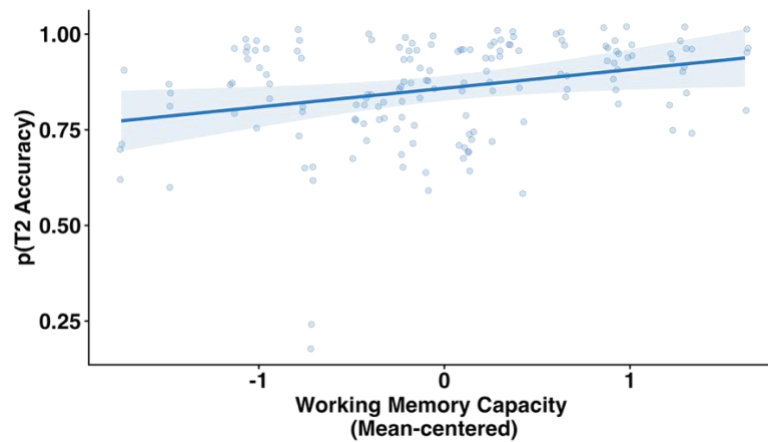


Figure 4. T2/T1 Accuracy as a function of working memory capacity. Shaded ribbons represent 95% CI.

P3 Latency

A linear mixed effects model with the same predictors of Lag, Condition, Distractor Type and Working Memory Capacity on P3 latency revealed main effects for Lag ($F(1,105) = 47.31, p < .001$) and Distractor Type ($F(1,105) = 9.55, p = .003$), as well as interactions between

Lag and Condition ($F(1,105) = 14.84, p < .001$) and Lag and Distractor Type ($F(1,105) = 4.22, p = .042$), (see Figures 5 and 6).

P3 latency was delayed across all conditions and distractor types in lag 3 ($M = 625, SE = 10.96$) compared to lag 8 ($M = 540, SE = 10.96$), $t(105) = 6.88, p < .001$. In addition, P3 latency was also delayed for experimental distractor types ($M = 602, SE = 10.96$) compared to neutral distractor types ($M = 563, SE = 10.96$), however, this effect was most pronounced in the shortest lag ($t(105) = -3.64, p < .001$) compared to the longest lag ($t(105) = -0.73, p = .466$) as observed in the interaction between lag and distractor type. These findings successfully corroborate previous work demonstrating the delayed consolidation of target information during shorter lags (Vogel & Luck, 2002). Crucially, we extend these findings by showing that this delay is prolonged when targets follow distractor items associated with either physical salience or selection history.

Interestingly, our between-subjects variable of experimental condition interacted with lag as well, revealing that the P3 component was significantly more delayed during the shortest lag for participants assigned to the physical salience condition ($M = 660, SE = 15.30$) compared to those assigned to the selection history condition ($M = 590, SE = 15.70$), $t(70.6) = -3.21, p = .002$. Remarkably, this delay occurred regardless of whether the distractor was neutral or physically distinct. This suggests that the experimental condition itself may have altered the attentional strategy participants engaged in to effectively deal with the unpredictable presentation of the specific distractor feature associated with their condition (i.e. physical salience, selection history).

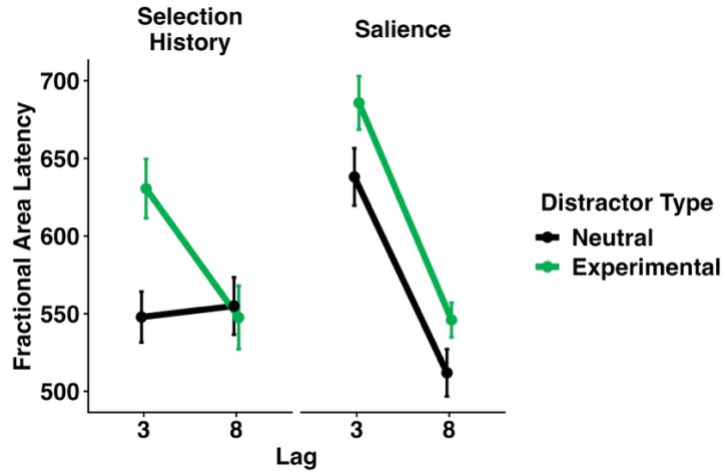


Figure 5. Fractional area latency of the P3 component as a function of lag, distractor type, and condition. Error bars are presented as Cousineau-Morey (Morey, 2008) corrected standard errors of the mean.

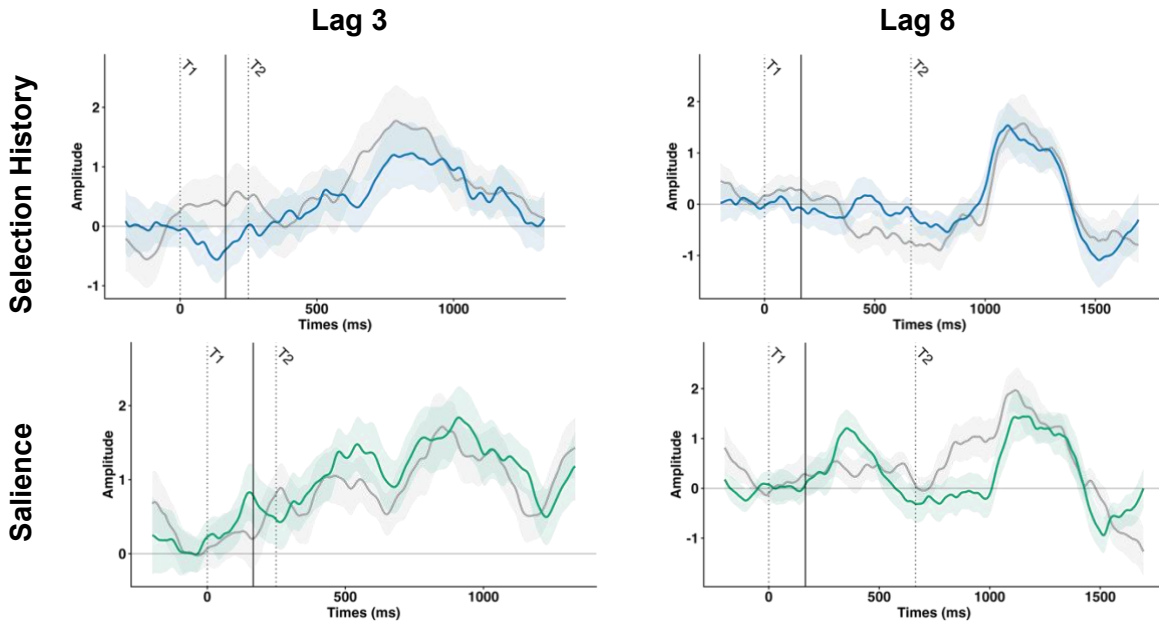


Figure 6. Event related activity time-locked to the first target in the RSVP stream. Neutral distractors conditions plotted in gray. Vertical solid lines represent the onset of the critical distractor and shaded regions represent Cousineau-Morey (Morey, 2008) corrected standard errors of the mean.

Exploratory Analyses

To better understand the influence of the distractor type on P3 latency, we calculated differences in the P2 and N2 components for each condition by subtracting the activity in trials with our neutral baseline distractor from those with the critical distractor present. Previous research has suggested both components within the posterior region are representative of early attentional processes related to the evaluation of physical characteristics tied to incoming stimuli (Potts & Tucker, 2001). Interestingly, others have shown that the N2 is attenuated for stimuli that match an existing memory representation and significantly enhanced for items that stand out from other task-relevant stimuli (Ferrari et al., 2010; Luck & Hillyard, 1994). For these reasons, comparing these components amongst our distractor conditions can provide useful insight regarding their sensory and early attentional influence on temporal processing.

P2 Amplitude

A linear mixed effects model was conducted to assess the predictors of Lag and Condition on mean P2 amplitude (Figure 7). We failed to observe a main effect of Lag ($F(1,37) = 0.17, p = .679$), Condition ($F(1,37) = 0.82, p = .371$), or their interaction, ($F(1,37) = 2.13, p = .153$), suggesting that the P2 component is unchanged across lags and conditions.

N2 Amplitude

A linear mixed effects model was conducted with the same predictors of Lag and Condition on mean N2 amplitude (Figure 7). We observed a significant interaction between Lag and Condition, ($F(1,37) = 4.65, p = .038$; Figure 7). The N2 amplitude increased significantly from lag 3 ($M = -0.093, SE = 0.48$) to lag 8 ($M = -1.089, SE = 0.48$) in the selection history

condition, $t(37) = 2.548, p = .015$, whereas the N2 amplitude was comparable across lags for the salience condition.

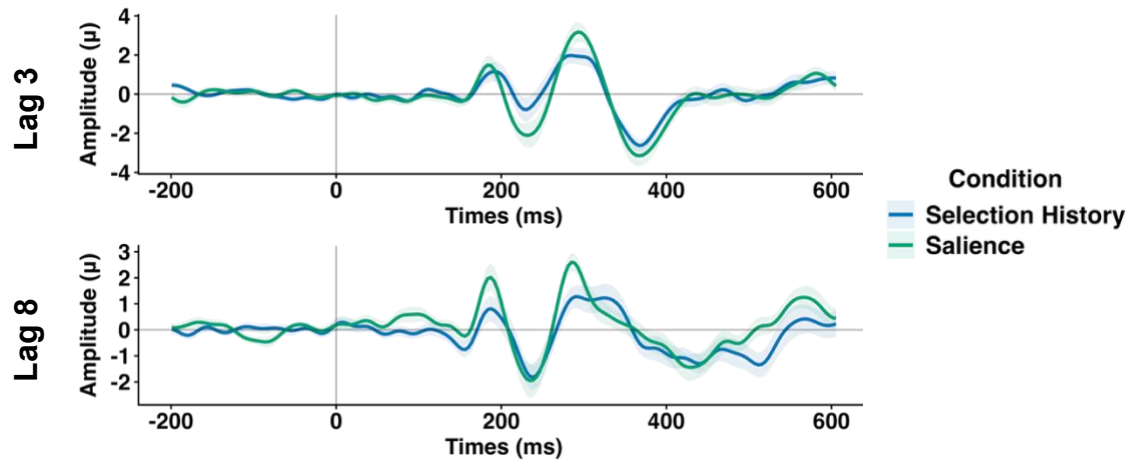


Figure 7. Event-related activity time-locked to the distractor. Shaded regions represent standard errors of the mean.

Discussion

The attentional system prioritizes physically salient and previously encountered stimuli to facilitate the rapid detection of meaningful and relevant information. The consequences of attending to such information when task-irrelevant is predominantly studied within the spatial domain of attention, where attention is typically captured at a specific spatial location and often requires the shifting of spatial attention to be avoided (Luck et al., 2021; Ruthruff & Gaspelin, 2018). However, attention is limited in the amount of information it can process both spatially *and* temporally (Capizzi et al., 2023), underscoring the importance in understanding the consequences of capture in temporal attention. In the present study, we incorporated a nonspatial task to study temporal attention and further understand the temporal profile of attentional capture when it is most disruptive and immune to spatial filtering. An RSVP paradigm was used to induce an attentional blink by presenting two targets either three or eight items away from each other while manipulating the physical characteristics of a distractor

presented two items after the first target. The critical distractor was associated with either selection history or physical salience and was presented on half of the trials, while a neutral distractor was presented on the remaining trials. To assess the impact of selection history and physical salience on temporal attention, we recorded neural activity at the scalp using EEG in response to the second target as well as the distractor itself. We were specifically interested in how the delay commonly observed in the P3 component within the temporal bottleneck of attention would be modulated as a function of distractor type (Vogel et al., 1998; Vogel & Luck, 2002).

Our behavioral results failed to show any effects related to the distractor, instead only confirming the presence of a blink at the earliest lag and a positive association between working memory capacity and overall performance. Due to the nature of isolating our ERP component of interest, the second target was either a frequent or an infrequent target letter, effectively raising chance performance. It is plausible that the identification of the second target lacked the difficulty necessary to elucidate any effects beyond our main findings. Nevertheless, our subsequent neural measures remain unaffected as the delay associated with processing a second target is only observed when it is fully processed and unmasked (Vogel et al., 1998).

In line with previous research, we were able to confirm a delayed P3 component within the shortest lag, demonstrating the temporal limitations of attention that arise when resources are occupied with previously presented information (Dell'Acqua et al., 2015; Vogel & Luck, 2002). Importantly, we also observed that this delay is significantly increased for unique distractors that are either physically salient or associated with previous information compared to neutral distractors that do not vary in their appearance. This finding suggests that distractors

with distinct features are prone to bias attention, a costly endeavor when resources are already strained, resulting in delayed attentional disengagement that further postpones the processing of upcoming target information. Although both distractor types (selection history and physical salience) delay subsequent target processing, the mechanisms responsible for their associated delay may differ.

While a substantial corpus of literature dedicated to unveiling the underlying mechanisms of the attentional blink propose this deficit is the product of limited attentional resources due to processing a prior target (Chun & Potter, 1995; Jolicoeur & Dell'Acqua, 1999; for a review see Martens & Wyble, 2010), there are several other compelling arguments that can account for this deficit independent of a resource-depletion account. In particular, the boost and bounce theory proposed by Olivers and Meeter (2008) suggests an attentional gating mechanism associated with fluctuations in excitatory and inhibitory attentional states that may also help explain our findings. This theory is based on the assertion that attention is *boosted* through excitatory feedback following the visual input of relevant information and *bounced* through inhibitory feedback following irrelevant visual input. Both resource-depletion and attentional gating theories will be applied to the present findings.

Our findings related to selection history are consistent with interpretations suggesting that previously seen information is compared to active short-term memory representations upon detection (Visser et al., 2004) and demonstrates support for the nonspatial contingent capture hypothesis (Folk et al., 2008). Knowing that observers often lack awareness of the template-matching process (Maljkovic & Nakayama, 2000), it is suggested that previously selected information continues to bias our temporal engagement of attention, even without our conscious effort. In support of this finding, N2 amplitude was markedly reduced in response

to distractors associated with selection history in the shortest lag. It has been proposed that the N2 amplitude reflects early attentional processing of novel information and is frequently attenuated when stimulus features match previously encountered contents (Ferrari et al., 2010). This coincides with the delayed disengagement hypothesis asserting that attentional processes are devoted to matching previously seen stimuli to a template upon detection. Taken together, these results firmly support the notion that prior top-down goals influence bottom-up processing (Awh et al., 2012); delaying further consolidation within the attentional blink window. These findings can be explained by resource-depletion accounts that attribute this delayed processing of upcoming information to the limited resources following the presentation of an attentionally demanding distractor (Chun & Potter, 1995; Isaak et al., 1999). The boost and bounce theory (Olivers & Meeter, 2008) would agree that the distractor containing overlapping features with a previously selected target is considered relevant to the attentional system, but would argue that as a result, it is subject to enhanced excitation. This attentional boost can be helpful in detecting the second target while still resulting in its delayed consolidation due to the temporal demands associated with comparing a present stimulus to an attentional set.

Physically salient distractors may delay attentional processing for two distinct reasons depending on the theoretical framework in which these findings are interpreted. In accordance with a resource depletion account of attention, physically salient distractors likely delay attentional disengagement due to their unique physical characteristics that are known to capture attention (Jolicoeur et al., 2006). Although previous accounts of distractor interference in RSVP tasks suggest that only distractors that share similarities with target features result in impaired target processing during the attentional blink (Akyürek & Hommel, 2005; Folk et al., 2008;

Maki & Mebane, 2006), these tasks commonly present targets that are at least as salient as the distractors themselves. It is plausible that salient distractors can be properly filtered out when they are no more physically salient than targets and when they contain predictable salient features. Further, research investigating the influence of emotionally salient distractors on target processing revealed that emotionally salient distractor images only capture attention when they are dissimilar to other distractor images (Baker et al., 2021). This finding argues that the salience, rather than the emotion, of a distractor image is responsible for capturing attention and impairing subsequent target detection. Therefore, given that physical salience is known to reliably capture attention (Theeuwes, 1992), this process results in delayed subsequent target processing, provided the salient signal is strong enough to establish physical dissimilarity. The current study revealed an enhanced N2 amplitude across all lags in response to the physically salient distractor compared to the neutral distractor. This consistent negativity is indicative of the perceptual system receiving visually novel input (Ferrari et al., 2010; Folstein & Van Petten, 2008), and confirms the unique physicality associated with this critical distractor in the present design. However, the boost and bounce theory provides a substantially different interpretation for the delayed consolidation of subsequent information. This theory would instead suggest that after attention boosts during the presentation of the first target and bounces following the initial distractor, it never receives an additional boost prior to the onset of the second target. In this scenario, the delay that follows the distractor is likely the result of an inhibitory signal that closes the attentional gate, requiring additional time to reopen the gate to appropriately detect upcoming target information. If this inhibitory signal were enhanced during the presentation of a physically salient distractor compared to a neutral distractor, we

would expect the gate to shut more completely, resulting in a more pronounced delay of target information.

Notably, participants in the physical salience condition were significantly more delayed in the consolidation of upcoming target information compared to those in the selection history condition, regardless of whether the distractor was neutral or physically distinct. This unexpected finding points to a flexible attentional system that proactively modulates the allocation of attention as a function of context. The experimental condition itself may have altered the attentional strategy participants engaged in to effectively deal with the unpredictable presentation of the specific distractor feature associated with their condition (i.e. physical salience, selection history). It is difficult to reconcile the finding that both neutral and experimental distractors in the physical salient condition delayed subsequent processing compared to the selection history condition with resource depletion accounts of temporal attention. These theories would contend that resources are most limited following the presentation of a physically salient distractor compared to a neutral distractor, and thus the neutral distractor in the physical salience condition should not differ from the experimental distractor in the selection history condition, as distractors associated with selection history are also expected to demand attentional resources. However, the boost and bounce theory of temporal attention is well suited to account for the influence of experimental context on the attentional gating process.

In the current study, those in the selection history group are exposed to a relevant first target followed by a distractor that matches a previously selected item from the beginning of the stream on half of the trials. Typically, target information is held in working memory to serve as a template to compare against incoming information to facilitate target identification

(Hout & Goldinger, 2015). Given that excitatory feedback is provided for stimuli matching this attentional template, regardless of whether the stimulus is a target or distractor (Olivers & Meeter, 2008), the distractor associated with selection history in the present task may have benefited from this excitation, boosting attention immediately prior to the presentation of the target. The time course of the gating mechanism in these trials would reflect an initial boost for the first target, followed by a bounce during the presentation of the first distractor, and a significant boost during the onset of the distractor that matches the contents held in working memory from the beginning of the stream. Consequently, those in the physical salience group may recognize that there is no relevant signal between the presentation of the first and second targets. In this instance, it is reasonable to surmise that attention is boosted for the first target followed by a strong inhibition to prevent the encoding of irrelevant stimulus information prior to the second target. Such strong inhibitory feedback could result in an attentional gate this is slammed shut, ultimately making it more difficult to open the gate for relevant target information immediately following the distractor. In other words, the attentional system recognizes a distractor that matches a previous item as relevant and boosts attention as a result, but the attentional system operates differently when distractor information is never associated with the current task. As a result, the attentional system in this condition closes the gate for incoming visual input following the first target, producing a strong inhibitory signal during the presentation of both neutral *and* physically salient distractors. This inhibition impedes target detection in the shortest lag due to the limited amount of time to reopen the attentional gate for the immediately following target.

In an effort to disentangle the temporal implications of involuntary attentional capture from stimuli associated with the prioritized attributes of physical salience and selection history,

we propose that both previously seen and physical salient information are prioritized and further delay subsequent target processing. These attentional demands delay the processing of upcoming information during the attentional blink period; however, their cost is eliminated once these items are separated temporally. Though our prior interpretations and hypotheses were generated with a resource-depletion and bottleneck account of temporal attention in mind, other interpretations related to an attentional gating mechanism may more accurately account for our findings. Distracting information imbued with features that overlap with previously selected stimuli are deemed relevant to the attentional system and enhance attention accordingly, providing a perceptual benefit for items presented while the attentional gate is open. The delay associated with subsequent target processing following these distractors can be credited to the process of matching the current relevant stimulus information with an existing attentional set, even when presented as a nontarget. Alternatively, when it is apparent that a physically salient and irrelevant distractor will appear, and thus no distractor items in this condition will contain relevant information, the attentional gate closes following the presentation of the first target. The delay in target processing following both neutral and physically salient distractors in this particular condition can be attributed to the time and effort required to reopen the attentional gate prior to the arrival of the upcoming target. In addition, the attentional gate may be closed more firmly during the presentation of a physically salient distractor, further delaying subsequent processing. Together, these findings illustrate a flexible attentional system that varies the allocation of temporal attention as a function of stimulus relevance and experimental context and provides further support for an attentional gating mechanism of temporal attention.

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The only modification made to the original work in this dissertation is the title change, which was updated to better align with the themes of the preceding chapters. This chapter is licensed under a [Creative Commons Attribution 4.0 International License](https://creativecommons.org/licenses/by/4.0/).

IV. Task-irrelevant salience and value-related spatial attention

Introduction

Selective processing requires efficiently sampling information from the environment and maintaining the resulting internal representation to serve as the basis for decisions, actions, and memories. Selectivity is impacted by both the physical properties of a stimulus (stimulus-driven) and internal influences related to our current goals (goal-driven) (Carrasco, 2011; Corbetta & Shulman, 2002; Theeuwes, 2019). The balance between stimulus- and goal-driven influences depends on cognitive control, which is a function that can flexibly modulate selective information processing at multiple stages (Awh et al., 2006; Luck et al., 2021).

Physically salient abrupt onsets are important external influences that guide selective attention by alerting the system to changes in the environment (Breitmeyer & Ganz, 1976; Egeth & Yantis, 1997; Jonides & Yantis, 1988; Theeuwes, 1994; Yantis & Hillstrom, 1994). While early evidence indicated that abrupt onsets automatically capture attention (Jonides & Yantis, 1988; Remington et al., 1992; Yantis & Jonides, 1984), subsequent studies demonstrate that the ability of abrupt onsets to involuntarily capture attention is tightly linked to attentional control settings (Folk et al., 1992; Ruthruff & Gaspelin, 2018; Yantis & Jonides, 1990). For instance, while search for abrupt onset targets is insensitive to set size, task-irrelevant abrupt onsets are not able to completely defy volitional goals, such as when spatial cues accurately inform subjects of the upcoming location of a target (Yantis & Jonides, 1990). Similarly, when abrupt onsets have different features from a target (Folk et al., 1992), they are able to be ignored. In other words, while abrupt onsets are able to involuntarily capture attention, this capture effect can be attenuated by goal-driven attention.

Goals are important internal influences that can guide the system using knowledge, expectations, and motivation. Multiple studies have demonstrated faster reaction times as well as more accurate responses with the prospect of reward (Bijleveld et al., 2010; Klink et al., 2017), a finding shown to correlate with neural activity related to proactive control following reward-associated cues (Frömer et al., 2021; Schevernels et al., 2014). While motivation provides a clear benefit for encoding, there are conflicting findings about the impact of motivation and value on prioritizing task-relevant information held in working memory. On the one hand, there is evidence for an increase in recall precision with monetary incentive; however, this only holds true when cues are presented prior to encoding as opposed to being presented retroactively (Brissenden et al., 2023). This finding suggests that reward enhances cognitive control by facilitating the proactive allocation of resources during encoding and not during maintenance. On the other hand, when items associated with a lower value are cued during maintenance, recall precision can increase to levels similar to recall precision for items associated with a higher value (Atkinson et al., 2022). This finding suggests that the motivational effects of reward on maintenance can be as powerful as explicit rehearsal cues. When considered together, it seems plausible that value related motivation could increase control during various junctures along the information processing hierarchy.

Given that value and reward influence performance both during encoding and maintenance, it is reasonable to predict that task-relevant value may shield information from even the most potent distractors. We tested this prediction in two experiments by investigating whether value associated information insulates information processing from distractors presented either after attention-directing cues, prior to encoding of the targets (Experiment 1) or during maintenance of task-relevant targets (Experiment 2). The results of Experiment 1

suggest that task-irrelevant abrupt onsets are most disruptive when 1) multiple spatial locations are associated with equal value and 2) presented latest in the cue-target interval. The results of Experiment 2 suggest improved performance when the task-irrelevant abrupt onset coincides with the location of valuable information, specifically for those with low working memory capacity.

Experiment 1

The goal of Experiment 1 was to investigate the impact of task-irrelevant abrupt onsets presented during a cue-target interval on the processing of value related information. In the present study, subjects were presented with two simultaneous value related cues parafoveally, indicating which subsequent targets to prioritize in the corresponding peripheral locations (Figure 1). The value cues were either different or equal in value, requiring the subjects to choose which locations to attend to accordingly. An abrupt onset appeared during the cue-target interval on one of the parafoveal cue locations. Given the benefits of expected reward on allocating attention to value associated information and promoting enhanced stimulus processing during encoding (Brissenden et al., 2023; Frömer et al., 2021; Krebs et al., 2013), subjects should appropriately allocate attention to the periphery in anticipation of the upcoming target display. When the cues are of different value, there may be no effect of the abrupt onset if attentional resources are predominantly allocated to the most valuable target location and when most of the display can be ignored. However, when the cues are of equal value, interference from abrupt onsets could be inescapable due to dividing attention across multiple target locations as well as the inability to filter out all but one target location in the display. When abrupt onsets appear in task-irrelevant locations, they can be immune from capture and properly ignored (Ruthruff & Gaspelin, 2018). However, it is unknown whether task-irrelevant

abrupt onsets presented at potential cue locations influence value-driven orienting and encoding prior to the presentation of multiple targets in the periphery. Further, when the targets are of equal but low value, it is possible that the process of orienting attention to these targets is more susceptible to interference than when equal targets of high value are presented, as one might expect to be the case given that previous findings demonstrate a linear relationship between value and cognitive control (Frömer et al., 2021). It could also be the case that there is no difference between targets of equal low and equal high value, a finding that would be supported by research indicating that only differential values have an impact on attentional weights (Philiastides et al., 2010).

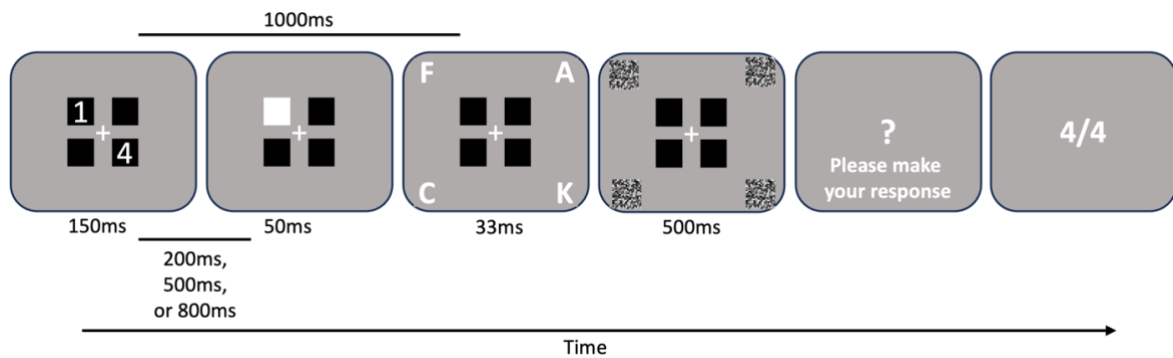


Figure 1. Sample trial sequence in Experiment 1. An example of a ‘different’ cue trial with the abrupt onset occurring on the ‘low-value’ cue location. The cue-target interval is 1000 ms prior to the letter display and the abrupt onset could occur either 200, 500, or 800ms into this interval. More specifically, if the abrupt onset occurred at 200 ms, there was a 750 ms blank period between the abrupt onset and the target display; if the abrupt onset occurred at 500 ms, there was a 450 ms blank period; and if the abrupt onset occurred at 800 ms, there was a 150 ms blank period before the target.

Methods

Participants

Thirty-five adult students aged 18 - 24 years old ($M = 18.97 \pm 1.19$; 11 males, 22 females, 2 non-binary) from the University of California, Santa Barbara volunteered to participate in the current study. Participants received 1 credit/hour (1.5 total credits) for their

participation. All procedures were approved by the University of California, Santa Barbara Human Subjects Committee.

Materials

All stimuli were generated using MATLAB with custom scripts and extensions from PsychToolbox and were presented on a CRT monitor with a refresh rate of 60Hz and running on Linux. Subjects were seated approximately 94 cm away from the computer screen and used a standard keyboard to type their response.

Stimuli

Stimuli were presented on a gray background ($RGB = 128, 128, 128$). Four black squares ($1.5^\circ \times 1.5^\circ$) were equally spaced around a white '+' presented at central fixation ($.5^\circ \times .5^\circ$). The number cues were white and presented in the center of their corresponding square (1.5°). The number cues were either equal in value (1 and 1; 4 and 4) or different in value (1 and 4; 4 and 1). The entire display size measured $16^\circ \times 12.8^\circ$. Each target letter (1.5°) was presented in a different peripheral corner of the display in white font. Target letters were masked by generating white gaussian noise centered on gray ($\sigma = 50$) and matching the size of the target letters. The letters on each trial were drawn randomly without replacement from the alphabet (except for 'm' and 'z').

Procedure

The task was a modified version of the multiple cue paradigm used to study shifts in endogenous attention (Oren et al., 2024). Each trial began with a center fixation jittered from 1050 ms to 1500 ms prior to the cue display. The two cue numbers were displayed for 150 ms followed by a 1000 ms cue-target interval. The cues depicted the number of points associated with each corresponding peripheral target location. During the cue-target interval, the abrupt

onset appeared for 50 ms at an onset of 200 ms, 500 ms, or 800 ms in the location of a high-value, low-value, or no-value associated parafoveal square (note: ‘high’ and ‘low’ value locations are arbitrary in the equal cue condition). After the 1000 ms cue-target interval, the four target letters appeared in the periphery for 33 ms before being immediately masked for 500 ms. Following the mask, subjects reported the target letter of their choice. Subjects were instructed to simply earn as many points as possible in the task. After their response, a feedback display appeared in the center of the screen for two seconds indicating how many points the subject earned out of the total possible number of points they could have earned on that given trial. Allowing the subject to choose which item to report is crucial to our design, as we are interested in the willful and voluntary allocation of attention. If we were to include a random response probe, we could only draw conclusions regarding that specific location or item, penalizing those that encoded the other equally rewarded location or item in the equal cue condition. The task consisted of 10 blocks with 36 trials each and was fully counterbalanced across all conditions of cue type, abrupt onset location, and abrupt onset time.

Analysis

The metric for performance in this experiment was the proportion of points earned relative to the maximum amount of possible points that could have been earned on a trial. Using the proportion of points earned as a proxy for performance ensures points are also given for suboptimal, though still correct, responses on different cue trials. Considering responses to the lower cue location in the different cue condition is important, as this could be an optimal strategy when the target in this location is the only one accurately remembered. This metric also ensures that 100% accuracy (proportion of points earned) reflects that the optimal choice was chosen regardless of condition. For example, choosing the optimal item to report in the

‘equal cue’ condition would result in $1/1 = 1$ or $4/4 = 1$, and choosing the optimal choice in the ‘different cue’ condition would result in $4/4 = 1$. Two subjects were removed from analysis as outliers (performance was greater than 2.5 standard deviations from the mean).

Results

Mean points acquired as a function of cue type, abrupt onset location, and abrupt onset asynchrony are shown in Figure 2. A repeated measures ANOVA was conducted to assess the effects of cue type (equal, different), abrupt onset asynchrony (200 ms, 500 ms, or 800 ms), and abrupt onset location (no value, low-value, high-value) on the proportion of points earned. All post-hoc comparisons were Bonferroni corrected. There was a significant main effect of cue type, ($F(1,34) = 6.68, p = 0.014, \eta^2 = 0.164$), with overall improved performance in the equal cue condition relative to the different value cue condition. There was also a main effect of abrupt onset asynchrony ($F(2, 68) = 18.11, p < 0.001, \eta^2 = 0.348$). Post-hoc comparisons revealed performance was significantly worse when the abrupt onset appeared late in the cue-target interval compared to when the abrupt onset appeared early (MD = 0.060, SE = 0.012, $t(34) = 5.18, p < 0.001, d = 0.428$) or in the middle of the cue-target interval (MD = 0.044, SE = 0.011, $t(34) = 4.06, p < 0.001, d = 0.312$). There was an additional main effect of abrupt onset location as well, ($F(2, 68) = 8.28, p < 0.001, \eta^2 = 0.196$), with post-hoc comparisons indicating significantly worse performance when the abrupt onset appeared on a no value cue location compared to when it appeared on either a low-value (MD = 0.025, SE = 0.009, $t(34) = 2.64, p = 0.037, d = 0.178$) or high-value (MD = 0.035, SE = 0.009, $t(34) = 3.86, p = 0.001, d = 0.252$) cue location.

A significant interaction between abrupt onset location and cue type also emerged, ($F(2, 68) = 5.85, p = 0.005, \eta^2 = 0.147$). Post-hoc comparisons indicated that the degradation in

performance when the abrupt onset was presented on a no value cue location was driven by the equal cue condition as performance is significantly worse with presence of the abrupt onset on the no value cue location compared to the low (MD = 0.050, SE = 0.012, $t(34) = 4.09$, $p = .004$, $d = 0.361$) and high (MD = 0.052, SE = 0.011, $t(34) = 4.70$, $p < 0.001$, $d = 0.371$) value cue locations for the equal cue condition only (Figure 2).

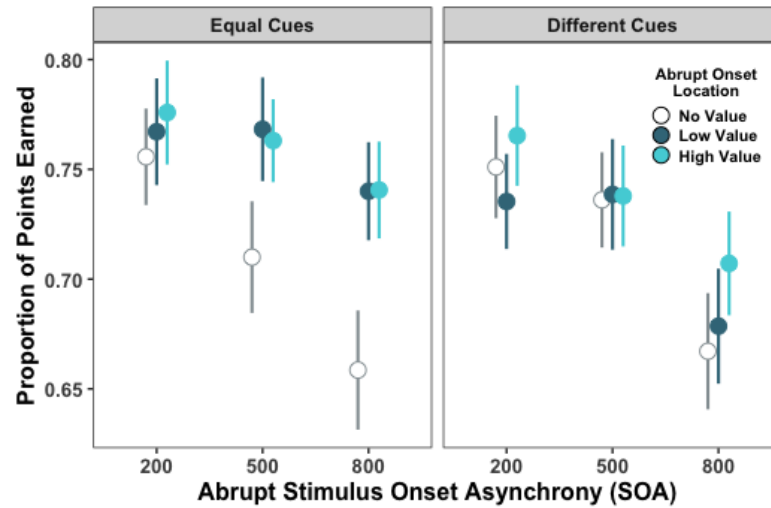


Figure 2. Results from Experiment 1. Figure displays means and standard errors of proportion of points earned.

Discussion

Experiment 1 investigated the competition between value related information and task-irrelevant abrupt onsets during the preparatory period of priority control. Overall, we observed an impairment in performance as the abrupt onset appeared later in the cue-target interval, likely because after getting captured by the abrupt onset, there was insufficient time to reorient attention back to the cued location prior to the presentation of the target.

Perhaps more interesting is the pattern of results suggesting that there is only an effect of the location of the abrupt onset when cued target locations are of equal value. While the present study cannot delineate the mechanisms responsible for this pattern, it does suggest that equally prioritizing multiple locations promotes greater disruption from task-irrelevant abrupt

onsets occurring in non-informative locations. We propose several potential explanations for these findings. If attention is divided across both equally valuable targets, the abrupt onset appearing in the parafoveal cue location could draw attention toward the center of the screen and away from the peripheral targets. If the abrupt onset is responsible for reorienting attention to the cue location, then performance should suffer the most when the abrupt onset occurs at a novel cue location for that trial, as this would delay the reorienting of attention to valuable locations in the periphery. This possible explanation is also consistent with the observation of degraded performance at longer abrupt onset SOAs. The present findings could also be explained by appealing to the quality of working memory representations. For example, holding multiple equally valuable items in memory may result in degraded representations of the locations, increasing their susceptibility to interference. This explanation is examined in Experiment 2.

Experiment 2

The goal of Experiment 2 was to better understand the consequences of abrupt onsets for holding multiple value related items in memory. If value related cues enhance processing only at the encoding phase, abrupt onsets presented during retention should have little impact on the representations of targets presented in high value locations. However, if the benefit of value related cues manifests as altered maintenance, abrupt onsets should impact performance. Further, if the findings from Experiment 1 are consistent with an account based on degraded representations, the abrupt onset occurring in the place of a target associated with no value should continue to impair performance during retention in the equal cue condition.

To investigate this question, Experiment 2 was a modified version of Experiment 1, with several critical changes. First, the abrupt onset appeared in the retention interval after the

target display and was placed on the location of one of the peripheral targets. Second, the value related cues depicted monetary value (cents) as opposed to points, with the intention of increasing the motivational salience attached to the target locations. Finally, the targets were randomly oriented lines between 0° to 360°. For the response, subjects were required to first click on the location of the target that would earn them the most money and then make a continuous response matching the orientation of that target. Responses within 15° of the chosen target orientation were considered ‘correct’ and resulted in the awarding of that target’s associated value. Using a continuous response measure affords the opportunity to assess if the representations of equally valuable orientations are in fact weaker, resulting in more recall error, then representations that should be differentially prioritized. With the fidelity of these representations in question, it is important to consider individual working memory capacity as those with lower working memory capacity could lack the cognitive control necessary for maintaining multiple relevant representations in the face of distraction (Adam et al., 2015; Adam et al., 2018).

Methods

Participants

Thirty-six adult students aged 18 - 24 years old ($M = 19.72 \pm 1.45$; 11 males, 24 females, 1 non-binary) from the University of California, Santa Barbara volunteered to participate in the current study. Participants received 1 credit/hour (1.5 total credits) for their participation. Additionally, participants were awarded money based on their task performance (up to \$11.70). All procedures were approved by the University of California, Santa Barbara Human Subjects Committee.

Materials

Stimuli for the change detection task were generated to directly replicate the change detection task created by Adam and colleagues (2018). All stimuli were created using MATLAB with custom scripts and extensions from PsychToolbox and were presented on a CRT monitor with a refresh rate of 85Hz and running on Linux. Subjects were seated approximately 100 cm away from the computer screen and used a standard keyboard and mouse to record their response.

Stimuli

Change detection task. The set sizes used in this task were three, six, and eight. Ten unique colors were used for the square stimuli ($RGB = 0, 0, 255; 0, 255, 0; 255, 0, 0; 255, 255, 0; 255, 0, 255; 0, 255, 255; 255, 128, 0; 255, 255, 255; 1, 1, 1$) and the background was gray ($RGB = 127.5, 127.5, 127.5$). All stimuli were presented within a background display size of $7^\circ \times 5.2^\circ$ with at least 1.8° of space between each item. The squares measured $1.2^\circ \times 1.2^\circ$, and the fixation measured $0.12^\circ \times 0.12^\circ$.

Main Experiment. Stimuli were presented on a gray background ($RGB = 128, 128, 128$). Four black squares ($1.5^\circ \times 1.5^\circ$) were equally spaced around a black oval presented at central fixation ($.4^\circ \times .4^\circ$). The number cues were white and presented in the center of their corresponding square (1.5°). The number cues were either equal in value (1 and 1; 4 and 4) or different in value (1 and 4; 4 and 1). The target display consisted of four black lines randomly oriented from 0° to 360° inside of four ovals outlined in black ($1.5^\circ \times 1.5^\circ$) and presented in the peripheral corners of the display ($16^\circ \times 12.8^\circ$). During the delay period, the abrupt onset occurred in either a high-value, low-value, or no-value target location in white for 50 ms. Responses were made with a computer mouse to report the target location associated with the most value. For the continuous response measure, the oval in the selected target location

displayed a randomly oriented line that could be reoriented with the mouse until the subject pressed the spacebar.

Procedure

Change detection task. Each trial began with a 1000 ms fixation period followed by the presentation of either three, six, or eight different colored squares. The colored squares were displayed for 250 ms prior to a 1000 ms delay period. One of the squares reappeared in either the same color (no change trial) or a different color (change trial) than the square previously presented in that location and remained on the screen until a response was made. Subjects were instructed to remain fixated on the center of the screen until it was time to make a response. For their response, subjects pressed the 's' key if the color was the *same* and pressed the 'd' key if the color was *different*. There were 48 trials per set size and three blocks. Half of all the trials were a 'change' trial and the other half a 'no change' trial. On 'change' trials, the square displayed in the response period was a different color than the square presented in that location during the encoding period. Capacity, as measured by ' K ', was computed as follows: $N \times (H - FA)$, where N represents set size, H refers to the hit rate, and FA refers to the false alarm rate (Cowan, 2011). Each subject was then given an overall working memory capacity score, calculated as the average K across all set sizes. For the current study, we conducted a median split on all subject K scores ($Median = 3.16$, $Min = 1.78$, $Max = 4.89$). All subjects with an average K score less than or equal to the median were considered 'low capacity' individuals ($n = 18$) and all subjects with a K score above the median were considered 'high capacity' individuals ($n = 18$).

Main experiment. Each trial began with a center fixation jittered from 1050 ms to 1500 ms prior to the cue display. The two cue numbers were displayed for 150 ms followed by a 200

ms inter-stimulus interval prior to the target display. The number cues depicted the amount of money (in cents) associated with each peripheral location. The target display was presented for 250 ms and followed by a 1000 ms retention interval. During the retention interval, an abrupt onset, a white filled oval, occurred in the location of a target associated with either a high-value, low-value, or no value for 50 ms. Importantly, the abrupt onset occurred either 200 ms, 500 ms, or 800 ms into the retention interval. Following the retention period, outlined ovals were presented in all previously displayed target locations until the subject chose the location of the target that they believed would earn them the most money. After indicating the appropriate target location, the oval displayed a randomly oriented line for the subject to adjust accordingly until the spacebar was pressed marking the end of the response period. If the subject reported an orientation within 15° of the actual orientation in the chosen target location, they received the money associated with that target. After making their response, subjects were shown feedback for 2000 ms informing them of how much money they earned for that trial. The task consisted of 10 blocks with 36 trials each and was fully counterbalanced across all conditions of cue type, abrupt onset location, and abrupt onset time.

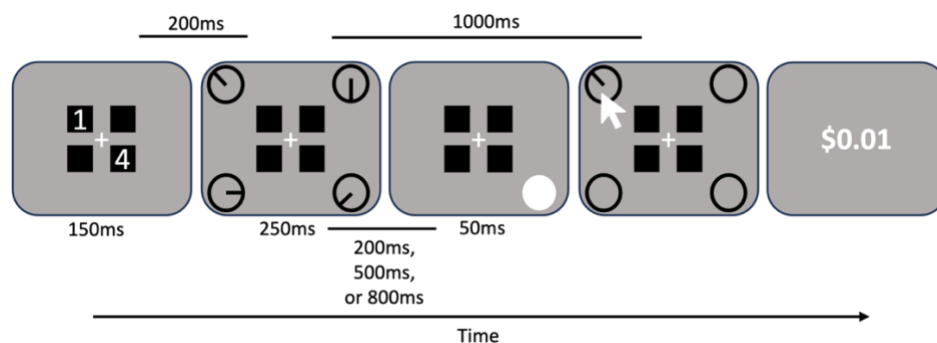


Figure 3. Sample trial sequence in Experiment 2. An example of a different cue trial with the abrupt onset occurring on the ‘high-value’ orientation location. The retention interval is 1000 ms following the orientation display and the abrupt onset could occur either 200, 500, or 800 ms into this interval. More specifically, if the abrupt onset occurred at 200 ms, there was a 750 ms blank period between the abrupt onset and the response display; if the abrupt onset occurred at 500 ms, there was a 450 ms blank period; and if the abrupt onset occurred at 800 ms, there was a 150 ms blank period before the response display. The white arrow depicts the subject’s cursor when making a response.

Results

Performance as proportion of money earned

To directly compare the results from Experiment 2 to Experiment 1, performance was first quantified as the proportion of money earned out of the total amount of money that could be earned on a trial. A mixed-design ANOVA was conducted to assess the effects of cue type (equal, different), abrupt onset asynchrony (200 ms, 500 ms, or 800 ms), abrupt onset location (no value, low-value, high-value), and the between-subjects factor of working memory capacity (high, low) on the proportion of money earned. All post-hoc comparisons were Bonferroni corrected. Unlike Experiment 1, there were no main effects of cue type, abrupt onset asynchrony, or abrupt onset location. However, there was a three-way interaction between working memory capacity, cue type, and abrupt onset location ($F(2, 68) = 4.09, p = 0.021, \eta_p^2 = 0.107$). To understand this interaction, three separate mixed-design ANOVAs were conducted to investigate how the simple interaction of cue type and working memory capacity differs across abrupt onset locations. A significant two-way interaction between cue type and capacity emerged for the high value condition only, ($F(1, 34) = 10.14, p = 0.003, \eta_p^2 = 0.230$). Follow up post-hoc comparisons show that when the abrupt onset occurs in the location of a high-value target, performance is significantly better in the different cue compared to equal cue condition for those with low working memory capacity ($MD = 0.038, SE = 0.013, t(34) = 2.85, p = 0.045, d = 0.284$) (Figure 4).

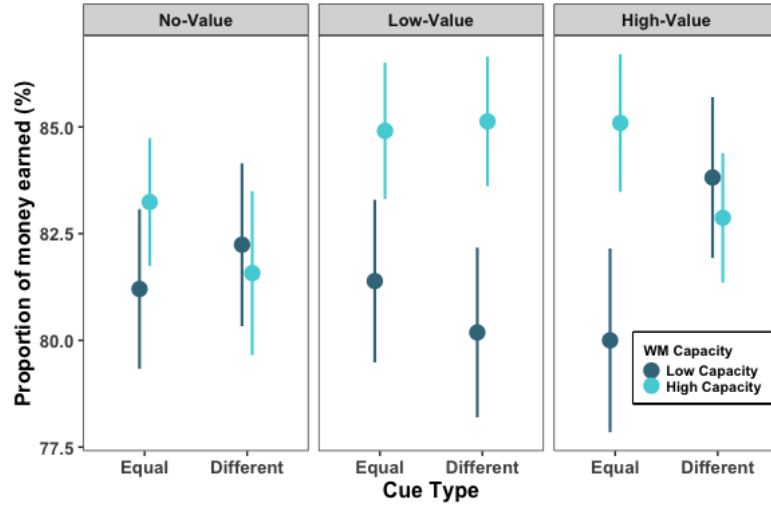


Figure 4. Results from Experiment 2 for proportion of money earned. Figure displays means and standard errors for proportion of money earned out of the total amount of money that could have been earned.

These results clearly show a different pattern than Experiment 1, as no main effects proved to be significant. However, the cue type and location of the abrupt onset did matter when considering working memory capacity. When one target was more valuable than the other, performance significantly improved when the abrupt onset appeared in the location of the high-value target, but only for those with low memory capacity.

Absolute Recall Error

Performance was also quantified in this task as recall error, or the absolute angular distance between the reported angle and the true angle at the location the subject chose with their cursor. A mixed-design ANOVA was again run with the same variables of cue type (equal, different), abrupt onset asynchrony (200 ms, 500 ms, 800 ms), abrupt onset location (no value, low-value, or high-value), and working memory capacity (low, high) on absolute recall error, with working memory capacity, K , as the only between-subjects factor. A three-way interaction between capacity, cue type, and abrupt onset location also emerged, ($F(2, 68) = 3.53, p = 0.035, \eta_p^2 = 0.094$). To break down the three-way interaction, we submitted each

level of abrupt onset location to separate mixed-design ANOVAs. There was a significant two-way interaction between capacity and cue type when the abrupt onset occurred in the high-value location only, ($F(1, 34) = 9.01, p = .005, \eta_p^2 = 0.209$). However, this finding should be interpreted with caution as no significant differences survived post-hoc comparisons (Figure 5).

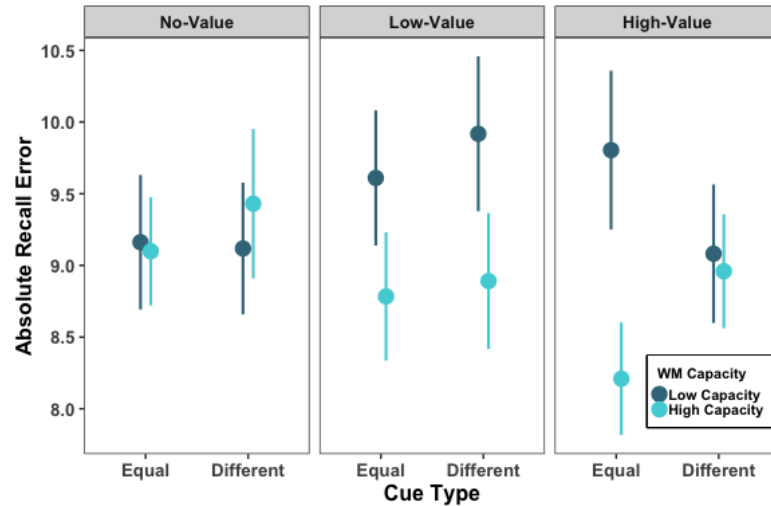


Figure 5. Results from Experiment 2 for absolute response distance. Figure displays means and standard errors of the absolute value of the response error in degrees.

Discussion

The purpose of Experiment 2 was to understand how value related cues and task-irrelevant abrupt onsets collectively modulate the retention of value related items in working memory. Experiment 2 was also necessary to further elucidate the findings from Experiment 1, which suggested that degraded representations in the equal cue condition could potentially explain the impaired performance observed when the abrupt onset occurred in an uninformative location during the cue-target interval. We observed that for those with low working memory capacity, performance was dependent upon the location of the abrupt onset and whether one or two targets were to be prioritized. Low working memory capacity

individuals performed better when an abrupt onset was presented in place of a high-value target in the different cue condition compared to when the abrupt onset occurred on any target in the equal cue condition. For individuals with low working memory capacity, an abrupt onset presented at a highly valuable target location may facilitate performance by acting like a rehearsal cue. It's possible this pattern would not be seen in high-capacity individuals as their performance was already very high, leaving little room for improvement. Relatedly, previous work has found that high-capacity individuals suffer from larger performance costs when probes are placed in target locations, perhaps due to the added disruption a probe mask elicits when attention is already very tightly focused (Fukuda & Vogel, 2009). In the absence of the abrupt onset acting as a rehearsal cue in the equal cue condition, those with low working memory capacity may be more susceptible to interference due to the difficulty in accurately holding multiple representations at once. Another possible explanation for this pattern is that subjects chose to remember only one of the equally valuable targets and in turn were subjected to interference from the abrupt onset when it occurred in the place of the other equally valuable target.

General Discussion

The present series of experiments presented an abrupt onset during two distinct phases of priority control (cue-target preparation and maintenance) while actively prioritizing task-relevant value related information. In both experiments, two value related cues were presented near the center of the screen indicating which peripheral target locations to prioritize. Critically, the valuable cues could either be equal or different, requiring the subject to decide which locations to prioritize on any given trial. The abrupt onset occurred on a location associated with no value, a low value, or a high value. In the equal cue condition, a low value

location would be either location when the equal cues were both 1's, and a high value location would be either location when the equal cues were both 4's. In Experiment 1, the abrupt onset appeared in the cue location and was presented either early, in the middle of, or late into the cue-target interval. In Experiment 2, the abrupt onset appeared in the location of the target and was presented either early, in the middle of, or late into the retention period.

The purpose of Experiment 1 was to investigate how abrupt onsets interact with goal-directed orienting to valuable information when presented after a spatial cue, but prior to encoding of the target. We found that the timing of the abrupt onset mattered, with performance decreasing as a function of when the abrupt onset occurred in the cue-target interval. We propose that performance may have suffered when the abrupt onset appeared shortly before the target display due to the limited amount of time remaining in the cue-target interval to reorient attention back to the appropriate target location (Cashdollar et al., 2013). Unique to the equal cue condition, performance was impaired when the abrupt onset appeared in a location that did not depict any value at all. There are two potential explanations for this finding. First, it is possible that in the equal cue condition subjects are dividing their attention across both valuable target locations. If this division of attention amounts to diffusely attending to a larger contiguous region of space (Hermann et al., 2010), this attended region may also include the parafoveal cue locations, resulting in an increased likelihood of interference on the presentation of the abrupt onset (Belopolsky et al., 2007). Second, it is also possible that remembering multiple target locations involves a division of resources that results in two less precise working memory representations compared to one more stable representation (Sprague et al., 2014). If the findings of Experiment 1 were driven by degraded memory representations in the equal cue condition, then there should be a similar decline in performance in the equal

cue condition when the abrupt onset coincides with the location of a target worth no value during the retention period in Experiment 2. However, this was not the case, as performance was similar for equal and different cue conditions when the abrupt onset appeared in an uninformative location, suggesting that the pattern of evidence is not consistent with the degradation of spatial memory representations.

The goal of Experiment 2 was to investigate the influence of abrupt onsets on value related information already encoded into working memory. Interestingly, the effects of cue type, abrupt onset location, and abrupt onset timing observed in Experiment 1 did not extend to Experiment 2. Instead, when the abrupt onset occurred during the retention period, its location and time of onset had no influence on performance. However, when subjects' working memory capacity is considered, abrupt onsets presented in the location of a high value target improved performance for those with low working memory capacity. In effect, it appears as though the abrupt onsets may provide a 'cue' for low-capacity individuals. In line with previous work, the abrupt onset could facilitate performance by inadvertently refreshing attention to the highly valuable target location (Atkinson et al., 2022). Previous research has demonstrated that spatial attention during maintenance contributes to the improved recall of information at that location, highlighting the importance of spatial rehearsal during retention (Awh et al., 1998). These results are also consistent with evidence suggesting that when instructional cues are used to elicit spatial rehearsal, less valuable items are recalled with the same level of accuracy as highly valuable items (Atkinson et al., 2022). It is plausible that those with low working memory capacity lack the attentional control necessary to rehearse prioritized locations, which could explain why the abrupt onset only facilitated performance for these individuals (Adam et al., 2015; Adam et al., 2018). From previous work, we know

that individuals with low working memory capacity have difficulty filtering out irrelevant information (Vogel et al., 2005). Additionally, while low and high-capacity individuals are similarly captured by salient distractors, low-capacity individuals have substantial difficulty suppressing these distractors following capture (Gaspar et al., 2016). When the abrupt onset is placed on a target location in the present study, failure to suppress this abrupt onset location could partially explain the enhanced performance in this condition for low-capacity individuals. Additionally, it has been shown that when several items are associated with graded priority, high priority items are most susceptible to interference from distraction, however, when low priority information can be discarded, this vulnerability is protected. This highlights an added potential explanation for increased performance in the different cue as opposed to equal cue condition for low-capacity individuals, with the abrupt onset in the high priority location promoting the removal of low priority information (Lorenc et al., 2021).

Overall, our results are consistent with the notion that abrupt onsets influence value related information processing differentially prior to encoding and during retention. Although the performance impairment observed in Experiment 1 is in line with a divided attention account rather than a degraded spatial memory representation account, we did not measure individual differences related to working memory capacity, and thus we cannot completely rule this out as a potential explanation. When incorporating working memory capacity in Experiment 2, we observed a surprising finding that not only provides evidence for previous accounts of priority control during maintenance (Atkinson et al., 2022) but may also help explain how these strategies differ amongst individuals. Given that those with low working memory capacity appear to benefit from spatial rehearsal, there could be deficits in these individuals related to cognitive control that are also associated with the allocation of attention

(Bleckley et al., 2003; Kane & Engle, 2003; Vogel et al., 2005). It is important to highlight the unique task designs and reward structures between our two experiments and their potential to limit the generalizability of our findings. Changing the reward earned from points to monetary value in Experiment 2 was done simply to enhance the size of the experimental effect via increasing the motivational effect of reward and subsequent motivation to prioritize value related information. It is unlikely this modification would fundamentally change our results as previous research has shown that both points and monetary value are capable of enhancing attentional control (Shen & Chun, 2011; Walsh et al., 2021). Therefore, we believe monetary value may have only strengthened the priority structure in Experiment 2 (Hübner & Schlösser, 2010). Additionally, the memoranda were changed from letters in Experiment 1 to orientations in Experiment 2. Using orientations allowed for a continuous measure of individual responses (i.e., recall error) as opposed to the binary outcome variable in Experiment 1 (i.e., correct or incorrect). While we recognize that changing these two factors introduces a potential confound, we felt that the potential gain from enhancing the value-driven effect with reward and using a continuous response was necessary. Future research should consider utilizing the same exact stimuli in both experiments to more tightly control for the influence of abrupt onsets during preparatory encoding and maintenance of the same type of valuable information.

Concluding Remarks

Previous work indicates that there is diminished capture by abrupt onsets in the presence of explicit goals. Here we investigated whether motivational salience related to value can protect one from the distracting effects of abrupt onsets. We found that task-irrelevant abrupt onsets influence value related information processing differently during preparatory encoding and maintenance. Abrupt onsets were most disruptive when presented just prior to

the target display and when attention was allocated to multiple valuable target locations. We also found that when one item was more valuable than another, abrupt onsets presented in the more valuable location increased performance for those with low working memory capacity. These findings not only contribute to our current understanding of stimulus- and goal-driven attention but also provide clarification as to how these two distinct properties of attention interact during two critical stages of information processing.

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V. Conclusion

The attentional system allows us to navigate a visually cluttered world, prioritizing the most relevant information in our visual field to facilitate goal-directed behavior. This selective process establishes, maintains, and protects relevant information across both space and time, fluctuating as a function of our current goals, prior experiences, and the physical characteristics of incoming information (Carrasco, 2011; Corbetta & Shulman, 2002; Desimone & Duncan, 1995). Though it is widely known that attention is limited both spatially and temporally, most empirical investigations on attentional priority are conducted in the spatial domain. Chapters two and three directly address this limitation by measuring the independent effects of previously learned and physical salient stimuli on temporal attention. Chapter four explores the tension between goal-driven and stimulus-driven priority at various points along the information processing stream, contributing to the vast corpus of literature on selective spatial attention. Surprisingly, few studies have compared how stimulus-driven interference affects value-directed attention from initial encoding to active maintenance.

In chapter two, priority signals improved performance when associated with targets, but had no such influence on performance when associated with distractors. These findings suggest that the influence of priority is modulated by task-relevance. This is consistent with research demonstrating enhanced cortical activity for prioritized targets relative to distractors within regions known to contribute to spatial priority maps (Conroy et al., 2023). In addition, history-driven priority markedly improved the consolidation of target information as a function of time. Though prior investigations assert a lingering bias of attention toward previously selected information, this assumption is evidenced by the sustained influence of previous information across experimental blocks as well as across entire experiments conducted over

the span of several months (Anderson & Yantis, 2013). Building upon these findings, the present chapter proposes that the protracted influence of history-driven priority can also be observed at the trial level.

Chapter three yielded insights into the neural consequences of priority-driven distraction. Although the preceding chapter failed to observe a behavioral influence of priority on distraction, the literature offers conflicting accounts regarding the temporal influence of distractor processing in RSVP tasks (Folk et al., 2008; Lagroix et al., 2016; Nieuwenstein, 2006; Nieuwenstein et al., 2005; Visser et al., 2004). These findings have informed several hypotheses related to the time course of attentional engagement, diverging in whether physical salience and selection history accelerate or delay detection and consolidation. The latency corresponding to the neural index of consolidation (Donchin & Coles, 1988) revealed that the temporal consequences produced by physically salient and history-driven distraction are present during constrained attention. Previously encountered features involuntarily capture attention and demand attentional resources to evaluate their primed features against short-term memory representations (Maljkovic & Nakayama, 2000). As a result, this evaluation delays the consolidation of subsequent information. However, this process appears to resolve relatively quickly; no longer impacting the consolidation of information presented after 500 ms. Physically salient distractors similarly delayed the consolidation of target information when presented in close temporal proximity to the target. Although resource depletion accounts predict that this delay in target processing is a consequence of the attentional capture afforded by physically salient and task-irrelevant distractors, this explanation cannot account for the overall delay observed across both neutral and experimental (salient) distractors for those in the physical salience condition compared to those in the selection history condition. Instead,

we propose the underlying mechanisms responsible for this pattern of results are more related to an attentional gating account of temporal attention. Within this framework, attention is enhanced for relevant information, including previously encountered stimuli, and inhibited for irrelevant information. Given that the physically salient condition always presented an irrelevant distractor, regardless of whether it was physically salient or not, individuals in this condition may have inhibited attention immediately following the first target to prevent the encoding of the subsequent irrelevant distractors. When the attentional gate is open, visual input is processed, and thus the target following a distractor associated with previous stimuli will benefit from an enhancement. However, when the attentional gate is closed, visual input must wait for the sluggish attentional gate to reopen following inhibition. As a result, the consolidation of target information following task-irrelevant distractors is significantly delayed. Taken together, the costs associated with these distractors is only observed when attention is temporally constrained, and the mechanisms by which these distractors delay target consolidation is dependent upon their physical properties as well as the conditions specific to the present task.

Our results from chapter four highlight the deleterious effects of abrupt onsets on divided attention. Though orienting attention to multiple value-related spatial locations in the presence of a physically salient distractor impeded performance, it is unclear whether this is due to an inability to filter out irrelevant locations under diffuse attention (Ruthruff & Gaspelin, 2018), or if distractor interference is the byproduct of degraded representations caused by a division of attentional resources (Sprague et al., 2014). In addition, salient abrupt onsets were most disruptive when presented just prior to the target display. This decrement in behavior can be attributed to the difficulty in rapidly disengaging attention once captured by abrupt onsets

(Cashdollar et al., 2013); an earlier presentation of the distracting stimulus provided ample time to reorient attention to target information. Furthermore, the negative impact of salient abrupt onsets on the encoding of information was not observed during the maintenance of value-related information. Instead, salient abrupt onsets facilitated performance for individuals with low working memory capacity; cueing the location of target information and resulting in refreshed spatial attention as well as improved recall (Atkinson et al., 2022).

The temporal and spatial profiles of attentional priority are nuanced and vary across individuals and contexts. The present body of work was conducted to better understand the global cognitive architecture of attentional priority. The influence of history-driven priority is exceptionally strong, influencing both target and distractor processing. There is a prolonged facilitative effect for targets associated with selection history; however, when these features are applied to distractors, there are significant capture-related costs when attention is limited temporally. Importantly, these effects are not always observed through behavior, emphasizing the advantage of incorporating neural measurements alongside behavioral outcomes. Finally, the competition between goal-driven attention and stimulus-driven distraction differs across the information processing hierarchy. Potent visual distractors are particularly disruptive during attentional orienting; however, their influence on the maintenance of goal-related information is dependent upon individual differences in cognitive control.