Title

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Publication Date

2023

Peer reviewed|Thesis/dissertation

UNIVERSITY OF CALIFORNIA

Santa Barbara

The generalizability of value-driven attention capture across time, attentional domains, and environments

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

by

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March 2023

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Kim, Y. J., Kumaran, R., Sayyad, E., Milner, A., Bullock, T., Giesbrecht, B., & Höllerer, T. (2022). Investigating Search Among Physical and Virtual Objects Under Different Lighting Conditions. *IEEE Transactions on Visualization and Computer Graphics*, *28*(11), 3788-3798.

Segaert, K., Lucas, S. J., Burley, C. V., Segaert, P., Milner, A. E., Ryan, M., & Wheeldon, L., (2018). Higher physical fitness levels are associated with less language decline in healthy ageing, Scientific reports, 8.

CONFERENCE PRESENTATIONS

Milner, A., & Giesbrecht, B. (2022). Persistent impact of rewarded visual features on sustained attention. Poster presented at Vision Science Society.

Milner, A. E. & Giesbrecht, B. (2021). Irrelevant rewarded visual features impact sustained non-spatial attention. Poster presented at Object Perception, Attention, and Memory (OPAM)

Milner, A. E., MacLean, M. H., & Giesbrecht, B. (2019) Frequency of exposure and target salient affect extinction of value-driven attention capture. Poster presented at Vision Science Society, St. Pete Beach, FL.

Milner, A. E., MacLean, M. H., & Giesbrecht, B. (2017). Can value-driven attentional capture be extinguished? Poster presented at Vision Science Society, St. Pete Beach, FL.

AWARDS

Richard E. Mayer Award: author of the best second year paper in the Psychological and Brain Sciences program and UC, Santa Barbara (2018)

ABSTRACT

The generalizability of value-driven attention capture across time, attentional domains, and environments

By

Anne E Milner

Visual features previously associated with reward can automatically capture attention even when task-irrelevant, no longer rewarded and not physical salient. This phenomenon is known as value-driven attention capture (Anderson et al., 2011b). The large majority of VDAC research uses a largely homogenous task and it remains unclear whether VDAC can generalize outside of this paradigm. This work aimed to investigate the generalizability of VDAC across three different factors: time, domain, and environment. VDAC has been shown to persist for a prolonged time after learning reward associations (Anderson, 2013; Anderson et al., 2011b). However, the apparent persistence is observed within tasks that have consistent features and it is unclear which of these features are necessary to observe the persistence of this phenomenon over time. In six experiments, these task features were manipulated including the task-relevance of the reward-associated feature, absent trials where no reward associated feature is present, and a target defined by a salient shape. It was found that VDAC was only reliably observed when replicating typical design features where there is the inclusion of absent trials and the target is defined as a salient shape singleton, factors that are known to influence search (Geyer et al., 2008; Lamy & Egeth, 2003). The second aspect of generalizability that was assessed was attentional domain, VDAC is often observed in a task that requires spatial selective attention. In three Experiments, the effects of VDAC were observed during a different type of attention, sustained attention. Results showed that when the reward-associated feature remained task-relevant there was a profound effect of reward on performance, such that participants showed a benefit on rewarded relative to non-rewarded trials. However, there was no impact of the reward-associated feature when it was rendered task-irrelevant at test suggesting that VDAC may not generalize to sustained attention when not relevant to the current goals. Finally, in two experiments the generalizability of VDAC across different environments was explored. In the first experiment, it was found that reward-associations learned in the typical VDAC search paradigm influenced performance in an unrelated task one-week later indicating that VDAC can generalize even when the task requirements and attentional set differ between learning and test. In Experiment 2 the generalizability of VDAC was assessed using eye-movements while interacting with real-world objects. An effect of reward history was not found indicating varied findings with regard to the generalizability of VDAC. Although, an effect of selection history was observed suggesting that selection history may have a stronger role in the real world when initiating movements to act upon objects.

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Chapter I: Introduction

Reward has a profound impact on both attention and behavior. Visual features previously associated with reward can automatically capture attention even when no longer predictive of reward creating an enduring change in the prioritization of visual attention (Anderson et al., 2011b; Anderson & Yantis, 2013). Biases toward reward-associated stimuli can improve task performance and are thought to be adaptive allowing an organism to maximize rewards. However, when reward-associated stimuli are no longer relevant to current goals it can result in detrimental effects on behavior, causing distraction and impairing task performance. Specifically, it has been extensively demonstrated that when a previously rewarded feature is presented as a distractor at a task-irrelevant location attention is biased towards that location, leading to increased reaction times and decreased accuracy to respond to targets (Anderson et al., 2011b; Anderson & Halpern, 2017; Anderson & Yantis, 2013; Failing & Theeuwes, 2014; MacLean et al., 2016; MacLean & Giesbrecht, 2015a, 2015b). This phenomenon has been referred to as value-driven attention capture (Anderson et al., 2011b). Considering the scope of the VDAC literature and the importance of reward-related biases in our environment there is little evidence that VDAC generalizes beyond the paradigms used in these experiments. The goal of the experiments reported here is to test three aspects of generalizability: time, domain, and environment.

VDAC has been shown to persist for several days to several months after learning the original reward association even without additional training (Anderson, 2013; Anderson et al., 2011b). However, the apparent persistence is observed within tasks that have very specific and consistent features and it is unclear which of these features are necessary or sufficient for the persistence of this phenomenon. To address this issue, chapter two presents a series of six experiments to examine the effects of typical VDAC task features on persistent VDAC. It remains unclear whether VDAC will continue to persist with repeated exposure in the absence of reinforcement and whether these persistent effects can be modulated by the demands of the specific task used[1].

VDAC has primarily been observed in spatial selective attention tasks where participants must search for a target among distractor items (Anderson, 2013; Anderson et al., 2011b). However, there is limited evidence on whether reward-associated feature can affect sustained attention where spatial shifts of attention are not required. To address this issue, chapter three presents a series of three experiments that tested whether VDAC would impact sustained attention.

VDAC has primarily been demonstrated through a set of largely homogenous tasks. There is limited evidence of whether VDAC can generalize both beyond both the typical paradigm but also into our natural environments. In chapter four, two experiments are presented that investigate the generalizability across learning and testing contexts. The first experiment examined if reward-associations learned in one task would transfer to another. The second investigated if VDAC can be observed in a naturalistic environment when interacting with objects in our environment.

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[1] These data have now been published: Milner, A. E., MacLean, M. H., & Giesbrecht, B. (2023). The persistence of value-driven attention capture is task-dependent. *Attention, Perception, & Psychophysics*. https://doi.org/10.3758/s13414-022-02621-0

Chapter II: Generalizability across time

Introduction

Selective attention is a key mechanism by which the processing of information sampled from the environment is prioritized. Models of visual attention commonly categorize the priority control scheme as either being top-down or bottom-up in nature. In this classic categorization of attentional control, top-down attention prioritizes information that is relevant to one's behavioral goals, often via explicit knowledge, whereas bottom-up attention prioritizes physically salient or unexpected information (Corbetta & Shulman, 2002; Desimone & Duncan, 1995; Egeth & Yantis, 1997; Itti & Koch, 2000; Posner & Petersen, 1990). However, there is evidence that information processing priority is not only controlled by goals and salience, but also by factors acquired via experience that are not readily accounted for by the classic top-down/bottom-up framework (Anderson et al., 2011a, 2011b; Awh et al., 2012; Chun & Jiang, 1998; Giesbrecht et al., 2013; Kasper et al., 2015; Kristjánsson & Campana, 2010). One such factor is reward history, whereby previously selected features predictive of reward magnitude and/or probability of reward bias attention, even when the features are irrelevant, not physically salient, and, importantly, *no longer predictive of reward* (Anderson et al., 2011a; Anderson & Halpern, 2017; Anderson & Yantis, 2013; Failing & Theeuwes, 2014; Hickey et al., 2010; MacLean et al., 2016; MacLean & Giesbrecht, 2015a, 2015b). During visual search, task-irrelevant features such as color (Anderson et al., 2011b; MacLean & Giesbrecht, 2015a), orientation (Laurent et al., 2015), and spatial location (Chelazzi et al., 2014; Cho & Cho, 2020; Liao & Anderson, 2020a; Sisk et al., 2019) can guide visual attention when previously associated with reward. Typically, in these tasks, participants learn a reward association when one type of target feature (e.g., one of two target colors) predicts a high magnitude reward and the other a low magnitude reward. The associations result in faster reaction times and greater accuracy for identifying the target associated with the higher magnitude reward than that associated with the lower magnitude of reward or no reward (Anderson et al., 2011a; Hickey et al., 2010a; MacLean et al., 2016; MacLean & Giesbrecht, 2015a, 2015b; Stankevich & Geng, 2014). However, reward associations can be distracting when they are no longer relevant to current task goals, capturing attention and impairing performance. When a previously reward-associated target feature is presented as a distractor feature in a subsequent test phase, target identification is slower and less accurate than when the reward-associated color is absent (e.g., Anderson et al., 2011a, 2011b; MacLean et al., 2016; MacLean & Giesbrecht, 2015b). Thus, attention continues to be biased in favor of previously reward-associated features even when irrelevant and no longer predictive of reward, a phenomenon referred to as *value-driven attention(al) capture* (VDAC).

VDAC has been observed several days after reward learning in the absence of reinforcement and can resist extinction of the reward-related bias even over the course of several hundred trials (Anderson et al., 2011a; Della Libera & Chelazzi, 2009; Stankevich & Geng, 2014). Furthermore, VDAC has been shown to persist for as long as 9 months after learning the original association without any additional reinforcement (Anderson & Yantis, 2013). In the absence of reinforcement, it is expected that a previously conditioned response to a reward-predictive stimulus would cease (e.g., Pavlov, 1927), and yet, when VDAC is reported, there is often no significant reduction in the impairment over the course of test (Anderson et al., 2011b; Anderson & Yantis, 2012, 2013; Bucker et al., 2015; Failing & Theeuwes, 2014; Rothkirch et al., 2013; Sali et al., 2014; Sha & Jiang, 2016; Stankevich & Geng, 2014; Theeuwes & Belopolsky, 2012), although occasionally such an effect has been observed (Anderson et al., 2011b, 2016; Asutay & Västfjäll, 2016a; Sali et al., 2018). These findings suggest that reward learning creates an unusually persistent change in attentional priority that is biased in favor of formerly reward associated features even when no longer predictive of reward. Moreover, this change in priority is highly resistant to extinction, similar to the persistent effects of spatial probabilities on attention (Geng et al., 2013; Jiang, Swallow, & Rosenbaum, 2013; Jiang, Swallow, Rosenbaum, et al., 2013).

The current investigation is focused on the unusual persistence of VDAC. In five experiments we investigated which task parameters affected the persistence or resistance to extinction of VDAC in the absence of reinforcement. In typical VDAC experiments reward is obtained by successfully selecting a target that is associated with reward during the learning phase. Prioritized selection during the test phase, where reward is no longer available, is due to an instrumentally conditioned response whereby habitual orienting is transferred from the learning phase to the test phase (Failing & Theeuwes, 2017). However, subsequent research has shown that VDAC is also observed via Pavlovian conditioning where no instrumental selection response is made (Bucker & Theeuwes, 2017). It remains unclear whether persistence of VDAC continues to be observed after classical conditioning or whether persistence is unique to instrumental reward learning. It is plausible that the persistence observed in many VDAC studies is amplified by the instrumental nature of the reward-associations in comparison to reward associations that are learned via classic Pavlovian conditioning. In particular, it has been demonstrated that an instrumental response alone, such as selecting a stimulus feature, can lead to prioritization of that feature, even when not associated with a reward. This phenomenon is known as *selection-driven attention capture* (SDAC; Brascamp et al., 2011; Eimer et al., 2010; M. Failing & Theeuwes, 2017; Kristjánsson & Campana, 2010). There is evidence that the mechanisms underlying reward and such selection-driven capture are dissociable (H. Kim & Anderson, 2019). However, the persistence of VDAC and SDAC were not addressed in this study so it remains unclear if persistent VDAC could be more vulnerable to extinction when learning occurs in the absence of an instrumental response.

VDAC has been replicated many times, by multiple different labs, and has even generalized across cognitive paradigms (Anderson & Yantis, 2012a; Mine & Saiki, 2015). The design features of the paradigms used to induce and observe VDAC are, however, quite consistent. Specifically, the primary paradigm used to learn the reward-feature association is a visual search task containing a physically non-salient target, defined by the reward-associated feature, which is typically color. Subsequently, during the test phase (when extinction may be observed) the same visual search task is repeated but with a physically salient target feature in a different dimension than the reward-associated feature, usually a shape singleton. The presence of the now task-irrelevant reward-associated feature is then probabilistic, usually $p = 0.5$ (Anderson et al., 2011a, 2011b; Anderson & Yantis, 2013). That homogeneity could provide both insights and limits on our understanding of VDAC, as it both facilitates the integration of evidence from different experiments but also provides little variability for assessing the boundary conditions of VDAC.

The current study was not intended to be an exhaustive catalogue of the boundaries of VDAC, its persistence, or extinction. Instead, the goal of the current study was to address the implications of typical design features of VDAC paradigms; where the relevance of the reward-associated feature, the use of salient targets, and the inclusion of absent trials are not widely discussed as having any consequence for the persistence of VDAC. Our results suggest that, indeed, such choices are not benign, particularly that of a physically salient target at test. This is important as the generalizability of VDAC effects, in the context of the present results, appears limited. Given the overwhelming homogeneity of these key features of VDAC paradigms in the published literature this issue is not trivial (see Table 1).

Table 1. Non-exhaustive list of VDAC literature using paradigms with the key features of the test paradigms investigated in the current study. Excluded were studies where rewards were still available at test (e.g., Bucker et al., 2015; Munneke et al., 2015), and studies showing trial-to-trial effects of reward (Hickey et al., 2010a, 2010b, 2011). The former was excluded as the presence of rewards at test makes it unclear whether extinction learning is taking place, and the latter as trial- to-trial effects may be at least in part due to priming. It is possible that this priming is operating in the same way as VDAC resulting from extensive conditioning, but we could find no evidence that this was the case.

Article	**Irrelevant reward-associated feature**	**Physically salient target feature**	**Absent trials included**
Anderson et al., 2011a	+	+	+
Anderson et al., 2011b	+	+	+
Anderson & Yantis, 2012	+	+	+
Anderson & Yantis, 2013	+	+	+
Bucker & Theeuwes, 2017	+	+	+
Della Libera & Chelazzi, 2009	+	-	-
Failing & Theeuwes, 2014	+	-	+
Jahfari & Theeuwes, 2017	+	+	+
Le Pelley et al., 2015	+	+	+
MacLean et al., 2016	+	-	+
MacLean & Giesbrecht, 2015a	+	-	+
Mine & Saiki, 2015	+	+	+
Qi et al., 2013)	+	+	+
Rajsic et al., 2017	+	+	+
Roper et al., 2014	+	+	+
Rutherford et al., 2010	+	+	+
Sali et al., 2014	+	+	+
Sali et al., 2018	+	+	+
Stankevich & Geng, 2015	+	+	-
Theeuwes & Belopolsky, 2012	+	+	+
Wang et al., 2015	+	+	-
Wang et al., 2013	+	+	+

In the present work, the task relevance of the reward-associated feature was manipulated, such that it was task-relevant at test in Experiment 1 and task-irrelevant in Experiments 2-5. The task-relevance of the reward-associated feature could play a role in the persistence of VDAC. Attention is a key component of successful learning (Jiang & Chun, 2001; Khadjooi et al., 2011) and whether a reward associated feature is to be attended (task relevant) or ignored (task irrelevant and distracting) could influence both the acquisition and persistence of the learned associations and their effects on attention capture.

The role of a physically salient target during test was also examined. Physically salient features, such as color singletons, have a robust, involuntary effect on priority (Egeth & Yantis, 1997; Folk et al., 1992; Itti et al., 1998). Shape singletons are widely used to define targets when observing VDAC during test by formerly reward-associated features that are either physically salient (Hickey et al., 2010b) or not (Anderson et al., 2011a, 2011b; Anderson & Yantis, 2013). Consequently, it is unclear whether the persistence of VDAC may be dependent on the presence of a physically salient target. Thus, in Experiments 2 and 4, the reward-associated feature was irrelevant, and the target was not a salient singleton, but rather defined by a specific color, just like the reward-associated feature. In contrast, the target was defined as a physically salient shape singleton in Experiments 3 and 5. Finally, the role of the frequency of exposure to the reward associated feature during test was investigated. Typically, in order to initiate VDAC, the reward-associated features appear more reliably and/or more frequently during learning than during test (Anderson et al., 2011a, 2011b; Anderson & Yantis, 2013). It is possible this asymmetry in exposure results not only in an asymmetry in learning, but also in the ability to ignore irrelevant, distracting features. In Experiments 4 and 5 absent trials where neither the previously rewarded or non-rewarded features were presented as distractors were included to assess the asymmetry in exposure between learning and test. We did not intend to manipulate these features within a single experiment but aimed to test whether a combination of task features resulted in the observation of VDAC or not and if observed was extinction also observed. See Table 2 for a summary of manipulated task features across Experiments.

Table 2. Summary of manipulated task features in Experiments 1-5.

Experiment	Irrelevant reward-associated feature	Physically salient target feature	Absent trials included
Experiment 1	-	-	-
Experiment 2	+	-	-
Experiment 3	+	+	-
Experiment 4	+	-	+
Experiment 5	+	+	+

Experiment 1

The main purpose of this experiment was to observe the effect of a reward-associated feature in a paradigm stripped of the stereotypical features present when persistent VDAC is observed. Specifically, the formerly reward-associated color remained task-relevant during test, just as it was during learning, and without the physically salient target and absent trials typical of many VDAC paradigms. When the reward-associated feature appears on a distractor during test (Anderson et al., 2011a, 2011b; Anderson & Yantis, 2013), such as a feature of a stimulus that is to be *ignored*, it is possible that the intention to ignore the stimulus with the reward-associated feature impairs the acquisition of the new association during test and thus the effect of the reward-associated feature persists. It is also possible that when the reward-associated feature remains task relevant, the resolution of the conflict between the original and the new association (extinction) at test is impaired in favor of the original association, in which case reward-related effects may be more likely to extinguish when task irrelevant. In Experiment 1 the feature associated with reward continued to be task relevant. We note that because the reward-associated feature continued to be goal-relevant during the test phase that any reward related effects do not necessarily reflect attention capture because these features would continue to be prioritized in a goal-directed manner, even though reward associations were no longer reinforced.

During the learning phase, participants identified the orientation of a line segment within either a red or blue target ring, one of which was reliably followed by the receipt of a reward and the other was not. We anticipated that participants would acquire the original reward-associations during the learning phase, such that reward-associated features would be given greater priority, thus we expected to observe better performance when responding to targets with reward-associated features (faster reaction times) compared to those with features not associated with reward. During the test phase of Experiment 1, participants continued to respond to the red and blue targets and, as such, the reward-associated feature was task relevant, i.e., was to be attended. We expected that a previously reward-associated color would continue to be prioritized in visual attention compared to the non-reward associated feature. Therefore, in the case of Experiment 1, we expected faster reaction times (RTs) for discriminating targets with a reward-associated feature compared to discriminating targets that did not.

Method

Participants

Participants were 27 undergraduate students (17 female, M_{age} = 19.30 years, SD_{age} = 1.41) recruited from the Psychological and Brain Sciences research participation pool at the University of California, Santa Barbara. Seven participants were excluded from the analyses because their accuracy during either learning or test was below chance thereby resulting in a final sample of 20 participants (11 female, M_{age} = 19.35 years, SD_{age} = 1.57). For all experiments, participants received course credit for their participation and monetary compensation based on performance in the learning phase (payout schedule described below). All participants reported normal or corrected-to-normal vision. All participants provided informed consent, and all procedures were approved by the University of California Santa Barbara Human Subjects Committee and the Army Research Office/Human Research Protection Office.

Apparatus and stimuli

All experiments were run using MATLAB R2013a and PsychToolbox, Version 3(Kleiner et al., 2007) installed on a Mac Mini and presented on a CRT monitor (36 × 27cm) viewed at a distance of 110 cm. Stimuli in the learning and test phases were presented on a black [0, 0, 0] background. Stimuli used in the learning and test phases were six different colored rings (2.3° in diameter), centered and equally spaced on the circumference of an imaginary circle with a radius of 5° visual angle (three rings in each hemifield to the left and right of fixation). The possible colors of the rings were red [RGB: 233, 0, 0], blue [17, 103, 241], orange [186, 93, 16], teal [22, 128, 109], brown [140, 111, 78], green [63, 129, 45], gold [146, 111, 16], violet [169, 60, 203], pink [199, 40, 154], mauve [166, 97, 100], moss [122, 122, 0], and gray [115, 115, 115]. Targets were defined as being red and blue rings, only one of which was presented per trial. A white [255, 255, 255] line segment was presented inside each of the colored rings and the orientations were tilted (45° to the left or right), horizontal or vertical.

Procedure

Participants attended two experimental sessions separated by exactly 1 week. In the initial session participants first completed a demographic questionnaire and the behavioral inhibition system (BIS) and behavioral activation system (BAS) scales (Carver & White, 1994). Participants then performed a change detection task designed to measure visual working memory capacity. Finally, participants completed the learning phase of the visual search task. In the second session participants completed the test phase of the visual search task.

Visual search: Learning

Each trial consisted of a fixation display, a stimulus display and a feedback display. A trial began with a white fixation circle (.5° in diameter) presented in the center of the display. The duration of the fixation circle was 500, 600, 700, or 800 ms and was randomly determined on each trial. The stimulus display followed the fixation circle and consisted of a target ring (either red or blue) and five distractor rings, the colors of which were randomly drawn without replacement from the color list above (see Fig. 1a). The line segments within the distractors were orientated 45° to the left or to the right. Within the target ring the line orientation was horizontal on half the trials and vertical on the other half (distributed equally within red and blue target trials). Participants were instructed to press “Z” on a standard QWERTY keyboard if the line orientation within the target was vertical and “M” if it was horizontal, using their left and right index fingers respectively. The stimulus display was presented for 800 ms or until a response was made. Once a response was made, the feedback display was presented for 1,500 ms, which indicated the amount of money the participant had won on that trial and the total amount accrued over the course of the experiment. Participants only received a reward when a correct response was made, although this was not made explicit to the participants. The color of the target (red or blue) that predicted a reward was counterbalanced across participants. On rewarded trials participants could win $0.05 and 80% of these trials had the potential to be rewarded (if a correct response was made). On non-rewarded trials there was no possibility of reward, regardless of accuracy.

The learning phase consisted of 20 practice trials that were not rewarded, followed by ten blocks each with 80 trials, resulting in 400 potentially rewarded and 400 non-rewarded trials. Participants were informed that they had the chance to win money on each trial and that they would be paid the total amount accrued over the course of the experiment at the end of the session. Participants could win a maximum of $16 in the learning phase and on average participants were paid $13.90. Accuracy was measured as the number of correct responses to the line orientation within targets and reaction time was measured relative to the onset of the stimulus display on correct trials.

Visual search: Test

The stimuli and procedure were identical to the learning phase, participants continued to respond to the line orientation within the red and blue targets. However, during the test phase participants were no longer rewarded and once a response was made, instead of the 1,500 ms feedback screen, the display was blank (see Fig. 1b). There were two conditions during test: (1) “rewarded” trials, where the target color was previously associated with reward, and (2) “non-rewarded” trials, where the target color was not previously associated with reward during the learning phase, both trials contain a former target color. The test phase began with 20 practice trials, followed by 20 blocks of 80 trials, yielding 800 rewarded and 800 non-rewarded trials.

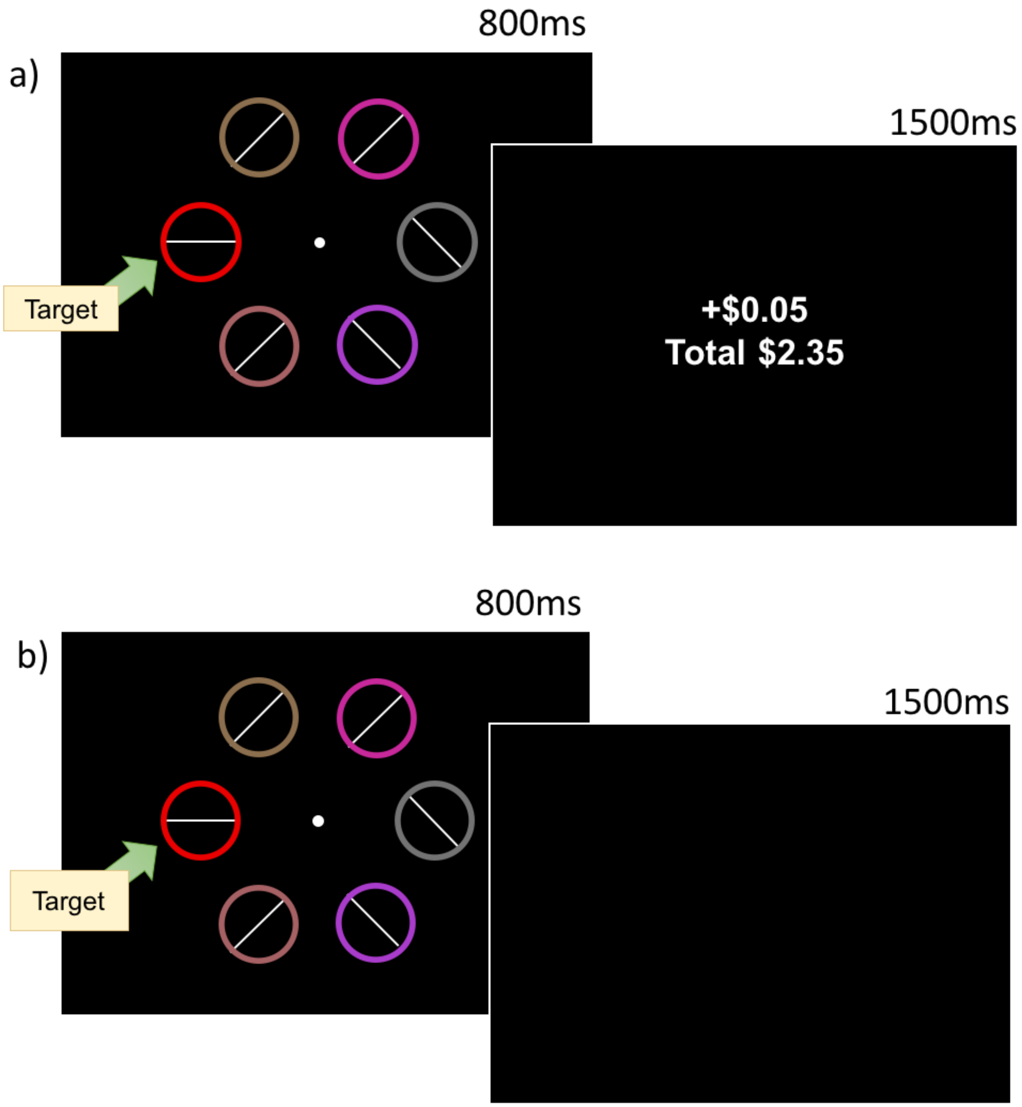

Figure 1. a) Learning task (800 trials): targets were either red or blue rings and only one target color was presented per trial. Inside target rings were either a horizontal or vertical line. When the line was vertical participants responded by pressing ‘z’ and when horizontal ‘m’. One of the target colors was rewarded ($0.05) if participants responded accurately while the color target color was not rewarded. b) Test task (1600 trials) same task but no longer an opportunity to win rewards. The feedback display which followed the stimulus display was blank.

BIS/BAS

The behavioral inhibition system (BIS) is thought to regulate aversive motives to move away from something unpleasant. Whereas the behavioral approach system (BAS) regulates appetitive motives to orient towards things that are desirable. The BAS scale has three sub-components: (1) drive, (2) fun-seeking, and (3) reward responsiveness. Previous evidence has demonstrated that there is an association between the BAS drive component and the effect that a high magnitude reward has on attention (Hickey et al., 2010a, 2010b).

Change-detection task

Previous evidence has shown that individual differences in visual working memory (VWM) capacity is associated with VDAC (Anderson et al., 2011b) such that those with greater capacity working memory capacities demonstrate less value-driven attention capture. Although not necessary to observe either the presence, or extinction of VDAC we attempted to replicate this correlation, and if present, examine whether it also affects the persistence and/or extinction of the effect. We measured each participant's VWM capacity using a change detection task (Luck & Vogel, 1997). Participants were briefly presented with a display that consisted of four or six squares (each .65°) distributed throughout the visual search space in a randomly determined pattern for 100 ms. Two-thirds of the trials were set-size 6 and the other third were of set-size 4. Following this a blank delay screen was presented for 900 ms and then another display appeared that contained only one square that occupied the same location of a square that had previously been presented. Participants indicated whether the color of the square in that location had remained the same or had changed by making an unspeeded key press (“Z” and “M,” respectively). Visual-working memory capacity was calculated using Cowan’s formula (Cowan, 2001), which is calculated separately for each set size by multiplying set size by the difference between the hit rate and the false alarm rate (Set size*(Hit rate - False alarm rate)). A weighted average was calculated across set-sizes to get an overall estimate of working-memory capacity (K). K was not measured for one participant in Experiment 4 due to experimenter error.

Design and analysis

Reinforcement learning and VDAC were measured by comparing RT on correct trials in the presence of reward-associated search items to that in the presence of non- rewarded targets in the learning and test phases respectively – the key, and only, difference being that during the test phase these features were no longer predictive of reward (i.e., the association was no longer reinforced). Our analyses focus on RT, as this was a speeded task and accuracy was expected to be high. Trials where RTs were less than 200 ms were removed from the analyses. For both learning and test participants accuracy data was divided into bins containing 200 trials averaged over reward condition (overall accuracy). The 95% confidence interval around chance accuracy (.5) was calculated for each time bin. Participants whose accuracy fell below the upper bound of this interval in two or more bins were performing effectively at chance and removed from the analyses. This approach was used to exclude participants across all experiments, the cut-off for exclusion ranged from 52.86–56.20% across experiments.

Our definition and calculation of VDAC, specifically as a difference between reward associated former targets and a control condition that accounts for selection history effects, is shared by many others (Bucker & Theeuwes, 2017; della Libera & Chelazzi, 2009; M. F. Failing & Theeuwes, 2014; le Pelley et al., 2015; Mine & Saiki, 2015; Rajsic et al., 2017; Roper et al., 2014; Theeuwes & Belopolsky, 2012; L. Wang et al., 2013), where VDAC is indicated by a difference in performance between trials with a reward-associated former target (present) and those without (absent). This operationalization of VDAC needs to be considered when placing our results in the context of the literature. Our calculation of VDAC is designed to exclude selection-history effects by contrasting conditions with the same degree of selection history. We address selection-driven attention capture (SDAC) effects in Experiment 4.

We analyzed our data using Bayesian generalized linear mixed effects models (GLMMs) using the stan_glmer function in the R package *rstanarm* (Goodrich et al., 2018). To determine whether the data were from a standard normal distribution we used the kstest function from the statistics and machine learning toolbox in MATLAB. All data were normally distributed across experiments. Therefore, we used the default link function in stan_glmer for normally distributed data. The default priors for the stan_glmer function were used which are weakly informative. The model structure across experiments included trial and reward condition as the fixed factors and a random effects structure with an intercept of 1 and reward condition and subject. We did not use the maximal random effects structure because it did not converge, likely because the model was overparameterized due to the inclusion of trial as a random effect. Based on a model comparison comparing four models with different random effects structures using the loo_compare function, we chose the best model, which included subject and reward condition in the random effects structure. Therefore, the following model structure was used across experiments separately for learning and for test: rt ~ trial*cond + (1 + cond|subject), where rt = reaction time in ms; trial = trial order/rank; and cond = rewarded, non-rewarded, absent (Experiments 4 and 5 only); and subject = subject number.

We used two approaches to provide information about the probability of, and evidence for (or against), possible effects. First, to provide information about the range of probable parameter estimates that received some support from the observed data, we constructed Bayesian Support Intervals (SIs; Wagenmakers et al., 2020). Bayesian SIs consider the posterior distribution and the prior distribution. In the present case, a SI was computed using a support criterion of BF = 3, which provides an interval that contains parameter estimates that are supported by a moderate amount of evidence. More specifically, it means that the SI contains only those parameter estimates that increased in probability by a factor of three based on the evidence. Second, to provide information about the strength of the evidence, we computed Bayes Factors relative to a region considered equivalent to the null hypothesis (as opposed to a point null, e.g., $H_0 = 0$). The null regions (Region of Practical Equivalence, RPE) were defined by calculating the standard deviation of each parameter estimate and multiplying by ±.1, which corresponds to a small effect, which was defined as: $[-.1*SD_{RT}, .1*SD_{RT}]$ for each model, as recommended by (Kruschke & Liddell, 2018) for linear models.

The Bayesian SI can then be compared to this null region. If the estimates bounded by the SI do not overlap the null region, then the effect can be considered probable. Evidence for an effect (or in favor of the null) was determined by computing the BF relative to the null region. Specifically, the reported BFs are a ratio of the change in posterior odds and change prior odds for the parameter falling inside or outside the null region. Interpretation of the BFs follows convention (Jeffreys, 1998), such that values of 1 or less indicate more evidence that there is practically no effect relative to the evidence in favor of there being an effect. As values increase above 1, there is increasing evidence in favor of the parameter falling outside the null region relative to the evidence in favor of the parameter falling inside the null region. Using these two approaches, we determine whether the effect is probable (i.e., via the SI) and the strength of the evidence for that effect or the null (i.e., via BF). The advantage of this approach is that we are able to quantify support in either the null or the alternative hypothesis.

Results

Visual search: Learning

A generalized linear mixed effects model (GLMM) was used to examine RT on correct trials with the fixed effects of reward condition (rewarded or non-rewarded target feature) and trial order (trials 1–800; see Fig. 2) during the learning phase. An effect of trial was probable, such that RTs got faster as trial order increased (*b* = -77.60, *SI* = [-99.24, -56.19], *RPE* = ± 4.59, *BF* > 1000; see Fig. 3). The effect of reward condition was not (*b* = 14.49, *SI* = [-15.14, 33.75], *RPE* = ± 3.30). Furthermore, there was substantial evidence in support of the null for the effect of reward condition (*BF* = 0.077; see Lee & Wagenmakers, 2014, p.105 for their heuristic scheme for interpreting BF_{10}). However, the interaction between trial and reward condition was probable, where RT decreased at a faster rate for rewarded than non-rewarded targets during learning (*b* = 34.98, *SI* = [21.82, 48.53], *RPE* = ± 5.22, *BF* > 1000).

Visual search: Test

The same GLMM approach was used to examine RTs on correct trials during the test phase (see Fig. 2). During the test phase the effect of trial was not probable (*b* = -10.78, *SI* = [-23.85, 1.55], *RPE* = ± 2.33; see Fig. 3), and there was moderate evidence in support of the null (*BF* = 0.059). An effect of reward condition was probable, such that RTs to rewarded target features were faster than to non-rewarded (*b* = 25.10, *SI* = [14.25, 35.54], *RPE* = ± 1.52, *BF* = 113.80). This[2] effect indicates that the effect of reward persisted during the test phase. An interaction between trial and reward condition was probable, such that the difference in RT to rewarded and non-rewarded target features was reduced as trial order

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[2] These correlations were not replicated in any of the subsequent Experiments reported here.

increased (*b* = -11.64, *SI* = [-19.93, -3.19], *RPE* = ± 1.60, *BF* = 3.10), indicating that there was moderate evidence of a reduction in the effect of reward.

To assess whether the effect of reward continued to persist throughout the test phase, a Bayesian paired-samples t-test examining the difference between rewarded and non-rewarded trials was conducted on the final 100 trials of the test phase. There was very strong evidence of an effect of reward (*BF* = 86.04). This suggests that despite the reduction between rewarded and non-rewarded features throughout the test phase the effect of reward continued to persist.

BIS/BAS

We aimed to examine whether such individual differences in the BAS sub-scales could account for variations in the VDAC effect. Three participants were excluded from these analyses due to failure to complete the BIS/BAS questionnaire. The mean score for the BIS scale was 2.92 (*SD* = 0.50). The mean and SD for each of the BAS components were: drive (*M* = 2.97, *SD* = .57), fun seeking (*M* = 2.91, *SD* = .57), and reward responsiveness (*M* = 3.61, *SD* = .42). We correlated the BIS and the three BAS factors with VDAC (defined as the difference in response time on previously rewarded compared to previously non-rewarded features) during both learning and extinction. There was substantial evidence of a correlation between score on the BIS scale and the VDAC effect during learning (*r*(15) = .60, *BF* = 5.68) and test (*r*(15) = .54, *BF* = 3.16). Both correlations indicate that the higher a participant's score on the BIS scale the larger their VDAC effect[1].

Working memory

We correlated K (*M* = 2.90, *SD* = 1.17) and VDAC (reward vs. no reward RT). There was no evidence of a correlation (*r*(18) = .018, *BF* = 0.28). Thus, we failed to find evidence for a relationship between working memory capacity and the effect of reward on attention in Experiment 1[3].

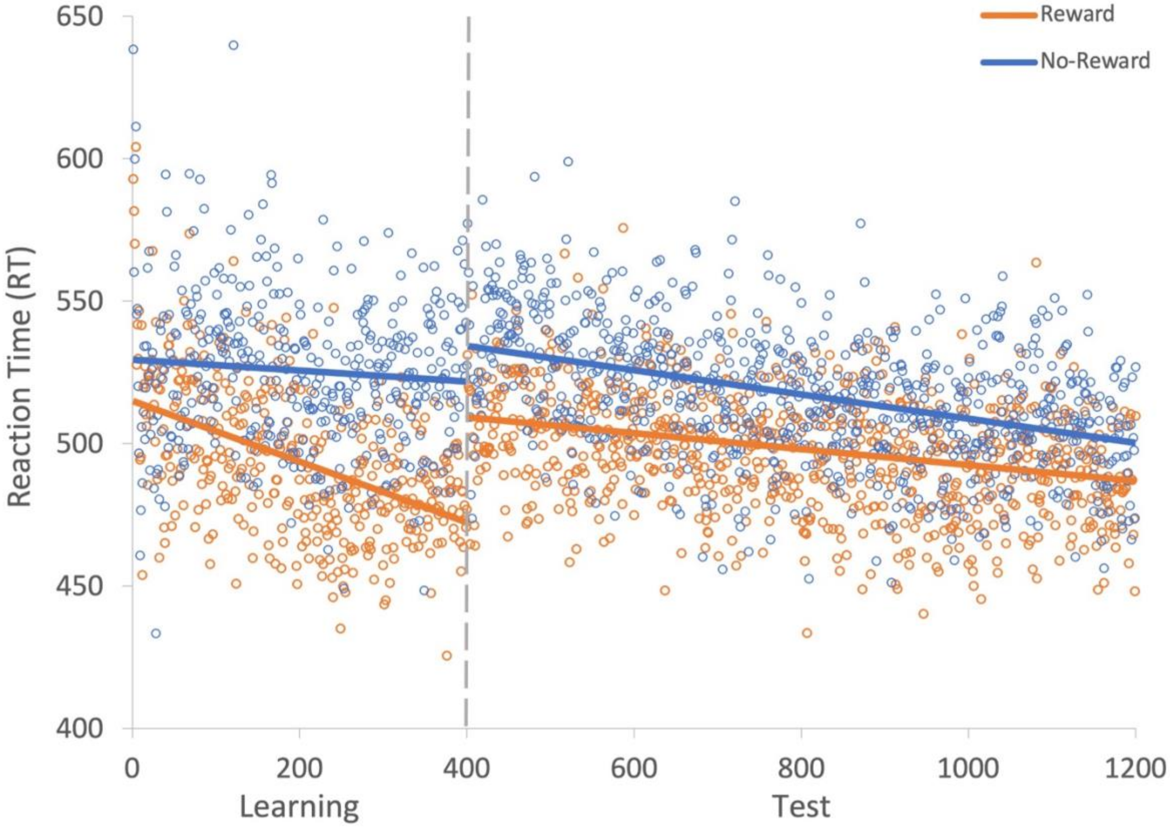

Figure 2. Results for both learning and the test phase of Experiment 1. Data points are the raw RT data averaged across participants for each trial for rewarded and non-rewarded trials separately. The regression lines are the predicted RT for rewarded and non-rewarded trials across time from the GLMM.

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[3] There was also no evidence for correlations in Experiments 2-4. However, there was anecdotal evidence of a correlation between VDAC (reward vs. no reward RT) and working memory capacity in Experiment 5 (r(33) = -.39, BF = 2.74). Thus, we failed to reliably replicate the relationship between VWM and VDAC previously observed in any of the five Experiments, despite observing VDAC. The lack of evidence for an effect may be the result of insufficient power to detect the correlation (although n = 24-26 in Anderson et al., 2011b). However, when we combined the samples across Experiments where there were equivalent conditions (the difference between reward and no-reward when on a distractor i.e. Experiments 2-5; M = 3.07, SD = 1.00), we still did not find evidence of a correlation (r(109) = -0.13, BF = 00.31). Another possibility is that our definition and calculation of VDAC differs from Anderson et al., and thus we did not replicate the effect as we did not replicate the calculation of VDAC. We define VDAC as the difference in reaction time in the presence of a reward associated distractor, and in the presence of a non-reward associated distractor. However, the correlation reported by Anderson et al. was between VWM capacity and the difference in reaction time in the presence of a high reward-associated distractor and the absence of any reward-associated distractor. When we calculated VDAC as Anderson et al., however, we still did not find sufficient evidence for a correlation (Experiment 4 and 5; r(51) = -.24, BF = 0.70).

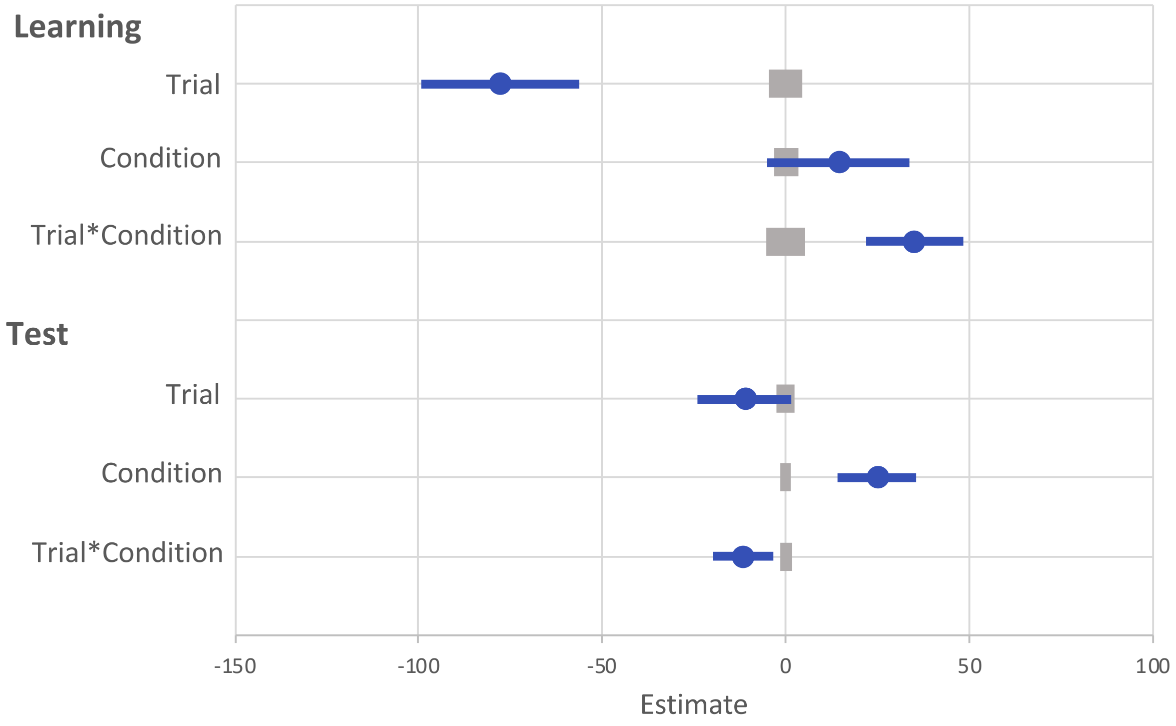

Figure 3. Mean point estimates and support intervals for each of the fixed effects from the GLMM for both learning and test in Experiment 1. Grey boxes denote the null region (RPE).

Discussion

During the learning phase of Experiment 1 there was extreme evidence that participants learned the reward association, as RTs decreased at a faster rate to rewarded than non-rewarded targets over repeated exposures. During the test phase of Experiment 1, participants continued to respond to the red and blue targets that were previously associated with either reward or the absence of reward. The feature associated with reward at learning thus remained task relevant during the test phase. We observed strong evidence for an effect of reward, as indicated by faster RTs to previously rewarded target features compared to those not previously associated with reward as has previously been observed (Hickey et al., 2010b; MacLean & Giesbrecht, 2015a). However, an interaction between reward condition and trial was probable, suggesting that while the effect of reward persisted, when the reward-associated feature remains task relevant, the effect is reduced although still persistent. These results establish a point of comparison as we introduce the stereotypical VDAC paradigm features to establish their effects on the persistence, and extinction of VDAC.

Experiment 2a

In Experiment 1 the reward-associated feature remained task relevant during test and there was evidence that VDAC persisted but was also subject to extinction. The main purpose of Experiment 2a was to examine the persistence of VDAC when the reward-associated feature was task-irrelevant, as is typical of VDAC paradigms, but again without the physically salient target feature and probabilistic reward-associated feature typical when observing VDAC during test. If VDAC persists we would expect that during the test phase the presence of a formerly reward-associated feature as a distractor would involuntarily capture attention and impair target response performance. Specifically, we expected slower RTs in the presence of a distractor with a formerly reward-associated feature compared to one with a feature not previously associated with reward.

Experiment 2 was identical to Experiment 1 except that during the test phase the colors that defined targets at learning were only ever presented as features of distractors. In this case the reward-associated feature is meant to be ignored, while different features of the same dimension (color) were meant to be attended, whereas in Experiment 1 the reward-associated feature was meant to be attended and all other colors were meant to be ignored. Not only is there a difference in whether the reward-associated feature is task relevant or irrelevant, but there is also a difference in relationship between the target defining and reward-associated features.

Method

Participants

Participants were 25 students from the University of California Santa Barbara recruited from the research participation pool (12 female, M_{age} = 20.60 years, SD_{age} = 4.39). Three participants were excluded from the analyses due to poor accuracy, resulting in a final sample of 22 participants (11 female, M_{age} = 20.68 years, SD_{age} = 4.67). On average participants were paid $14.14 upon completion of the learning phase.

Stimuli

Stimuli were the same as Experiment 1, but moss [122, 122, 0] and gold [146, 111, 16] were not included as possible ring colors due to their similarity to green [63, 129,45] and orange [186, 93, 16], which were used as additional target colors in this experiment.

Procedure

Unless mentioned below, all procedures were the same as in Experiment 1.

Visual search: Learning

The task to respond to the line orientation within the target colors remained the same as in Experiment 1. The learning phase had two different target color sets: blue/red or orange/green. The target color pairs (red/blue or green/orange) were counterbalanced across participants.

Visual search: Test

During the test phase the features that defined targets at learning (either red/blue or orange/green) were then only presented as features of distractors during test (i.e., one ring that contained a white line orientated 45° to the left or right was rendered in one of two target colors used during learning). Half of trials contained a formerly reward-associated color and the other half the color that was not formerly associated with reward. The other target color set that was not presented during learning became the new target colors during test (e.g., if a participant had red and blue targets at learning, targets at test were orange and green with red and blue circles as the critical distractors; see Fig. 4).

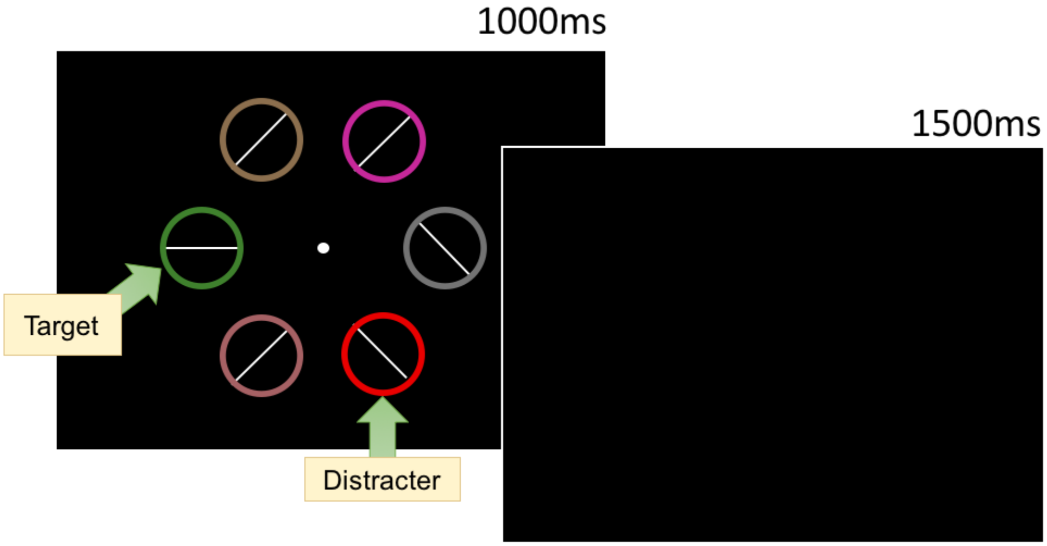

Figure 4. Extinction task (1600 trials): targets at learning become distracters at extinction and the other color set that was not presented at learning become the targets at extinction.

Results

Visual search: Learning

A GLMM was used to examine RTs on correct trials during the learning phase (see Fig. 5). The effect of trial was probable, such that RTs became faster as trial order increased (b = -127.32, SI = [-147.05, -107.39], RPE = ± 5.57, BF > 1000; see Fig. 6). The effect of reward condition was also probable such that RTs were faster to rewarded than to non-rewarded target features (b = 27.80, SI = [11.61, 43.65], RPE = ± 2.70, BF = 54.92). Furthermore, the interaction between trial and reward condition was probable such that RTs decreased at a faster rate for rewarded than non-rewarded target features, indicating that participants learned the reward associations (b = 40.85, SI = [27.85, 53.14], RPE = ± 5.53, BF > 1000).

Visual search: Test

The same GLMM was used to examine the effect of reward during the test phase. The effect of trial was not probable (*b* = -15.15, *SI* = [-29.10, -1.07], *RPE* = ± 3.85; see Fig. 6). and there was moderate evidence in support of the null (*BF* = 0.29). The effect of reward condition was not probable (*b* = -6.21, *SI* = [-15.43, 3.27], *RPE* = ± 1.34), and there was strong evidence in support of the null (*BF* = 0.043). The interaction between reward condition and trial was also not probable (*b* = -0.12, *SI* = [-8.52, 8.96], *RPE* = ± 2.37), and there was decisive evidence in support of the null (*BF* < 0.01).

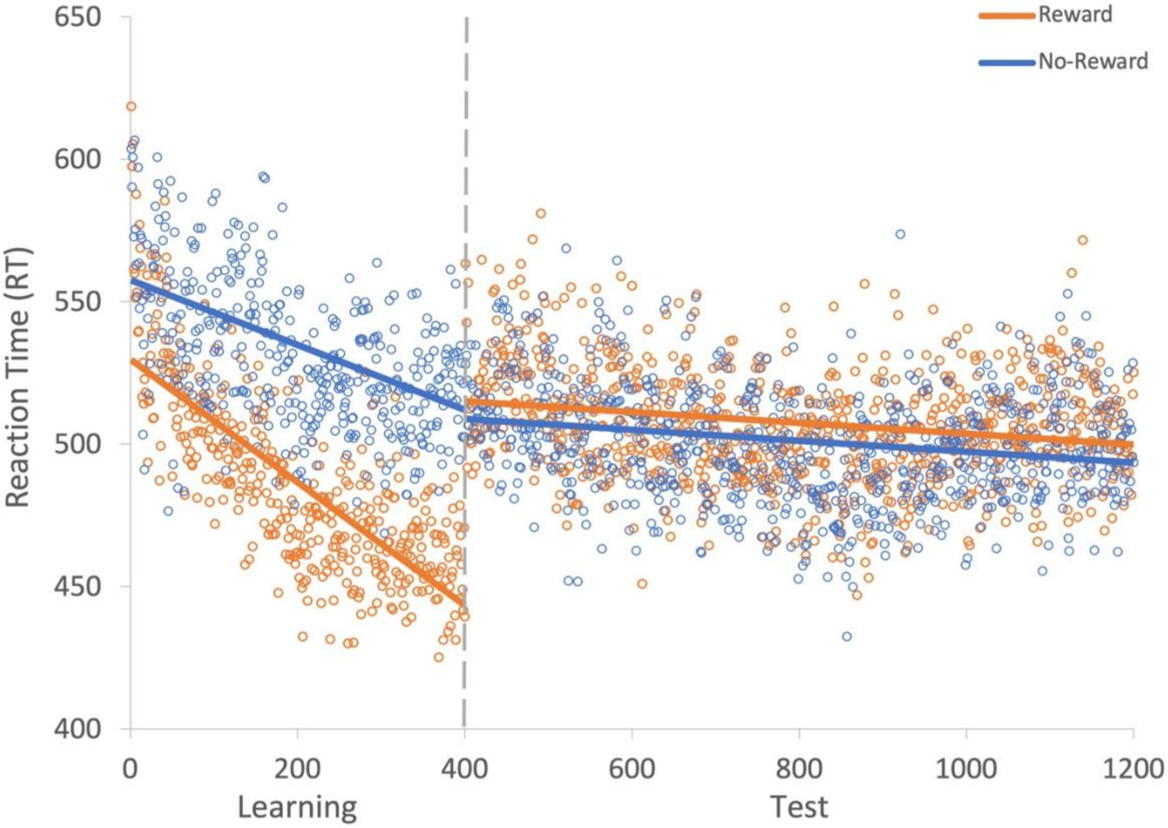

Figure 4. Results for both learning and the test phase of Experiment 2a. Data points are the raw RT data averaged across participants for each trial for rewarded and non-rewarded trials separately. The regression lines are the predicted RT for rewarded and non-rewarded trials across time from the GLMM.

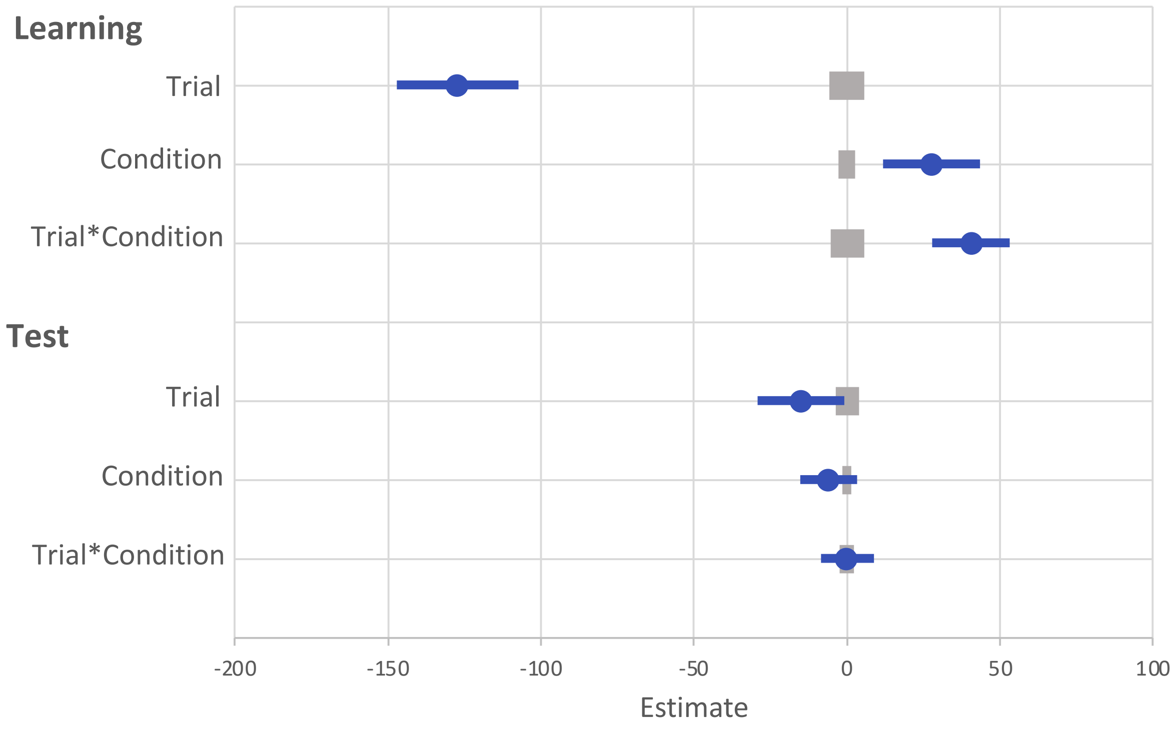

Figure 6. Mean point estimates and support intervals for each of the fixed effects from the GLMM for both learning and test in Experiment 2a. Grey boxes denote the null region (RPE).

Discussion

In Experiment 2a during the test phase the features that defined targets during learning became features of distractors rendering these features *task-irrelevant*, as is typical when observing persistence VDAC. In Experiment 2a we again found strong evidence for reinforcement learning. However, unlike in Experiment 1, during the test phase we did not find evidence for VDAC, instead we found strong evidence for the absence of VDAC. The difference between Experiments 1 and 2a was to make the reward-associated feature task irrelevant, as such the lack of VDAC in Experiment 2a was unexpected. Due to the unexpectedness of these results, we conducted a replication of Experiment 2a with a new sample.

Experiment 2b

The replication was identical to Experiment 2a except that the response time window was increased from 800 to 1,000 ms. We expected the longer response window to allow for greater opportunity for distraction during test.

Method

Participants

Participants were 21 students from the University of California Santa Barbara recruited from the research participation pool (14 female, M_{age} = 18.85 years, SD_{age} = 1.82). Two participants were excluded because of poor accuracy resulting in a final sample size of 19 (13 female, M_{age} = 18.79 years, SD_{age} = 1.90). On average participants were paid $13.47 after the learning phase.

Procedure

The visual search tasks during learning and test task were identical to Experiment 2a except that the response time window was increased from 800 ms to 1,000 ms.

Results

Visual search: Learning

A GLMM was used to examine RTs on correct trials during the learning phase (see Fig. 7). An effect of trial was probable such that RTs got faster as trial order increased (*b* = -133.52, *SI* = [-158.11, -110.33], *RPE* = ± 6.24, *BF* > 1000; see Fig. 8). There was anecdotal evidence of an effect of reward such that RTs were faster to rewarded than to non-rewarded target features (*b* = 22.20, *SI* = [4.12, 40.01], *RPE* = ± 2.63, *BF* = 0.94). The interaction between trial and reward condition was probable such that RT decreased at a faster rate for rewarded than non-rewarded target features (*b* = 48.14, *SI* = [33.83, 62.83], *RPE* = ± 5.11, *BF* > 1000).

Visual search: Test

The same GLMM was used to examine the effect of reward during the test phase. The effect of trial was probable such that participants responded faster to targets over time (*b* = -31.47, *SI* = [-52.44, -10.20], *RPE* = ± 4.43, *BF* = 5.24; see Fig. 8). The effect of reward condition was not probable (*b* = -12.07, *SI* = [-24.54, 0.57], *RPE* = ± 1.46), and there was anecdotal evidence in support of the null (*BF* = 0.44). The interaction between reward condition and trial was also not probable (*b* = 8.95, *SI* = [-4.42, 21.19], *RPE* = ± 2.64), and there was strong evidence in support of the null (*BF* < 0.01).

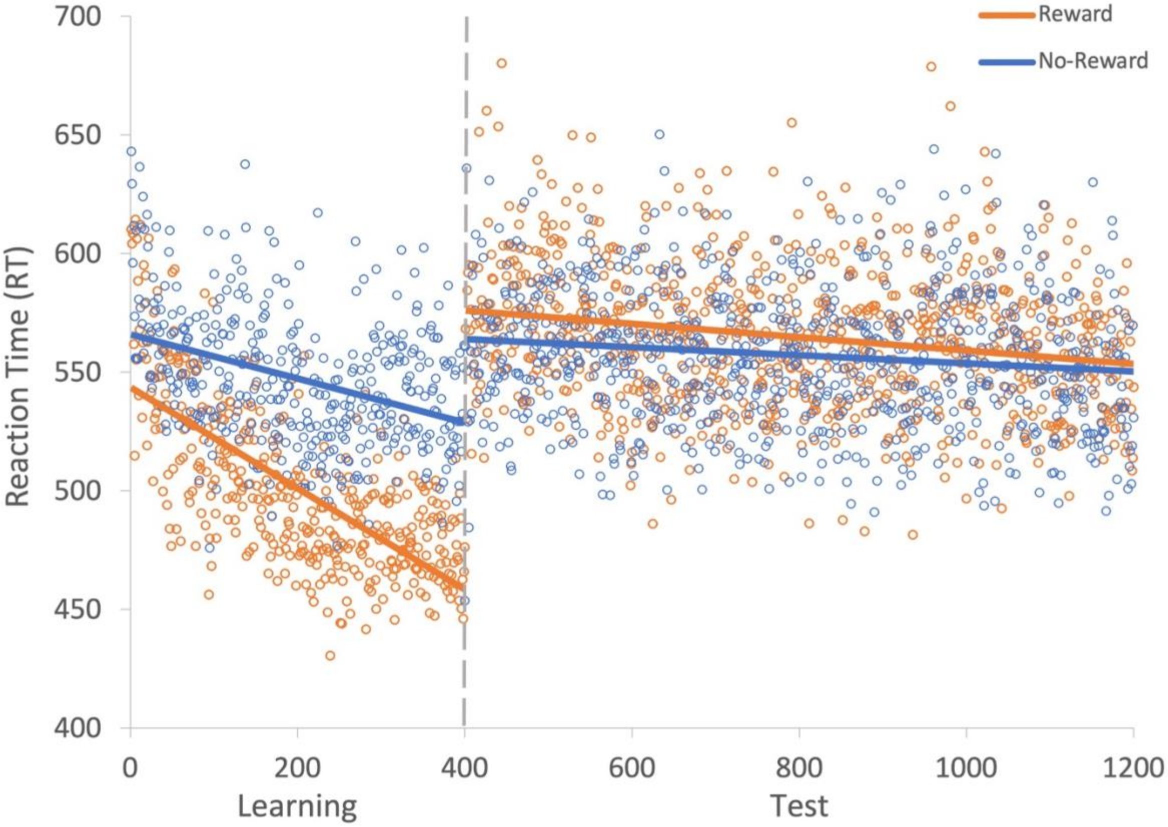

Figure 7. Results for both learning and the test phase of Experiment 2b. Data points are the raw RT data averaged across participants for each trial for rewarded and non-rewarded trials separately. The regression lines are the predicted RT for rewarded and non-rewarded trials across time from the GLMM.

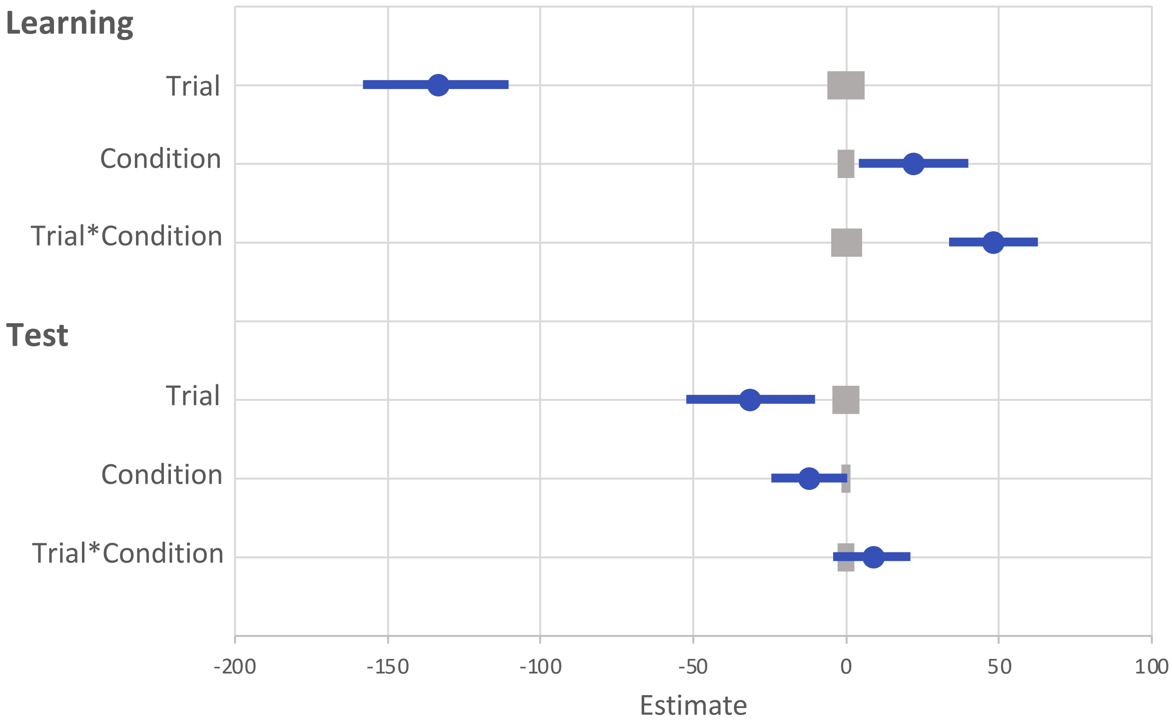

Figure 8. Mean point estimates and support intervals for each of the fixed effects from the GLMM for both learning and test in Experiment 2b. Grey boxes denote the null region (RPE).

Discussion

In Experiments 2a and 2b, where the reward-associated feature was task-irrelevant, we failed to find evidence for VDAC at test. Furthermore, in Experiment 2a there was strong evidence, and in Experiment 2b anecdotal evidence in support of the null, i.e., evidence for the lack of VDAC. It is possible that the longer response time window of 1,000 ms in 2b, compared to 800 ms in 2a, accounts for the discrepancy in the strength of the evidence for the null. Thus, we have mixed evidence for the absence of VDAC when the reward-associated feature is task-irrelevant. This was unexpected, but it points to two possibilities for the conditions under which VDAC does and does not occur. First, it is possible that when the reward-associated feature is task-irrelevant, as is typical, but is also in the same dimension as the new target feature (i.e., they are both colors) VDAC is suppressed. Second, it is also possible that without other common features of VDAC paradigms, such as the inclusion of a physically salient target or absent trials, VDAC is suppressed. We investigated these two possibilities in Experiments 3 through 5. We should note that these possibilities are not mutually exclusive and may even interact.

Experiment 3

Typically, in VDAC experiments, to make the formerly reward-associated feature task-irrelevant, the target feature during test was a physically salient feature from an orthogonal feature dimension (i.e., shape vs. color; see Table 1), unlike in Experiment 2a/b where the target feature during test was the same dimension as the reward-associated feature. That difference amounts to a difference in selection demands of the test task: whether the target could be selected as the most salient feature within a dimension (e.g., shape singleton), or whether it required selection of some features in a dimension and not others without the benefit of a physically salient target feature (as in Experiments 2a/b). Physically salient features compete strongly with other factors to drive attention, including voluntary attention to relevant features which are also physically salient (Theeuwes et al., 1998). Likely, a physically salient target results in a "pop out" effect (Brascamp et al., 2011), whereby the target is automatically prioritized for attention. The persistence of VDAC may be dependent on the presence of a physically salient target when the target defining feature is in an orthogonal feature dimension to that of the reward-associated one.

For example, it is possible that when search is primarily driven by involuntary attention to a physically salient target, involuntary attention to other salient features, as is suggested to be the case with VDAC, is facilitated (ie., singleton search; Bacon & Egeth, 1994; Connor et al., 2004; Lamy et al., 2006; Lamy & Egeth, 2003). Furthermore, as the task-irrelevant feature was in a different feature dimension than the target this may complicate the competition between two salient features for attention.

In Experiment 3 we included a salient target shape to assess whether the salience and orthogonality (relative to the reward-associated feature dimension) of the target feature would influence the persistence and/or extinction of VDAC. Previous work has already produced evidence that VDAC can persist when the target defining feature at test is orthogonal, but not physically salient (MacLean & Giesbrecht, 2015a, 2015b; target was defined as letters amongst numbers, reward associated feature was color). The following experiment focuses on the combination of salience and orthogonality, a combination that is frequently seen in VDAC literature (see Table 1), specifically whether that combination alone is sufficient to produce VDAC when the reward-associated feature is task-irrelevant.

Experiment 3 was identical to (Anderson & Yantis, 2013) except that there were no absent trials included at test and there were twice as many exposures to the reward-associated feature at test as there were during learning. During the test phase the target was a salient shape singleton and critical distractors could be one of the previously selected target colors at learning.

Method

Participants

Participants were 25 students from the University of California Santa Barbara recruited from the research participation pool (18 female, M_{age} = 18.41 years, SD_{age} = 1.10). Eight participants were excluded from the analyses due to poor accuracy resulting in the final sample of 17 participants (15 female, M_{age} = 18.44 years, SD_{age} = 1.15). On average participants were paid $13.53 after the learning phase.

Procedure

Visual search: Learning

The learning phase of the experiment was identical to Experiment 1 (see Fig. 1a).

Visual search: Test

The test phase was identical to Experiment 1 except that the target was defined by shape not color. Participants were instructed to search for the unique shape in the stimulus display. The unique shape could either be a diamond among circles (Fig. 9a) or a circle among diamonds (Fig. 9b). Participants responded to the line orientation inside the shape, regardless of whether the shape was a circle or a diamond. The color of the shape singleton was randomly selected from the color list without replacement and was never red or blue.

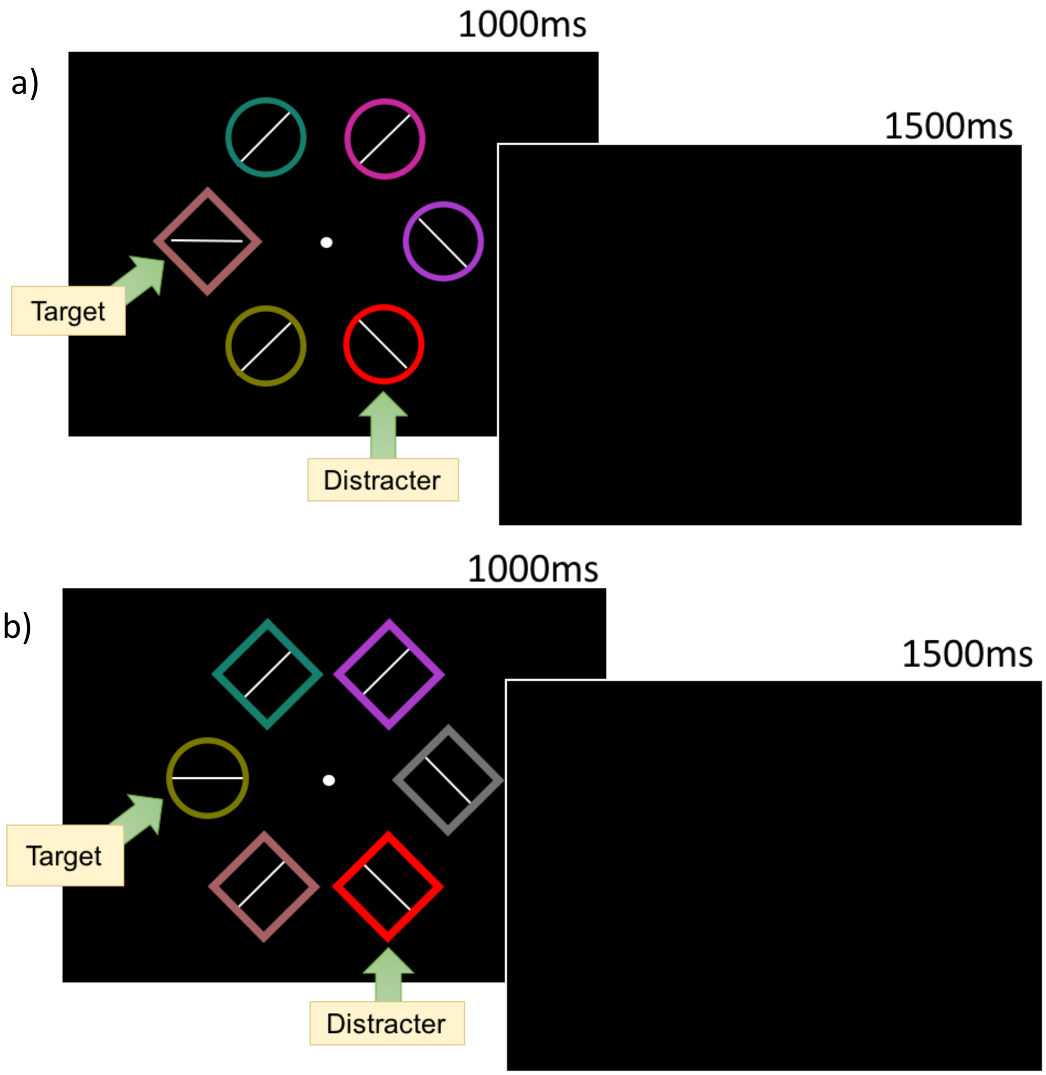

Figure 9a) Example of diamond target among circles with a critical distractor present during test *b)* Circle target among diamonds with a critical distractor present during test.

Results

Visual search: Learning

A GLMM was used to examine RTs on correct trials during the learning phase (see Fig. 10). The effect of trial was probable such that RTs became faster as trial order increased (*b* = -117.17, *SI* = [-140.13, -93.64], *RPE* = ± 4.79, *BF* > 1000; see Fig. 11). The effect of reward condition was not probable (*b* = 7.07, *SI* = [-13.72, 27.51], *RPE* = ± 2.99), and there was strong evidence for the null (*BF* = 0.019). However, the interaction between trial and reward condition was probable such that RT decreased at a faster rate for rewarded than non-rewarded target features, indicating that they learned the reward associations (*b* = 62.63, *SI* = [48.20, 76.80], *RPE* = ± 4.25, *BF* > 1000).

Visual search: Test

A similar GLMM was used to examine RT on correct trials during the test phase (see Fig. 10). The effect of trial was probable such that RTs got faster as trial order increased (*b* = -82.90 *SI* = [-105.50, -59.44], *RPE* = ± 4.40, *BF* > 1000; see Fig. 11). The effect of reward condition was not probable (*b* = -16.48, *SI* = [-34.63, 2.06], *RPE* = ± 2.57), and there was strong evidence for the null (*BF* = 0.13). The interaction between reward condition and trial was probable such that the difference in RT between rewarded and non-rewarded was reduced as trial order increased (*b* = 31.49, *SI* = [17.58, 44.77], *RPE* = ± 4.14, *BF* = 536.88).

The interaction between reward and trial could indicate that VDAC was present at the beginning of the text phase but was extinguished. To assess this possibility VDAC a Bayesian paired-samples t-test examining the difference between rewarded and non-reward was conducted on the first 100 trials of the test phase. There was no evidence of an effect of reward (*BF* = 0.37).

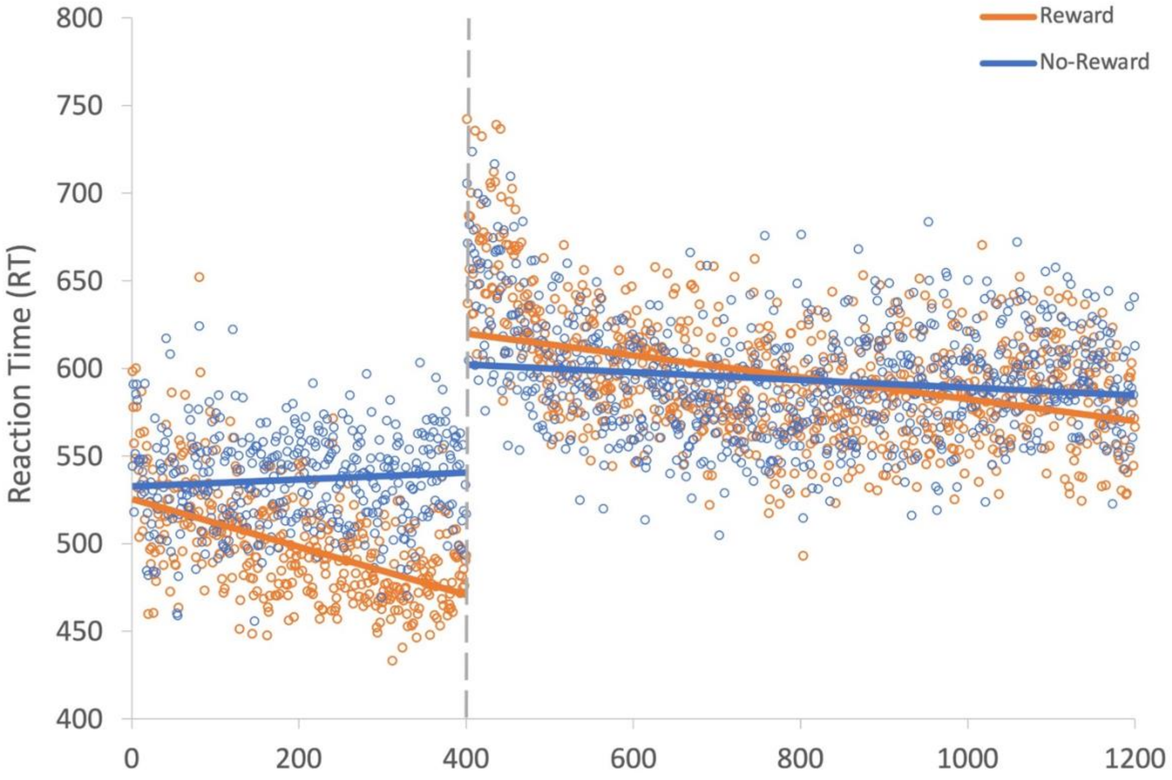

Figure 10. Results for both learning and the test phase of Experiment 3. Data points are the raw RT data averaged across participants for each trial for rewarded and non-rewarded trials separately. The regression lines are the predicted RT for rewarded and non-rewarded trials across time from the GLMM.

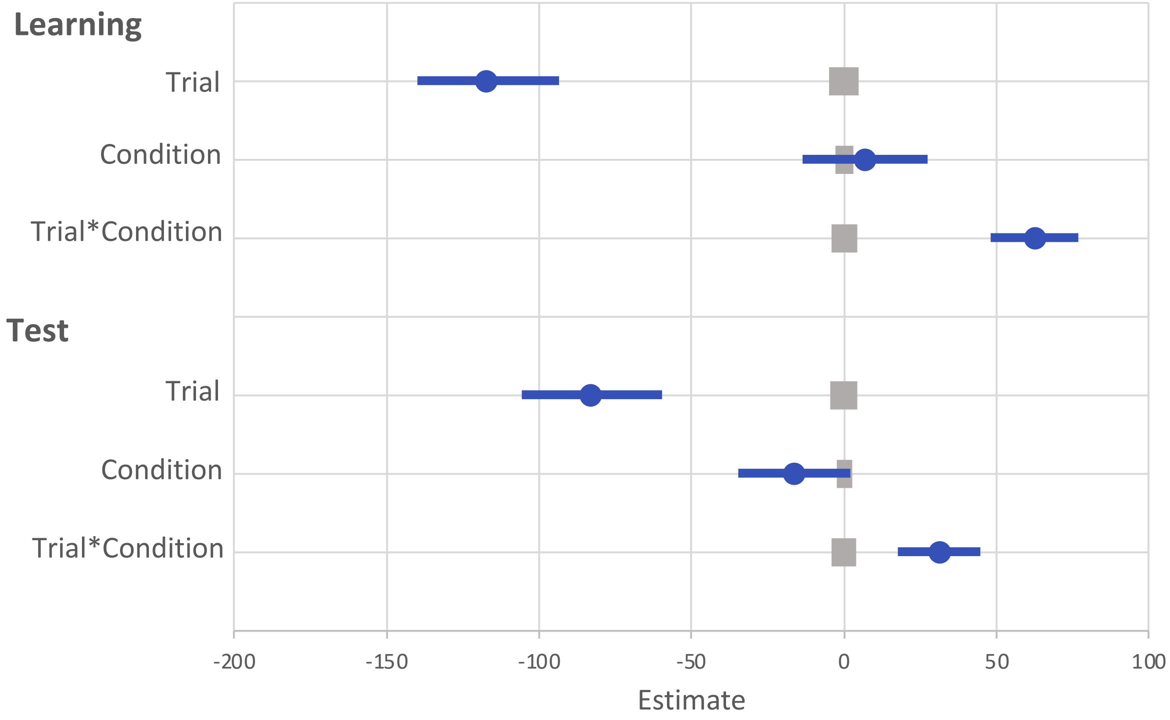

Figure 11. Mean point estimates and support intervals for each of the fixed effects from the GLMM for both learning and test in Experiment 3. Grey boxes denote the null region (RPE).

Discussion

In Experiment 3 we found that there was no overall VDAC effect. However, there was evidence of an interaction between rewarded and non-rewarded trials which suggests that there is a change between rewarded and non-rewarded trials over time. Numerically, participants were slower on rewarded compared to non-rewarded trials at the beginning of the test phase and became faster on rewarded relative to non-rewarded trials over time. One possible explanation for this finding is that when participants engage in singleton detection search mode, the interference by the reward-associated feature is suppressed over time. It has recently been shown that attention capture by salient stimuli can be prevented by inhibitory processes (Cosman et al., 2018; Gaspelin & Luck, 2018). Furthermore, it has been demonstrated that locations that are likely to contain a salient distractor are learned to be suppressed compared to locations with a lower probability of a distractor occurring (Wang & Theeuwes, 2018). We suggest that the reward-associated distractor creates an enhanced priority signal relative to non-rewarded stimuli, but over time participants actively suppress the reward-associated distractor resulting in faster RTs to rewarded trials over time compared to non-rewarded trials (See Fig. 8). When utilizing singleton detection mode, the priority signal for any salient item in the display is increased, requiring suppression of the reward-associated distractor to avoid distraction. This interaction was not observed in experiments in which a salient singleton was not present.

The evidence of an interaction is inconsistent with previous research reporting both a main effect of reward and a lack of extinction of VDAC in the absence of reinforcement when using a very similar paradigm including a physically salient target feature orthogonal to the reward-associated feature but without absent trials (Anderson et al., 2011b; Anderson & Yantis, 2013). However, Experiment 3 included no absent trials which could have resulted in the absence of VDAC due to a higher frequency of exposure to the reward-associated feature (the reward associated feature was presented on 50% of trials compared to only 25% of trials in experiments with no absent trials).

Experiment 4

We found evidence for the decrease in the effect of a reward-associated distractor in Experiment 3 when the formerly reward-associated feature was task irrelevant, and the target was a physically salient shape singleton as is typical when observing persistent VDAC (see Table 1). This indicates that the salience/orthogonality of the target feature at test may contribute to the effect that an irrelevant reward associated feature has on attention; a factor that has not been discussed extensively in the existing VDAC literature (although see MacLean & Giesbrecht, 2015a). In this experiment, we investigate one more typical feature of VDAC paradigms, the inclusion of absent trials, that is trials where no reward-associated feature is present as a distractor. Although the inclusion of absent trials is included as a convenient control condition to better capture the VDAC effect at test, it is possible that the inclusion of absent trials, much like the choice of a salient/orthogonal target, may in fact be key to the persistence of VDAC.

Control over attention, i.e., the ability to ignore distractors, is affected by the frequency of those distractors such that infrequent distractors are less effectively ignored than frequent ones (Geyer et al., 2008; Müller et al., 2009). It is possible that in addition to impairing the learning required for extinction, the reduced probability of the appearance of the reward-associated feature affects the ability to ignore the formerly reward-associated feature, allowing VDAC to persist.

In Experiment 4, during the test phase, we replicated the design of Experiment 2b but also included an absent condition whereby neither a previously rewarded nor previously selected target was presented as a feature of a distractor. This third condition had the additional benefit of allowing us to examine both VDAC (difference in performance between previously rewarded and non-rewarded features) and selection-driven attention capture (SDAC; difference in performance between trials with a non-rewarded previously *selected* feature and absent trials with no previously selected feature present) separately.

Method

Participants

Participants were 23 students from the University of California Santa Barbara recruited from the research participation pool (14 female, M_{age} = 19.04 years, SD_{age} = 2.16). Four participants were excluded from the analyses because their performance was below chance, resulting in a final sample of 19 participants (12 female, M_{age} = 19.20 years, SD_{age} = 2.28). Participants had the opportunity to win a maximum of $8 during the learning phase and on average were paid $6.68.

Procedure

Visual search: Learning

The learning task was identical to that used in Experiment 2b, except participants were given 50 practice trials, and a reduced number of learning trials – 200 rewarded and 200 non- rewarded trials compared to 400 of each in Experiment 2b. The inclusion of equally probable absent trials during the test phase meant that the total number of trials would have doubled as compared to Experiments 1-3. This would have made the time to complete the task unfeasibly long and exacerbated confounding issues of fatigue. For that reason, we halved the number of trials during the test phase in Experiment 4 as compared to that in Experiments 1-3, resulting in the same number of trials overall with the addition of absent trials. This also meant that we needed to halve the number of learning trials, in order to have twice as many presentations of the previously reward associated distractor during test, as there were exposures during learning – an important design feature for examining persistence of VDAC during test.

Visual search: Test

During the test phase, features that were targets at learning became distractors at test, as in Experiment 2b. However, there was a third type of condition where no previous target colors were presented as a feature of a distractor (absent trials). The test phase began with 20 practice trials, followed by 20 blocks each with 80 trials, yielding 400 rewarded trials, 400 non-rewarded trials and 800 absent trials. Thus, as is typical of value-driven capture paradigms, the probability of a former target feature appearing was 1.00 and .50 for learning and test respectively (Anderson et al., 2011a, 2011b; Anderson & Yantis, 2013), unlike in Experiments 1, 2a, and 2b where the probability was 1.00 for both learning and test.

Results

Visual search: Learning

Another GLMM was used to examine RTs on correct trials during the learning phase (see Fig. 12). The effect of trial was probable such that RTs got faster as trial order increased (*b* = - 107.55, *SI* = [-137.64, -76.79], *RPE* = ± 5.84, *BF* > 1000; see Fig. 13). The effect of reward condition was not probable (*b* = 16.18, *SI* = [-1.43, 33.58], *RPE* = ± 2.45), and there was strong evidence in support of the null (*BF* = 0.15). However, the interaction between trial and reward condition was probable such that RT decreased at a faster rate for rewarded than non-rewarded targets, indicating that they learned the reward associations (*b* = 32.92, *SI* = [14.50, 52.07], *RPE* = ± 2.93, *BF* > 1000).

Visual search: Test

A similar GLMM was used to examine RTs on correct trials during the test phase. The effect of trial was probable such that RTs got faster as trial order increased (*b* = -38.17, *SI* = [-54.70, -20.99], *RPE* = ± 4.57, *BF* = 381.48; see Fig. 13). There was anecdotal evidence for an effect of reward (*b* = -12.07, *SI* = [-22.41, -3.29], *RPE* = ± 2.46, *BF* = 1.22), but the interaction between trial and reward condition was not probable (*b* = 3.37, *SI* = [-3.68, 9.84], *RPE* = ± 3.41), and there was decisive evidence in support of the null (*BF* = 0.007).

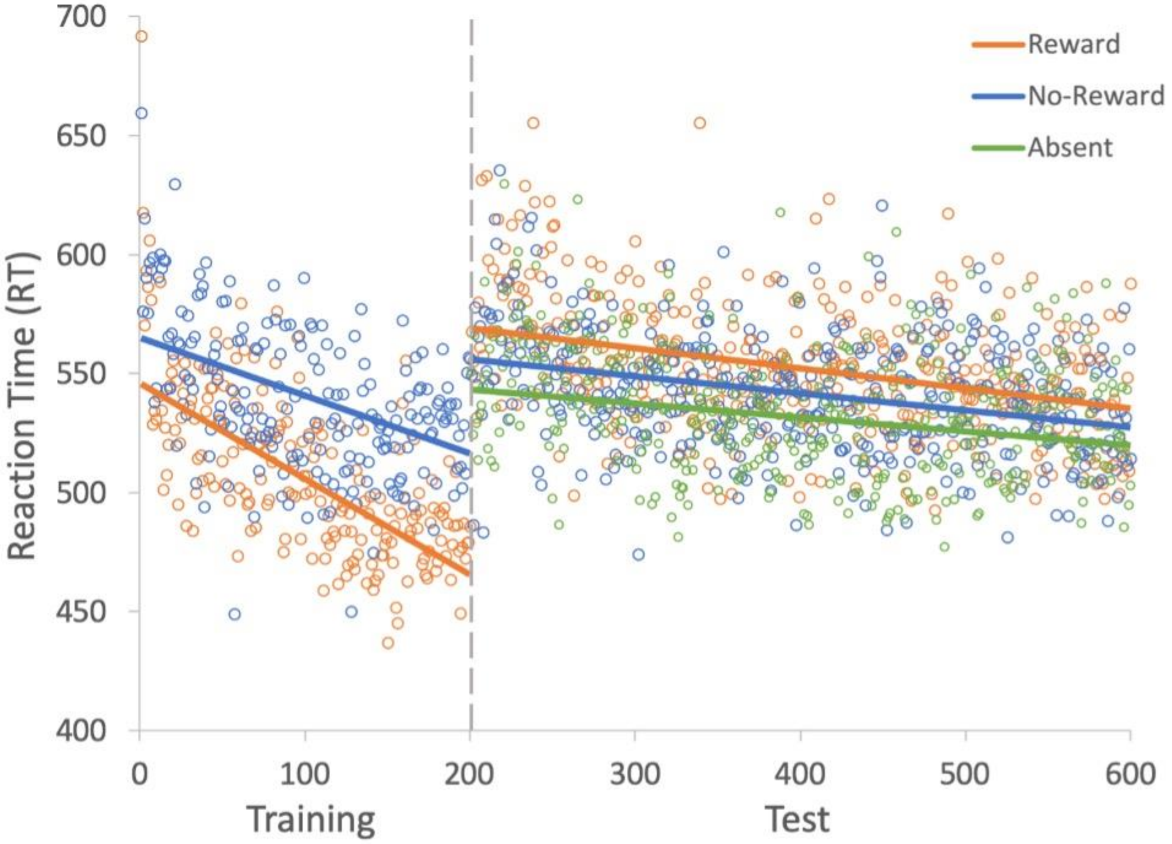

Figure 12. Results for both learning and the test phase of Experiment 4. Data points are the raw RT data averaged across participants for each trial for rewarded and non-rewarded trials separately. The regression lines are the predicted RT for rewarded and non-rewarded trials across time from the GLMM.

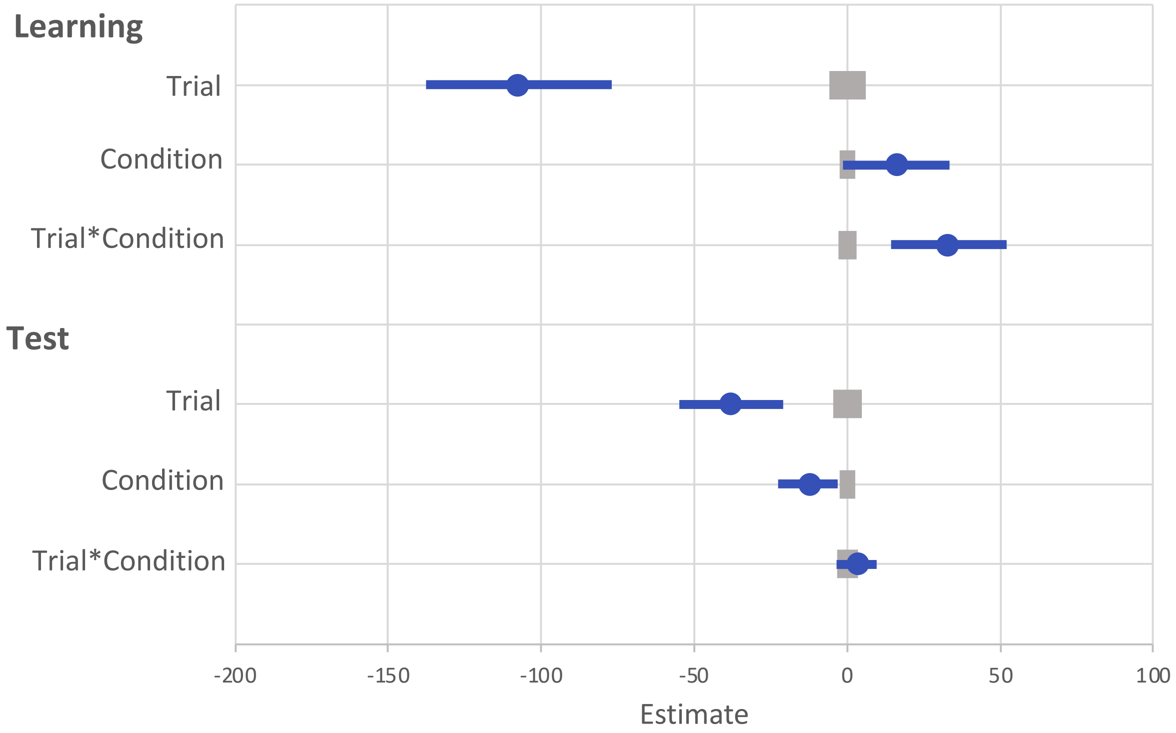

Figure 13. Mean point estimates and support intervals for each of the fixed effects from the GLMM for Experiment 4 in both learning and test. Grey boxes denote the null region (RPE).

To compare the three levels of condition (rewarded, non-rewarded, and absent) we conducted three additional GLMMs to compare reward versus no-reward, no-reward versus absent, and reward versus absent conditions.

Reward versus no-reward

The GLMM with the fixed effects of reward condition (reward vs. no-reward) and trial indicated that the effect of trial was probable (*b* = -46.88, *SI* = [-72.25, -22.61], *RPE* = ± 4.63, *BF* = 58.48; see Fig. 14). The effect of reward condition was not probable (*b* = -14.96, *SI* = [-32.55, 1.31], *RPE* = ± 2.41), and there was moderate support for the null (*BF* = 0.13). The interaction between reward condition and trial was also not probable (*b* = 10.80, *SI* = [-4.44, 25.97], *RPE* = ± 3.32), and there was decisive evidence in support of the null (*BF* < 0.01).

No-reward versus absent

The effect of trial was not probable (*b* = -25.26, *SI* = [-55.63, 5.40], *RPE* = ± 4.81), and there was strong evidence in support of the null (*BF* = 0.08). The effect of reward condition (no reward vs. absent) was not probable (*b* = -10.78, *SI* = [-22.64, 2.22], *RPE* = ± 1.70), and there was strong evidence in support of the null (*BF* = 0.095). The interaction between reward condition and trial was also not probable (*b* = 0.15, *SI* = [-11.89, 12.27], *RPE* = ± 3.64), and there was decisive evidence in support of the null (*BF* < 0.01).

Reward versus absent

The effect of trial was probable (*b* = -41.44, *SI* = [-59.23, -22.85], *RPE* = ± 4.91, *BF* = 781.95). There was anecdotal evidence of an effect of reward condition (reward vs. absent) such that participants were faster on absent trials than in the presence of formerly rewarded features (*b* = -12.92, *SI* = [-21.77, -3.80], *RPE* = ± 4.92, *BF* = 1.25). However, the interaction between reward condition and trial was not probable (*b* = 5.61, *SI* = [-0.93, 12.11], *RPE* = ± 3.46), and there was very strong evidence in support of the null (*BF* = 0.03).

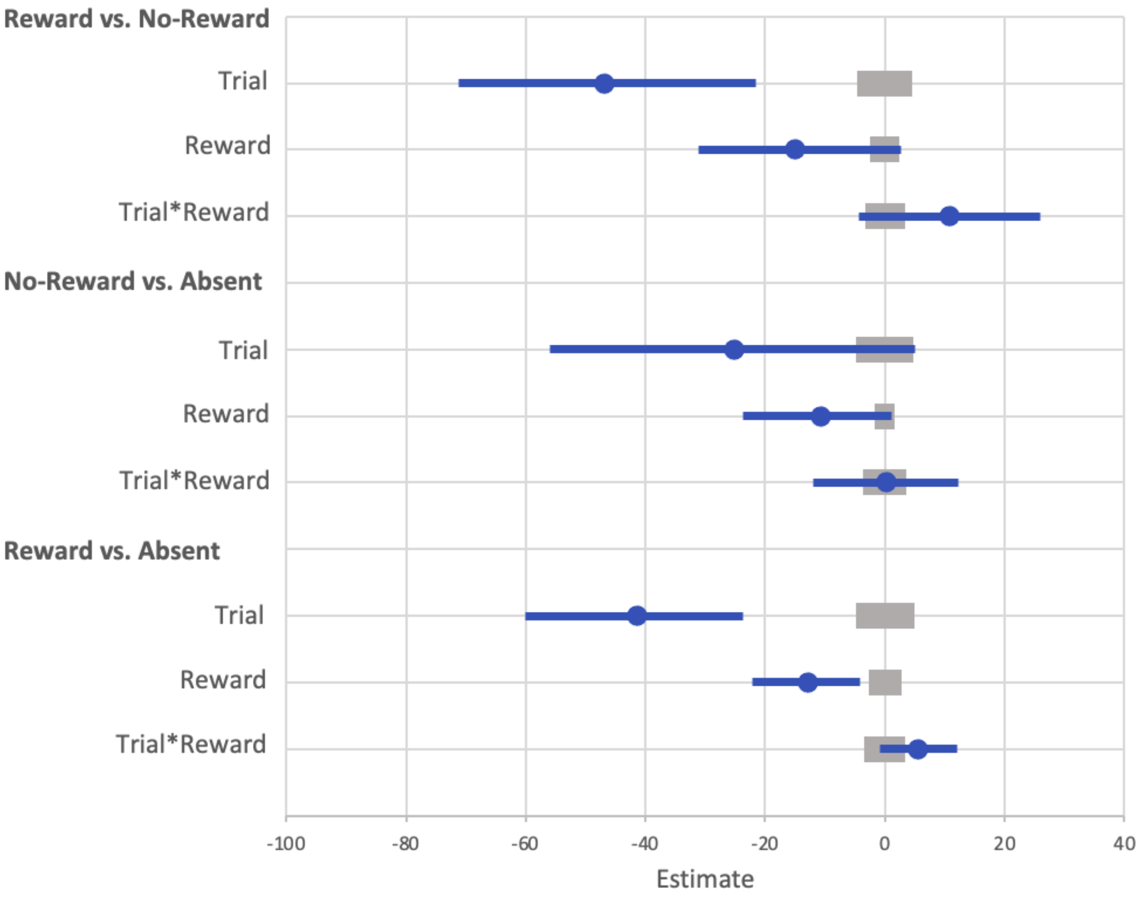

Figure 14. Mean point estimates and support intervals for each of the fixed effects from the GLMM for the 3 comparison models during test in Experiment 4. Grey boxes denote the null region (RPE).

Discussion

The purpose of Experiment 4 was to assess how absent trials, i.e., the reduced frequency of exposure to the formerly reward associated feature in the absence of reinforcement, impacted the persistence of VDAC. We did not find evidence for either VDAC (reward vs. no reward) or SDAC (no reward vs. absent), or the extinction of either, and in fact found moderate evidence for the null in both cases, that is there was evidence for the lack of either a pure VDAC or SDAC effect. We did however find anecdotal evidence for an effect of VDAC+SDAC (reward vs. absent), which is to say evidence that the combination of reward-association and selection history of a feature did affect performance. However, there was no evidence that this effect was subject to extinction, as there was strong evidence for the null for the interaction.

We cannot exclude the possibility that the reduced number of learning trials may account for the lack of support for pure VDAC/SDAC effects. However, we note that the number of trials is in line with those previously reported in other VDAC experiments (e.g., VDAC effects have been reported with only 240 training trials; Anderson et al., 2011b), and that the proportion of extinction trials to training trials is the same as that in the other experiments reported here. This means that the factor of "trial" in the model is conceptually equivalent across all five experiments.

The inclusion of absent trials, which in effect reduced the probability of the presence of a reward-associated feature (as a distractor), was not sufficient to produce VDAC, nor SDAC when the reward-associated/formerly selected feature was task-irrelevant at test. However, the inclusion of absent trials did function as a useful control condition. This condition allowed us to observe that when the reward-associated feature is task-irrelevant, it is able to capture attention, but only when combined with the effects of selection. Furthermore, it appears somewhat resistant to extinction unlike VDAC alone, as we saw in Experiments 1 and 3, although the inclusion of the absent trials themselves may also have contributed to the effect due to the reduced probability of the reward-associated feature.

In Experiment 4 we also found substantial evidence in support of the null (i.e., the lack of a VDAC effect). The evidence favoring the lack of a VDAC effect paralleled the results of Experiments 2a/b. So, across three experiments when the reward associated feature was task irrelevant, but the target feature was not salient, there was evidence of varying strength from anecdotal to moderate, *against* the presence of VDAC.

Experiment 5

In Experiment 4 the inclusion of absent trials was not sufficient to elicit VDAC in the absence of a salient singleton target at test. An interaction between reward and trial when the reward-associated feature was task irrelevant was only observed in Experiment 3 when the target was defined by a salient shape singleton. This indicates that the presence of a salient shape singleton at test may be necessary to observe an effect of reward in the typical VDAC paradigm.

In Experiment 5 we wanted to replicate the typical task features used in VDAC paradigms, the experiment was identical to Anderson & Yantis (2013) as targets were defined as the salient singleton during the test phase and there were absent trials. The motivation behind this experiment was to assess whether VDAC continued to be observed when the target was defined as a salient shape singleton at test when the frequency of exposure to the reward associated feature was reduced. The inclusion of absent trials and a non-rewarded but previously selected feature condition allowed us to obtain a measure of selection history. Although a salient singleton target was used in Experiment 3 this experiment design did not allow for the observation of selection history. In Experiment 4 where there was no salient singleton at test SDAC was not observed. It’s possible that the presence of a salient singleton during test could also lead an effect of selection history if previously selected features gain salience.

Method

Participants

Participants were 39 students from the University of California Santa Barbara recruited from the research participation pool (24 female, M_{age} = 18.82 years, SD_{age} = 1.19). Four participants were excluded from the analyses because of poor performance, resulting in a final sample of 35 participants (20 female, M_{age} = 18.77 years, SD_{age} = 1.11). Participants had the opportunity to win a maximum of $8 during the learning phase and on average were paid $6.67.

Procedure

Visual search: Learning

The learning task was identical to that used in Experiment 1, except participants were given 50 practice trials, and a reduced number of learning trials – 200 rewarded and 200 non-rewarded trials compared to 400 of each in Experiment 1 (Fig. 1a). The number of learning trials in Experiment 5 were reduced for the same reasons as noted in Experiment 4.

Visual search: Test

During the test phase, features that were targets at learning became distractors at test, as in Experiments 2-4. In the current Experiment, targets were defined by the unique shape in the display as in Experiment 3 (Fig. 9a & 9b). However, unlike Experiment 3 there was a third type of condition where no previously selected target colors were presented as a feature of a distractor (absent trials). The test phase began with 20 practice trials, followed by 20 blocks each with 80 trials, yielding 400 rewarded trials, 400 non-rewarded trials and 800 absent trials.

Results

Visual search: Learning

Another GLMM was used to examine RTs on correct trials during the learning phase (see Fig. 15). The effect of trial was probable such that RTs got faster as trial order increased (*b* = -97.19, *SI* = [-119.24, -75.13], *RPE* = ± 3.97, *BF* > 1000; see Fig. 16). The effect of condition was not probable (*b* = 16.28, *SI* = [0.11, 33.19], *RPE* = ±3.57), there was substantial evidence in support of the null *BF* = 0.20 However, the interaction between trial and reward condition was probable such that RT decreased at a faster rate for rewarded than non-rewarded targets, indicating that the reward associations had been learned (*b* = 43.36, *SI* = [29.57, 57.53], *RPE* = ± 5.99, *BF* > 1000).

Visual search: Test

A similar GLMM was used to examine RTs on correct trials during the test phase. The effect of trial was probable such that RTs got faster as trial order increased (*b* = -67.25, *SI* = [-81.78, -52.08], *RPE* = ± 6.18, *BF* > 1000; see Fig. 16). The effect of the reward condition during the test phase was also probable (*b* = -10.71, *SI* = [-17.43, -3.32], *RPE* = ± 1.34, *BF* = 5.26). The interaction between trial and reward condition was also probable (*b* = 11.19, *SI* = [5.87, 18.02], *RPE* = ± 3.30, *BF* = 67.63).

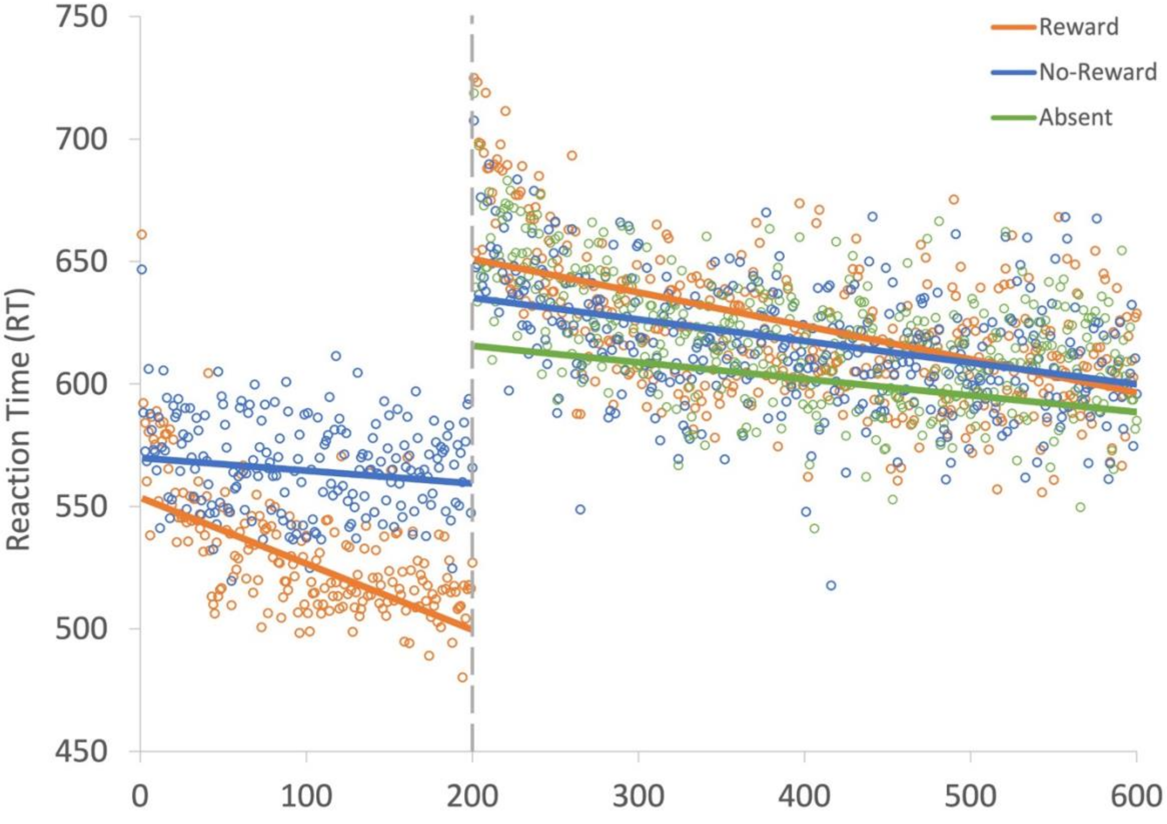

Figure 15. Results for both learning and the test phase of Experiment 5. Data points are the raw RT data averaged across participants for each trial for rewarded and non-rewarded trials separately. The regression lines are the predicted RT for rewarded and non-rewarded trials across time from the GLMM.

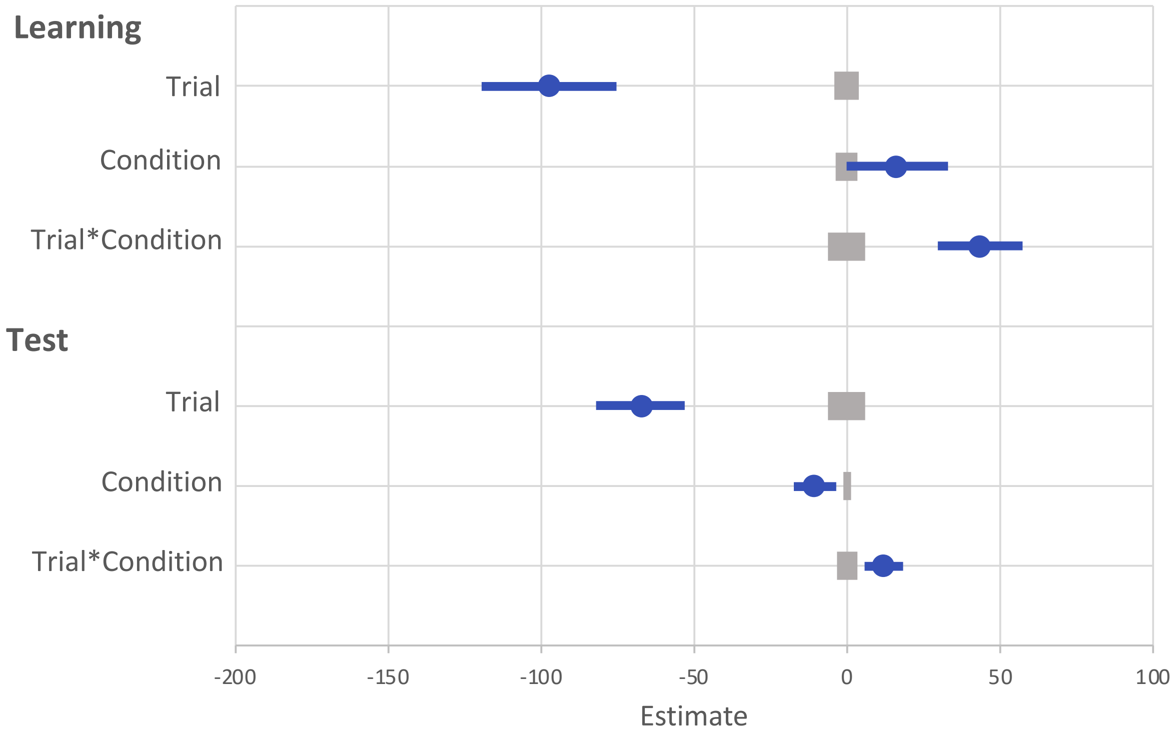

Figure 16. Mean point estimates and support intervals for each of the fixed effects from the GLMM for Experiment 5 in both learning and test. Grey boxes denote the null region (RPE).

To compare the three levels of condition (rewarded, non-rewarded, and absent) we conducted three additional GLMMs to compare reward versus no-reward, no-reward versus absent, and reward versus absent conditions.

Reward versus no-reward

The GLMM with the fixed effects of reward condition (reward vs. no-reward) and trial indicated that the effect of trial was probable such that participants became faster over the test phase (*b* = -73.89, *SI* = [-94.85, -53.33], *RPE* = ± 5.20, *BF* > 1000; see Fig. 17). The effect of reward condition was probable such that participants were slower on trials where the reward associated feature was presented compared to the non-reward associated (*b* = -15.92, *SI* = [-26.38, -5.34], *RPE* = ± 1.41, *BF* = 6.03). The interaction between reward condition and trial was also probable such that the difference in reaction time between rewarded and non-rewarded trials decreased throughout the test phase (*b* = 19.30, *SI* = [6.21, 32.15], *RPE* = ± 3.64, *BF* = 2.59).

To assess whether VDAC was completely extinguished in the test phase, a Bayesian paired-samples t-test examining the difference between rewarded and non-reward was conducted on the final 100 trials of the test phase. There was anecdotal evidence in support of the null (*BF* = 0.55) suggesting that VDAC was no longer present at the end of the test phase.

No-reward versus absent

The effect of trial was probable such that participants became faster over the test phase (*b* = -51.11, *SI* = [-80.85, -20.82], *RPE* = ± 5.29, *BF* = 11.92). The effect of reward condition (no reward vs. absent) was not probable (*b* = -7.19, *SI* = [-22.68, 8.44], *RPE* = ± 3.08), there was very strong evidence in support of the null (*BF* = 0.015). The interaction between reward condition and trial was also not probable (*b* = 8.01, *SI* = [-3.91, 19.63], *RPE* = ± 4.45), and there was strong evidence in support of the null (*BF* = 0.033).

Reward versus absent

The effect of trial was probable such that participants became faster over the test phase (*b* = -67.99, *SI* = [-83.86, -52.61], *RPE* = ± 5.20, *BF* > 1000). The effect of reward condition (reward vs. absent) was probable such that participants were slower in the presence of formerly reward associated feature compared to absent trials (*b* = -11.62, *SI* = [-18.65, -4.98], *RPE* = ± 2.54, *BF* = 17.57). The interaction between reward condition and trial was also probable (*b* = 13.60, *SI* = [7.32, 19.66], *RPE* = ± 3.90, *BF* = 218.98), suggesting that the difference between rewarded and absent trials decreased throughout the test phase.

To assess whether the difference between reward and absent trials was still present at the end of the test phase. A Bayesian paired-samples t-test examining the difference between rewarded and absent trials on the final 100 trials revealed that there was substantial evidence in support of the null (*BF* = 0.25) suggesting that the effect of both VDAC and SDAC was no longer present.

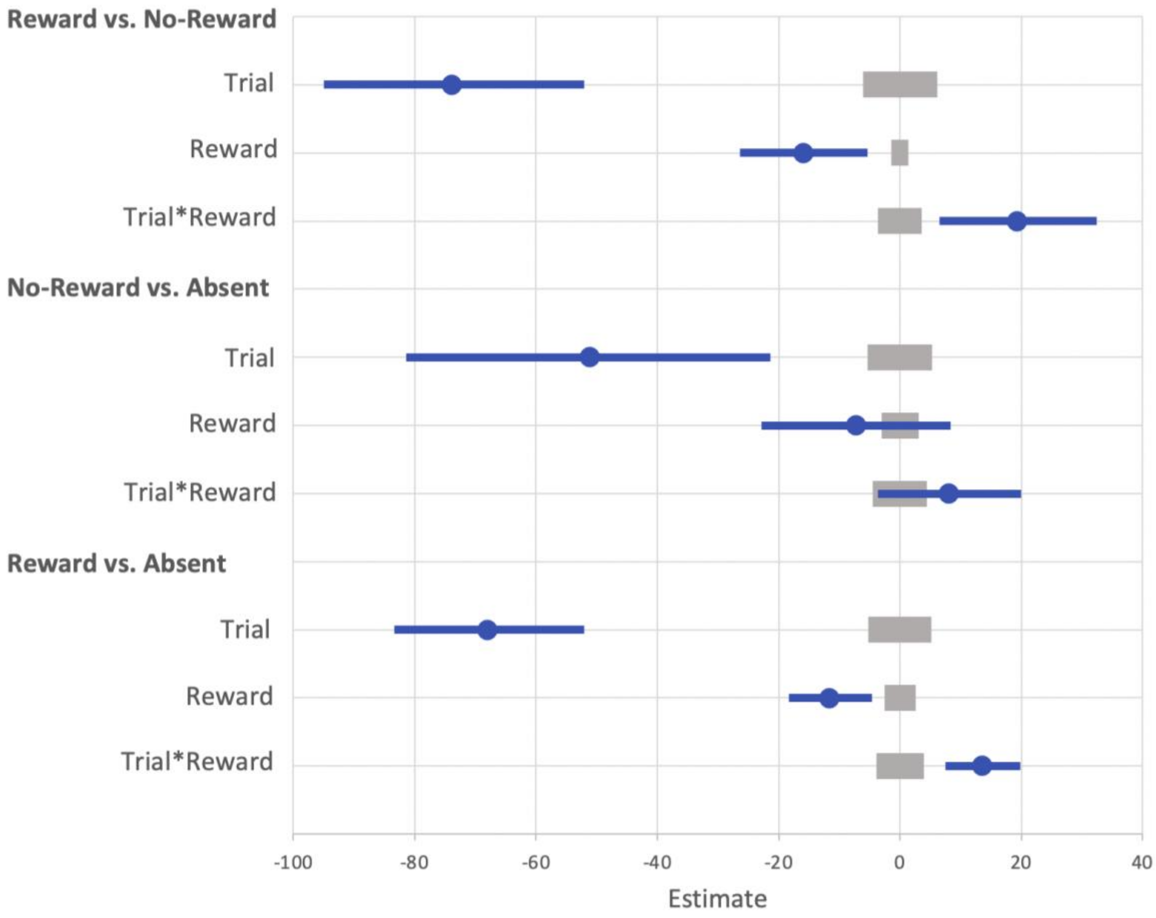

Figure 17. Mean point estimates and support intervals for each of the fixed effects from the GLMM for the 3 comparison models during test in Experiment 4. Grey boxes denote the null region (RPE).

Discussion

The purpose of Experiment 5 was to assess whether the VDAC would be observed with the inclusion of absent trials and a physically salient target. In the current experiment it was possible to examine the effects of selection history in the presence of a physically salient singleton but no evidence of a purely selection history driven effect was found. However, we did find evidence for VDAC consistent with Anderson & Yantis (2013). These results suggest that for VDAC to be observed both a physically salient target must be present during test and frequency of exposure to the reward-associated feature must be reduced. This supports the possibility that when searching for a target defined as a physically salient singleton, salient features gain weight across dimensions, including both the target and the reward-associated distractor, and this, at least when complicated by inter-dimension competition, is sufficient for VDAC when the reward-associated feature is task-irrelevant (e.g., Bacon & Egeth, 1994). The inclusion of absent trials may have also contributed to the observation of VDAC in the current experiment. The reduced exposure to the reward-associated feature in Experiment 5 may have increased the time to learn the association between the reward-associated feature and the absence of reward which resulted in the main VDAC effect being observed in this experiment, but not in Experiment 3. These findings are consistent with findings showing that infrequent distractors are less effectively ignored than frequent ones (Geyer et al., 2008; Müller et al., 2009).

The VDAC effect was found to decrease over time and was no longer present in the final 100 trials of the test phase suggesting that VDAC is subject to extinction. Furthermore, a similar pattern of results to Experiment 3 can be seen as RTs to rewarded trials become faster relative to non-rewarded trials suggesting that the reward-associated distractor may be suppressed over time to avoid distraction. These results contrast with Anderson & Yantis (2013)the main VDAC effect being observed in this experiment, but not in Experiment 3. These findings are consistent with findings showing that infrequent distractors are less effectively ignored than frequent ones (Geyer et al., 2008; Müller et al., 2009).

The VDAC effect was found to decrease over time and was no longer present in the final 100 trials of the test phase suggesting that VDAC is subject to extinction. Furthermore, a similar pattern of results to Experiment 3 can be seen as RTs to rewarded trials become

faster relative to non-rewarded trials suggesting that the reward-associated distractor may be suppressed over time to avoid distraction. These results contrast with Anderson & Yantis (2013) who report a lack of extinction of VDAC in the absence of reinforcement. Therefore, we failed to replicate that VDAC results in an enduring change in attentional priority even when using identical task features.

We also found evidence of an impact of the combination of both VDAC and SDAC but no pure selection driven effect consistent with results in Experiment 4. In the context of the current experiment and the inclusion of the salient shape singleton target, these findings could suggest that reward associated features gain salience across both feature dimensions leading to VDAC. However, previously selected features are not subject to the same gains is salience as previously reward associated features, as SDAC was not observed even when a physically salient singleton is present.

General Discussion

VDAC is an involuntary bias of attention for a feature that was predictive of a rewarding outcome, in the absence of reinforcement of the reward association (Anderson et al., 2011b; Anderson & Yantis, 2013). In the present study, we investigated how typical design features of VDAC paradigms affect the persistence of VDAC, and its extinction. In all experiments, during the learning phase, there was either an effect of reward condition and/or an interaction between reward condition and trial order, which indicated that participants learned the feature-reward contingencies. The reliable observation of reinforcement learning here is in contrast to many reports where VDAC was observed at test without evidence of reinforcement learning during the learning phase (Mine & Saiki, 2015; Rajsic et al., 2017; Roper et al., 2014; Sali et al., 2018; Theeuwes & Belopolsky, 2012). During the test phase it was found that VDAC task-features affect whether VDAC is observed or not, VDAC was only reliably observed when there was a salient singleton target and absent trials were present which are the typical design features. Therefore, to observe VDAC it may be necessary to have the combination of the salient singleton and absent trials as both factors are known to increase vulnerability to capture. When VDAC was observed it was subject to extinction suggesting that reward-associations do not create an enduring change in attentional priority and can be overcome when the reward-associated distractor is presented in the absence of reward over many trials.

Presence of value-driven attention capture

Evidence of an effect of reward was observed in two cases in the test phases of the current study: either when (1) the formerly reward-associated feature remained task relevant (Experiment 1), or (2) the target feature was physically salient and orthogonal to the task-irrelevant, reward-associated feature and there was a reduced frequency of exposure to the reward-associated feature (Experiment 5). Indeed, when the reward associated feature was task-irrelevant at test, as is typical of VDAC paradigms, we found evidence against the presence of VDAC in four separate experiments (Experiments 2a, 2b, 3, and 4).

The only experiment where we reliably found evidence of VDAC was in Experiment 5, which was a direct replication of typical VDAC design features (a physically salient target and the inclusion of absent trials). This indicates that the combination of these design features may be necessary to give rise to VDAC. VDAC was also not persistent throughout the test phase suggesting that VDAC does not create an enduring change in attentional priority and is very much subject to extinction which is inconsistent with previous claims (e.g., Anderson & Yantis, 2013). In Experiment 3 we did find evidence of an extreme interaction between reward condition and trial which indicated that reward did have an impact on attention as trails with the reward-associated feature present became faster over time relative to trials with the non-reward associated feature, an effect that was similarly observed in Experiment 5.

As described earlier, the current study was not intended to be an exhaustive investigation of the boundaries of the VDAC effect, its persistence, or extinction. However, our study does investigate, and indeed support, the possibility that common paradigm design features, not typically described as being particularly critical, are in fact important for the persistence of VDAC. One feature appears to be critical, and there are good reasons for that to be so. Specifically, to make the reward-associated feature irrelevant at test the target feature is often orthogonal to the reward-associated feature, i.e., from a different feature dimension and also physically salient. Our results show that this choice is not benign. The implications for this result are discussed further in the following section. The inclusion of absent trials in Experiment 5 could have also contributed to the observation of VDAC as the control of attention is affected by the frequency of distractors such that infrequent distractors are less effectively ignored than frequent ones (Geyer et al., 2008; Müller et al., 2009). The combination of both factors could be necessary to observe to VDAC.

Extinction of value-driven attention capture

In addition to the persistence of VDAC we also investigated the extinction of VDAC – that is, the reduction of the VDAC effect with repeated exposures in the absence of reinforcement (Pavlov, 1927). VDAC extinction, or lack thereof, is not often reported (but see Anderson et al., 2011a, 2016; Asutay & Västfjäll, 2016; Sali et al., 2018). As discussed earlier, VDAC has been observed following both Pavlovian (Bucker & Theeuwes, 2017) and instrumental learning (Failing & Theeuwes, 2017). In either case, if VDAC is an example of such conditioning, one would expect to observe its extinction. If VDAC does not extinguish, it suggests that conditioning alone does not result in the acquisition or persistence of VDAC, but rather that there is some additional factor that uniquely prevents typical extinction learning. We found evidence of extinction of a reduction in the effect of reward in both cases where there where there was an effect of reward during test in the absence of reinforcement when the formerly reward associated feature: (1) remained task relevant (Experiment 1); and (2) was task irrelevant, but was orthogonal to the target feature, which itself was physically salient (Experiment 5). Evidence for extinction of the effect of reward was anecdotal in the case of Experiment 1, where the reward-associated feature remained task relevant at test (during extinction learning). The evidence of an interaction between reward and trial was extreme in the case of Experiments 3 and 5, where the reward-associated feature was task irrelevant at test, in the context of a salient and orthogonal target feature. Experiment 5 is closest to the typical VDAC paradigm, and the results indicate that VDAC is very much subject to extinction. The fact that evidence of a reduction in the effect of reward in Experiment 1 was only anecdotal may be due to the interference to extinction learning where the conditioned stimulus (reward-associated feature) must still be attended, although other possibilities exist and deserve to be investigated further. While our results are not conclusive as to what factors influence the extinction of VDAC in the absence of reinforcement, they do allow us to conclude that: (1) VDAC is subject to extinction, and (2) whether VDAC is extinguished may depend on whether the reward-associated feature is unattended, and (3) also possibly whether it is outcompeted for visual attention by an orthogonal and physically salient target feature (Treisman, 1985; Wolfe, 1994). One possible explanation of why the presence of the singleton increases the likelihood of extinction of VDAC is that the conspicuity of the target facilitates the resolution of the competition between the previously rewarded associations and the new associations. Capture by the reward-associated feature may be actively suppressed when using singleton search due to such competition. We observed that trials containing the reward-associated feature became faster relative to the non-rewarded trails in both Experiments 3 and 5 consistent with the suggestion that the reward-associated feature is suppressed over time to avoid distraction.

Furthermore, the length of our test phases were 1600 trials with 800 and 400 exposures to the reward associated feature in Experiment 3 and 5 respectively. In contrast, previous work has used between 60 and 120 trials with a reward-associated feature during the test phase (Anderson et al., 2011a, 2011b; Anderson & Yantis, 2012, 2013). Capture by the reward-associated feature may be actively suppressed when using singleton search due to such competition. We observed that trials containing the reward-associated feature became faster relative to the non-rewarded trails in both Experiments 3 and 5 consistent with the suggestion that the reward-associated feature is suppressed over time to avoid distraction.

Furthermore, the length of our test phases were 1600 trials with 800 and 400 exposures to the reward associated feature in Experiment 3 and 5 respectively. In contrast, previous work has used between 60 and 120 trials with a reward-associated feature during the test phase (Anderson et al., 2011a, 2011b; Anderson & Yantis, 2012a, 2013). It’s likely that previous studies did not have a sufficient number of trials to observe extinction. However, our results demonstrate that over many exposures in the absence of reward that VDAC is subject to extinction.

Selection demands

The key pattern of evidence emerging from the current study is that it appears that when the reward-associated feature is task-irrelevant at test, VDAC depends on how the target is defined. Specifically, we only observed VDAC in the presence of a salient shape singleton target and the inclusion of absent trials. As mentioned earlier, this difference in how the target is defined amounts to a difference in selection demands of the visual search task at test. In Experiments 2a/b/4 the target could not be selected based on salience and *required* the distinction between kinds (or feature values) of the same feature dimension. In contrast, in the two Experiments where there was evidence of an effect of reward when task irrelevant (Experiments 3 and 5), the visual search task at test was a singleton search that demanded the most salient feature of a specific dimension be selected and did not require the discrimination within that dimension. Arguably, this task also did not demand that salient features from other dimensions be ignored. I(Bacon & Egeth, 1994; Lamy et al., 2006; Lamy & Egeth, 2003). If the presence of VDAC requires singleton search, then why has VDAC been observed in tasks that do not demand singleton search (e.g., Della Libera & Chelazzi, 2009; Failing & Theeuwes, 2014; MacLean & Giesbrecht, 2015a, 2015b)? It is important to note that the tasks used in these studies were either not visual search (Della Libera & Chelazzi, 2009; Failing & Theeuwes, 2014), or were visual search with partial report (MacLean & Giesbrecht, 2015a, 2015b). These tasks make very different demands than the visual search task typically used in VDAC experiments, and it appears that the type of search demanded by the task plays a very important role in whether VDAC is observed or not.

One possible explanation for this seemingly discrepant pattern of results is the nature of the task-relevant attentional set. In each of the studies that observed VDAC in the absence of a target defined by a salient singleton, the potential target set was greater than one. A focused, or singular, attentional set may prevent distraction by the reward-associated feature, while a wider set (>1) creates a vulnerability to capture or distraction. When searching for one specific target item, as is the case with the shape singletons in typical VDAC experiments (and the present Experiments 3 and 5), all other features/dimensions can be ignored. When search involves a greater set, more features/classes must be attended, thereby increasing the likelihood that an irrelevant feature/dimension captures attention. Importantly, if this is the case, then it appears that the larger attentional set must also consist of a different class (or dimension/category) than the previously rewarded feature, in the absence of a salient target; at least in the context of a visual search task as used here, and as is typical of VDAC experiments. This is because in Experiments 2a/b/4, the target set was >1 (two colors), but the target set and the previously rewarded feature were the same feature class (i.e., color). More generally this means that VDAC occurs more reliably when there is some vulnerability introduced by the search mode, either by salience, a wider attentional set, and/or inter-class competition. The vulnerability required to elicit VDAC is likely task dependent. Further work would be required to test this possibility; however, it does suggest that VDAC is not unavoidable and can be prevented quite effectively with a narrow focus of attention as demanded by the task.

Selection-driven attention capture (SDAC)

In addition to reward, selection history – previous experience selecting a feature – appears to play a critical role in shaping attention, unique from that of reward history. In the current study, two experiments allowed us to explore the persistence of SDAC and its extinction – Experiments 4 and 5, where the use of absent trials provides a baseline for comparison with trials where a former target feature was present (non-rewarded), and where a former target and former reward-associated feature was present (rewarded). We did not find evidence that selection history resulted in persistent SDAC in the absence of reinforcement or selection. However, the combination of selection and reward history's effects on performance was a unique case among those experiments where no evidence of VDAC was observed. It appears that while reward and selection history alone are not sufficient to produce effects in some cases, the combination of the two may, although possibly only when the presence of the reward-associated feature is relatively rare. This provides further support for the premise that attention is not driven only by current goals but also by several features that have guided our attention in the past (Awh et al., 2012). However, it also reinforces the need to consider that the interaction of selection history with reward history may contribute to VDAC when observed using reward-associated features that were also previously selected.

Predictors of value-driven attention capture persistence

Finally, we failed to replicate that individual differences in VWM capacity could predict VDAC inconsistent with previous findings (Anderson et al., 2011b). Previous evidence has shown that VDAC is predicted by individual differences in visual working memory (VWM) capacity (Anderson et al., 2011b). However, none of the experiments reported here employ a paradigm identical to that used in the context where the relationship was previously reported (Anderson et al., 2011b). It is possible that the relationship between VWM capacity and VDAC is particular to that paradigm. Furthermore, we found evidence that BIS was associated with VDAC during Experiment 1, such that those who have a higher BIS score also had a larger capture effect. However, these correlations were not replicated in any of the other experiments. We should also note that the sample sizes we have in each experiment may not have been sufficient to detect such relationships.

Conclusions

Overall, the findings from the current study indicate that attention can be captured by features that have guided our attention in the past and features previously associated with reward, providing further evidence that the top-down and bottom-up dichotomy does not sufficiently account for the factors determining priority for attention (Awh et al., 2012). However, our findings indicate that observing VDAC depends on the design of the VDAC paradigm used. Specifically, the use of a salient and orthogonal target feature may increase the likelihood of capture because of the type of search strategy employed in these tasks. In addition, the inclusion of absent trials may further enhance the effects of a reward-associated distractor when the target feature is salient as less frequent distractors are more difficult to ignore. We only reliably found evidence of VDAC in Experiment 5 which used identical features typically used in VDAC visual search tasks suggesting these typical features may be a necessary task design to observe VDAC. Furthermore, we found that VDAC in Experiment 5 did not persist in the absence of reinforcement which is inconsistent with reports that VDAC creates an enduring change in attentional priority. Given the homogeneity of the paradigms used when drawing conclusions about VDAC this has implications for a large part of the literature

Chapter III: Generalizability across domains of attention

Introduction

As discussed in Chapter two there has been a considerable amount of work examining how attention can be involuntarily captured by stimuli previously associated with reward (e.g., Anderson et al., 2011a; Anderson & Halpern, 2017; Anderson & Yantis, 2013; Failing & Theeuwes, 2014; Hickey et al., 2010; MacLean et al., 2016; MacLean & Giesbrecht, 2015a, 2015b). VDAC has been shown to result from a broad set of reward stimulus associations including color (Anderson et al., 2011b; MacLean & Giesbrecht, 2015a), orientation (Laurent et al., 2015), spatial location (Chelazzi et al., 2014; Cho & Cho, 2020; Liao & Anderson, 2020a; Sisk et al., 2019) and even complex objects or visual scenes (Failing & Theeuwes, 2015; Hickey & Peelen, 2017). VDAC has also been shown to generalize to auditory attention (Anderson, 2016; Asutay & Västfjäll, 2016b; Kim, Grégoire, et al., 2021; Kim, Lee, et al., 2021), olfactory attention (Pool et al., 2014), and from one task to another unrelated task (Anderson et al., 2012). Recent studies examining VDAC have primarily focused on involuntary shifts of spatial attention where attention is captured by task-irrelevant features that were previously associated with reward (Anderson et al., 2011; Anderson & Yantis, 2013). Considering the broad range of impacts that VDAC has been demonstrated to have on attention, it would be expected that VDAC could also affect other types of attention other than selective attention but there is limited research on how such features could impact sustained attention.

Sustained attention is the ability to maintain goal-directed focus over a long period of time despite the mundaneness of the task or the presence of distractors (Robertson et al., 1997). Sustaining attention over time is critical to many tasks that we carry out in our everyday lives. However, our ability to maintain attention is an effortful process that can be vulnerable to lapses in attention over time due to factors such as distraction, fatigue, motivation, and arousal. The decrement in performance when sustaining attention over time has been studied for many decades (Mackworth, 1956). Performance errors arising from lapses in attention can have disastrous outcomes when performing high-stakes tasks such as driving, screening security footage, or riding a bike. Consider the example of driving, this task requires a great deal of attentional resources and lapses in attention due to both external factors (distractors, abrupt onset of stimuli) and internal factors (fatigue, mind-wandering) could result in failure to detect something in the environment that requires an immediate response e.g., braking to avoid hitting the car in front of you. Distraction due to mobile phone use has been shown to impair driving performance due to such failures in visual attention (Strayer et al., 2003).

There are two prominent theories that provide different predictions for the possible effects of reward on sustained attention. The first is Resource theory which proposes that sustaining attention relies on a limited pool of resources that reduces with time-on-task resulting in a deterioration in performance (Grier et al., 2003). Under this framework, enhancement in sustained attention due to the presence of reward would deplete these limited resources more rapidly resulting in a larger vigilance decrement over time. In contrast, Underload theory suggests that lapses in sustained attention are due to the intrusion of task-unrelated thoughts and under arousal due to the mundaneness of sustained attention tasks (Manly et al., 1999). Therefore, factors that increase motivation such as reward would be expected to improve sustained attention under this model.

Research has shown improved sustained attention performance when rewarded (Bergum & Lehr, 1964; Esterman et al., 2014; Horne & Pettitt, 1985; Massar et al., 2016). Furthermore, it has been demonstrated that reward can enhance overall performance during sustained attention, but that time-on-task is insensitive to reward as performance decrements continued to be observed over time regardless of whether participants were rewarded or not (Esterman et al., 2014). Further research has demonstrated that anticipation of higher rewards improved sustained attention by increasing the allocation of attentional resources when rewarded consistent with increased effort (Massar et al., 2016). These effects of reward on sustained attention are not consistent with Resource theories which assume that maximal attentional effort is constant. The effects are also not easily explained by Underload theories as an increase in effort does not account for mindlessness that can occur during sustained attention tasks.

Although, research has demonstrated that reward can improve sustained attention, there is limited evidence of whether arbitrary visual features previously associated with reward can disrupt sustained attention when presented as a distractor. However, one study by Bachman, Hunter, Huettel and Woldorff (2021) has examined value-driven attention capture during a sustained attention task when a transient distractor previously associated with reward was introduced at a different spatial location. The distractor was found to decrease sustained spatial attention as reflected by a reduction in the steady-state visual evoked potential (SSVEP) response elicited by the task. This effect was not found to be modulated by prior reward-associations. Accuracy and reaction time on the sustained attention task were also not found to differ between reward conditions. The authors concluded that VDAC does not exert a universal influence upon all forms of attention. In this study, there was no introduction of a novel distractor (all distractor colors at test had been presented during the learning task), it would be interesting to explore whether selection history would have also had an impact in this task as previous work has demonstrated the impact of selection history in the absence of reward history (Milner et al., 2023). Nonetheless, previous research has not examined whether arbitrary visual features that have previously been associated with reward that no longer relate to current goals can continue to either enhance or impair performance over a prolonged period when attention must be maintained in the absence of any shifts of spatial attention. i.e., where the reward-associated features appear at the same location as the sustained attention task.

Research has demonstrated that salient features are also able to cause distraction during sustained attention (Demeter et al., 2008; Demeter & Woldorff, 2016). Like salient distractors, VDAC research has primarily focused on the orienting of spatial attention in an exogenous fashion. However, there have been some studies demonstrating that previously rewarded stimuli that are no longer task-relevant are able to bias task performance in the absence of spatial shifts of attention (Failing & Theeuwes, 2015; le Pelley et al., 2017, 2019).

The experiments in this chapter will examine how visual features associated with reward will impact attention during a sustained attention task. These experiments will allow for the investigation of whether reward-associated features impact attention even when spatially independent i.e., reward-associated features and targets/non-targets occur at the same location. In the current study, the effect of reward-associated features during sustained attention was investigated, where participants are presented with a serial presentation of stimuli. Standard stimuli are 800 ms and target stimuli are presented for a 40% longer duration of 1120 ms. To complete the task participants must continuously monitor the stimuli to detect the long duration stimulus. This task is referred to as the continuous temporal expectancy task (CTET; O’Connell et al., 2009). The task is demanding when continuously performed and lapses of attention occur often. The typical finding in this task is consistent with Resource theories such that detection performance declines within a block (O’Connell et al., 2009). In the experiments reported here, we tested whether sustained attention was impacted when a reward-associated feature was presented on a target (Experiment 1), the reward-associated feature was also presented on a target but the frequency of exposure to the reward-associated feature was reduced (Experiment 2) and when a reward associated feature was presented on a distractor (Experiment 3).

Experiment 1

The purpose of the first Experiment was to investigate if visual features associated with reward would improve performance on a sustained attention task when the reward-associated feature was presented on a target. During the learning phase, participants responded to long-duration stimuli within a rapid visual serial presentation (RSVP) stream. Targets were always surrounded by a red or blue border, one color resulted in a reward and the other with no reward. It was expected that during the learning phase, participants would respond to a greater number of rewarded than non-rewarded targets thereby improving performance on the task when rewarded. During the test phase, participants continued to respond to long-duration targets that were surrounded by the same-colored borders. It was expected that the reward-associated feature would continue to be prioritized in visual attention as it remained task-relevant and would continue to benefit performance when targets are surrounded by a reward-associated color relative to a non-reward associated.

Method

Participants

Forty-six healthy participants (32 Female, M_{age} = 21.39, SD_{age} = 4.41) were recruited from the Psychological and Brain Sciences paid research participation pool at the University of California, Santa Barbara. Eight participants were excluded from the final analyses due to either a high false alarm rate or poor accuracy during the task resulting in a final sample of 38 participants (25 Female, M_{age} = 21.34, SD_{age} = 4.30). For all Experiments, participants received $10 per hour for participation and momentary compensation depending on performance on the learning task (average of $4.21). All participants reported normal or corrected-to-normal vision. All participants provided informed consent prior to completing the experiment, and all procedures were approved by the University of California Santa Barbara Human Subjects Committee and the Army Research Office/Human Research Protection Office.

Apparatus and Stimuli

The experiment was created using OpenSeasame/OSWeb (Mathôt et al., 2012) and run online using JATOS (Lange et al., 2015). Participants were instructed to sit approximately 60cm away from their computer screen. Stimuli in the learning and the test phases were grayscale images of 12 faces and 12 cars taken from the Max Planck Institute for Biological Cybernetics face database (Troje & Bülthoff, 1996). Images were presented in the center of a black screen [RGB: 0, 0, 0]. Different colored borders surrounded the images during the task.

Continuous Temporal Expectancy Task (CTET)

A modified version of the continuous temporal expectancy task (CTET; O'Connell et al., 2009) was used. Participants were presented with a rapid serial visual presentation (RSVP) of images of faces and cars. The length of presentation of each of the images varied depending on whether the image was a target or not, target stimuli were presented for 1120ms a 40% longer duration than for non-targets which were presented for 800 ms (see Figure 1). Target stimuli were randomly presented after the presentation of 7 to 15 standard duration trials (average 11). Participants were instructed to attend the RSVP stream and when they perceived a long-duration target to report whether the image was either a face or a car by pressing either “z” or “m” (counterbalanced across participants).

CTET: learning

During both the learning and test phase the images of faces and cars were surrounded by a colored border (see Figure 1a). Non-target stimuli had a colored border randomly selected from the following list: orange [186, 93, 16], teal [22, 128, 109], brown [140, 111, 78], green [63, 129, 45], gold [146, 111, 16], violet [169, 60, 203], pink [199, 40, 154], mauve [166, 97, 100], moss [122, 122, 0] and gray [115, 115, 115]. The only restriction was that no two colors could be presented consecutively. Target stimuli were always red [233, 0, 0] or blue [17, 103, 241]. One of these colors resulted in a momentary reward with 80% probability (5¢) while the other color resulted in no reward. Red was the rewarded color for half of the participants and blue for the other half. The color of the border was independent of whether the image was a face or a car. Incorrect responses resulted in the delivery of no reward. Once a response was made, participants were presented with the reward that they received for 800 ms which was simultaneously presented with the ongoing RSVP stream. During the entire learning phase, the total amount of money accrued over the course of the task was presented under the RSVP stream.

CTET: test

During the test phase, participants continued to respond to target stimuli and indicate whether a face or car was presented. Targets continued to be surrounded by red or blue borders, but participants were no longer rewarded (see Figure 1b).

Procedure

Participants completed two 1.5-hour sessions that took part on separate days exactly one-week apart. In the initial session, participants completed informed consent, a demographic questionnaire, and the BIS/BAS scales. Participants then completed the change-detection task to measure working memory. Participants were then familiarized with the main task and were provided with an oral description of the task. Participants completed a practice block that was identical to the learning except that there were no colored borders and participants were not given reward feedback. Instead, participants were given on-screen feedback indicating correct or incorrect responses. Once participants passed the practice block, they completed the learning task. One-week later participants returned for the second session and completed the test task that was identical to learning but participants no longer received reward feedback.

Design and Analysis

To complete the practice participants had to attain greater than 70% of correct detections of the long duration target and a false alarm rate below 10%. Both the learning and the test phase consisted of 10 blocks, each with 320 stimulus presentations. Of the 320 stimuli presentations, there were 26 long-duration targets (13 rewarded, 13 non-rewarded).

Detections, discriminations, and response time were measured. After the onset of the target participants could respond within a 2,720 ms time-window (1120 ms target presentation and two subsequent standard duration stimuli). Detections are defined as correctly identifying a long duration target regardless of whether the face/car discrimination was correct. Discriminations were defined as correctly identifying the target and correctly identifying whether the target was a face or a car. Detections and discriminations tracked closely so the analyses so only the detection data are reported. Response time was measured from the time it was possible to detect that the stimulus was of a longer duration (800 ms). Only trials where the target was correctly detected were included in the analyses.

Participants whose false alarm rate was greater than 2 standard deviations from the mean in either the learning or the test phase were excluded from the analyses. To exclude participants based on poor detection accuracy in the task, we used the upper bound of the

95% confidence interval around 0 as a cut-off. Participants whose accuracy fell below this threshold for more than half of the 10 blocks in either learning or test were excluded from the analyses. The same exclusion criteria were used across all the following Experiments, this resulted in a cut-off of between 6.69%-10.33% across all Experiments.

BIS/BAS and Change-detection task

See the BIS/BAS and Change-detection sub-sections in Chapter two Experiment 1 methods.

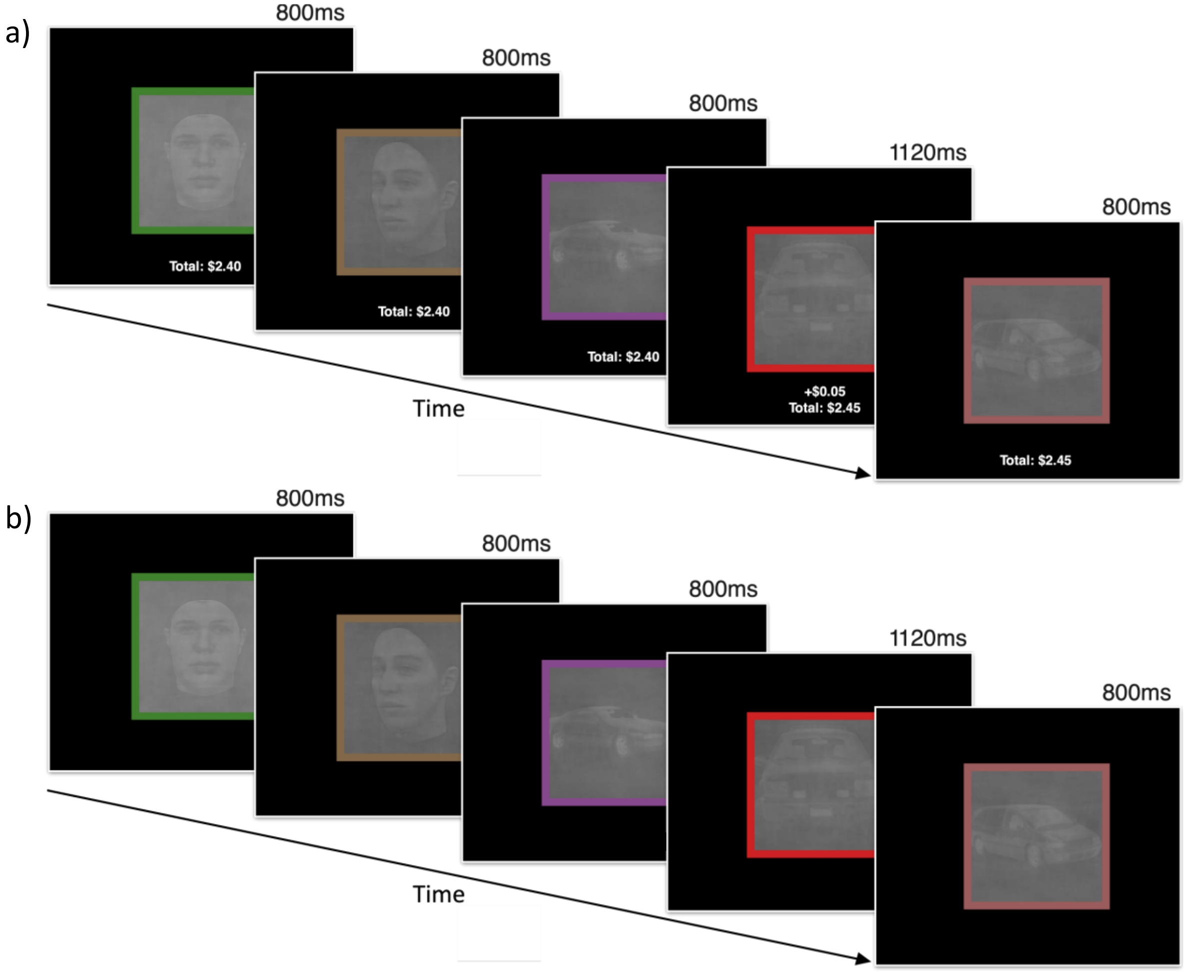

Figure 1. a) Trial sequence in the learning phase. Non-target stimuli were presented for 800 ms and target stimuli for 1120 ms. Targets were always surrounded by a red or blue border. One of these colors resulted in the delivery of a reward upon correct response and the other color with no reward. Reward feedback was presented on the screen for 800 ms after making a response. b) Trial sequence was identical to learning, targets continued to be red or blue long-duration images, but participants were no longer rewarded in the test phase.

Results

CTET: Learning

Detections

A general linear mixed effects model (GLMM) was used to examine detections during the task with the fixed effects of block (1-10), trial (1-26), and reward condition (reward, non-rewarded; see Figure 4). There was an effect of block such that overall detections decreased over the course of each block (*b* = 1.06, *SI* = [0.66, 1.46], *RPE* = ± 0.05, *BF* > 1000; see Figure 2). There was no evidence of an effect of trial (*b* = -0.21, *SI* = [-0.62, 0.21], *RPE* = ± 0.05; see Figure 3), there was strong evidence in support of the null (*BF* = 0.036). There was an effect of reward condition such that participants responded to a greater number of rewarded than non-rewarded targets (*b* = -1.30, *SI* = [-1.82, -0.77], *RPE* = ± 0.05, *BF* = 187.48). There was no evidence of an interaction between block and trial (*b* = 0.53, *SI* = [-0.78, 1.94], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.028). There was an interaction between block and condition such that participants responded to a greater number of rewarded relative to non-rewarded over the course of each block indicating that participants had learned the reward association (*b* = -2.78, *SI* = [-3.27, -2.27], *RPE* = ± 0.05, *BF* > 1000; Figure 2). There was no evidence of an interaction between trial and condition (*b* = -0.31, *SI* = [-0.82, 0.21], *RPE* = ± 0.05, Figure 3), there was strong evidence in support of the null (*BF* = 0.047). There was no evidence of a three-way interaction (*b* = -0.20, *SI* = [-1.89, 1.50], *RPE* = ± 0.05), with very strong evidence in support of the null (*BF* = 0.017).

Reaction Time

A similar GLMM on the dependent variable reaction time revealed that there was an effect of block such that RTs became faster as block order increased (*b* = -209.21, *SI* = [-

244.95, -174.35], *RPE* = ± 20.87, *BF* > 1000; see Figure 7). There was no evidence of an effect of trial on RT (*b* = 0.23, *SI* = [-36.14, 34.62], *RPE* = ± 6.98; see Figure 5), there was decisive evidence in support of the null (*BF* = 0. 002). However, there was evidence of an effect of condition on RTs such that participants were faster to respond to rewarded than non-rewarded targets (*b* = 84.70, *SI* = [37.43, 133.92], *RPE* = ± 12.07, *BF* = 59.07; see Figure 6). There was no interaction between block and trial (*b* = -24.61, *SI* = [-150.14, 101.12], *RPE* = ± 5.91), there was decisive evidence in support of the null (*BF* < 0.01). There was evidence of an interaction between block and condition such that participants became faster to rewarded compared to non-rewarded targets over the course of each block (*b* = 155.32, *SI* = [104.59, 208.80], *RPE* = ± 22.67, *BF* > 1000; Figure 5). There was no interaction between trial and condition (*b* = 44.96, *SI* = [-8.24, 97.92], *RPE* = ± 8.05; Figure 6), there was strong evidence in support of the null (*BF* = 0.068). There was no three-way interaction (*b* = 58.63, *SI* = [-125.61, 241.83], *RPE* = ± 44.24) and decisive evidence in support of the null (*BF* > 0.01).

CTET: Test

Detections

Another GLMM was used to assess detections during the test phase. There was an effect of block such that detections decreased over the course of each block (*b* = -0.68, *SI* = [-1.09, -0.29], *RPE* = ± 0.05, *BF* = 28.66). During the test phase, there was evidence of an effect of trial suggesting a decline in overall detections within a block (*b* = -0.69, *SI* = [-1.09, -0.29], *RPE* = ± 0.05, *BF* = 19.82; see Figure 2). There was an effect of condition such that participants continued to respond to a greater number of rewarded than non-rewarded targets during the test phase (*b* = -1.44, *SI* = [-1.98, -0.88], *RPE* = ± 0.05, *BF* = 222.90; see Figure 3). There was no evidence of an interaction between block and trial (*b* = 0.58, *SI* = [-0.74, 1.89], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.030). There was no interaction between block and condition (*b* = -0.015, *SI* = [-0.55, 0.48], *RPE* = ± 0.05; Figure 2), there was very strong evidence in support the null (*BF* = 0.015). There was no evidence of an interaction between trial and condition (*b* = -0.091, *SI* = [-0.58, 0.41], *RPE* = ± 0.05, Figure 3), there was very strong evidence in support of the null (*BF* = 0.016). There was no evidence of a three-way interaction (*b* = -0.24, *SI* = [-2.07, 1.60], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.018).

Reaction Time

A similar GLMM was used to assess RTs during the test phase. There was no effect of block (*b* = 53.07, SI = [16.68,89.17], *RPE* = ± 19.92; see Figure 5), there was anecdotal evidence for the null (*BF* = 0.77). There was no effect of trial (*b* = 4.75, *SI* = [-34.54, 44.08], *RPE* = ± 5.58; see Figure 6), there was decisive evidence in support of the null (*BF* < 0.01). Critically, there continued to be evidence of an effect of condition such that RTs to rewarded targets continued to be faster than non-rewarded targets throughout the test phase (*b* = 98.20, *SI* = [40.46, 158.29], *RPE* = ± 13.30, *BF* = 7.69). There was no interaction between block and trial (*b* = -52.49, *SI* = [-178.87, 85.45], *RPE* = ± 5.56), there was decisive evidence in support of the null (*BF* = 0.008). There was no interaction between block and condition (*b* = -11.14, *SI* = [-69.23, 46.91], *RPE* = ± 21.95; see Figure 5), with decisive evidence in support of the null (BF < 0.01). There was no interaction between trial and condition (*b* = 13.81, *SI* = [-43.51, 70.92], *RPE* = ± 8.61; see Figure 6), with decisive evidence in support of the null (*BF* < 0.01). There was also no three-way interaction (*b* = 64.74, *SI* = [-135.89, 265.72], *RPE* = ± 40.70), there was decisive evidence in support of the null (*BF* < 0.01).

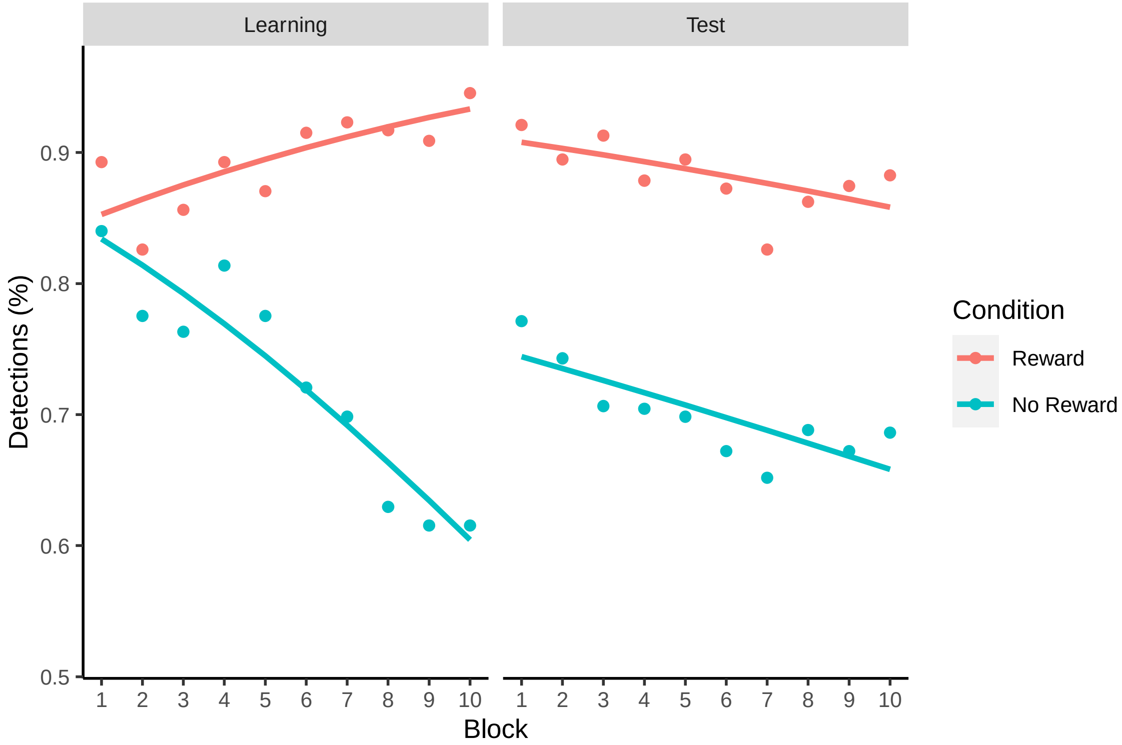

Figure 2. Detections plotted as a function of block and condition during the learning and test phase.

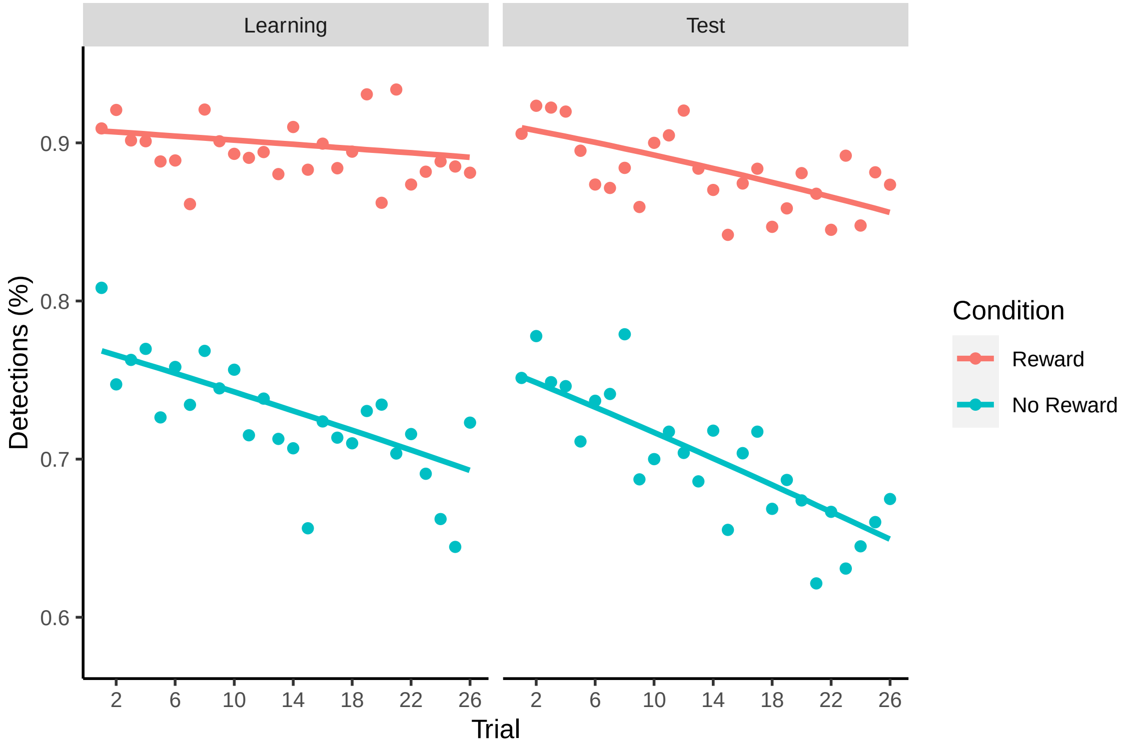

Figure 3. Detections plotted as a function of trial and condition during the learning and test phase.

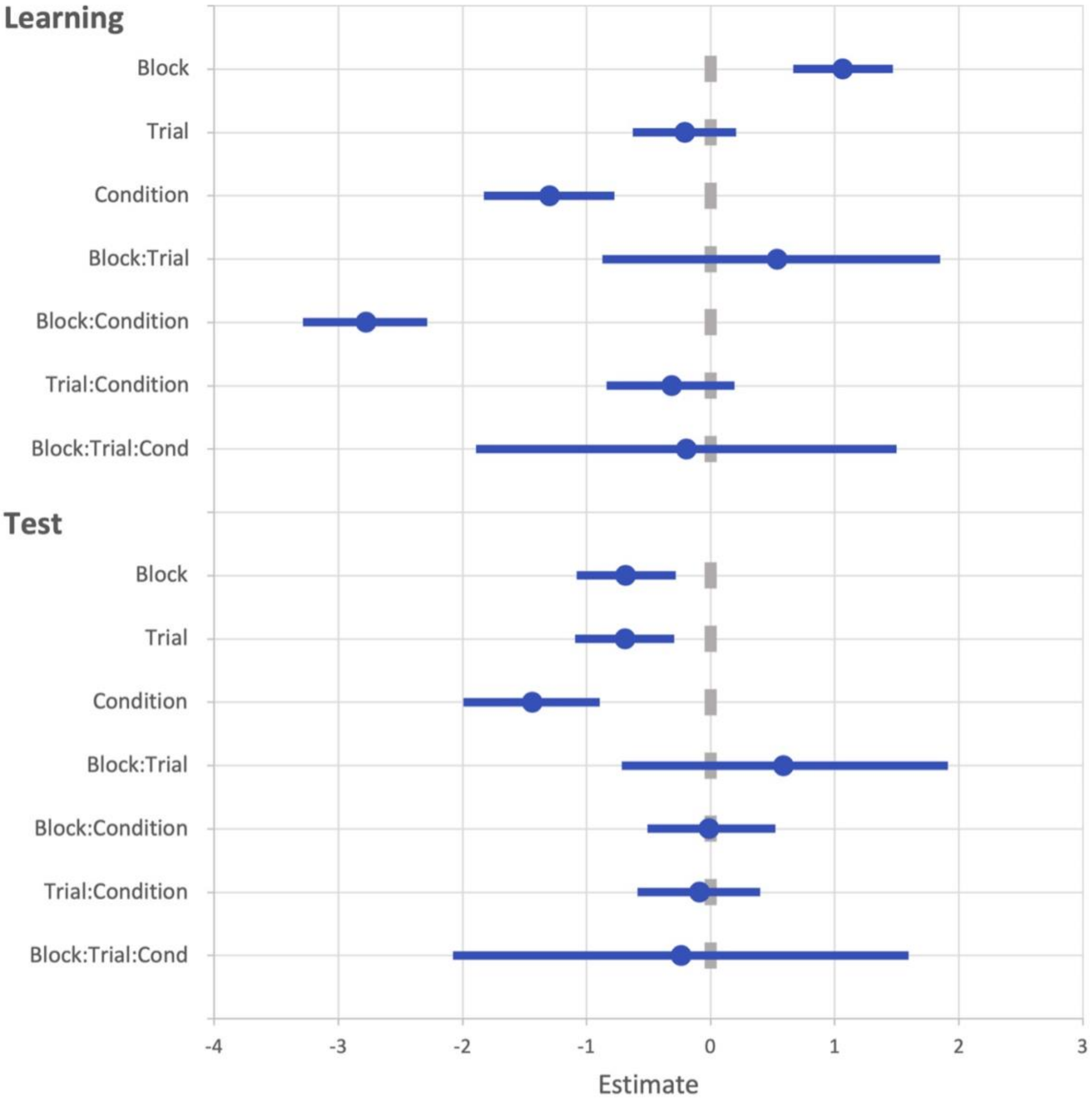

Figure 4. Mean point estimates and support intervals for each of the fixed effects from the generalized linear mixed effects model (GLMM) for detections in Experiment 1. Mean estimates are on the log odds scale. Grey boxes denote the null region (region of practical equivalence, *RPE*).

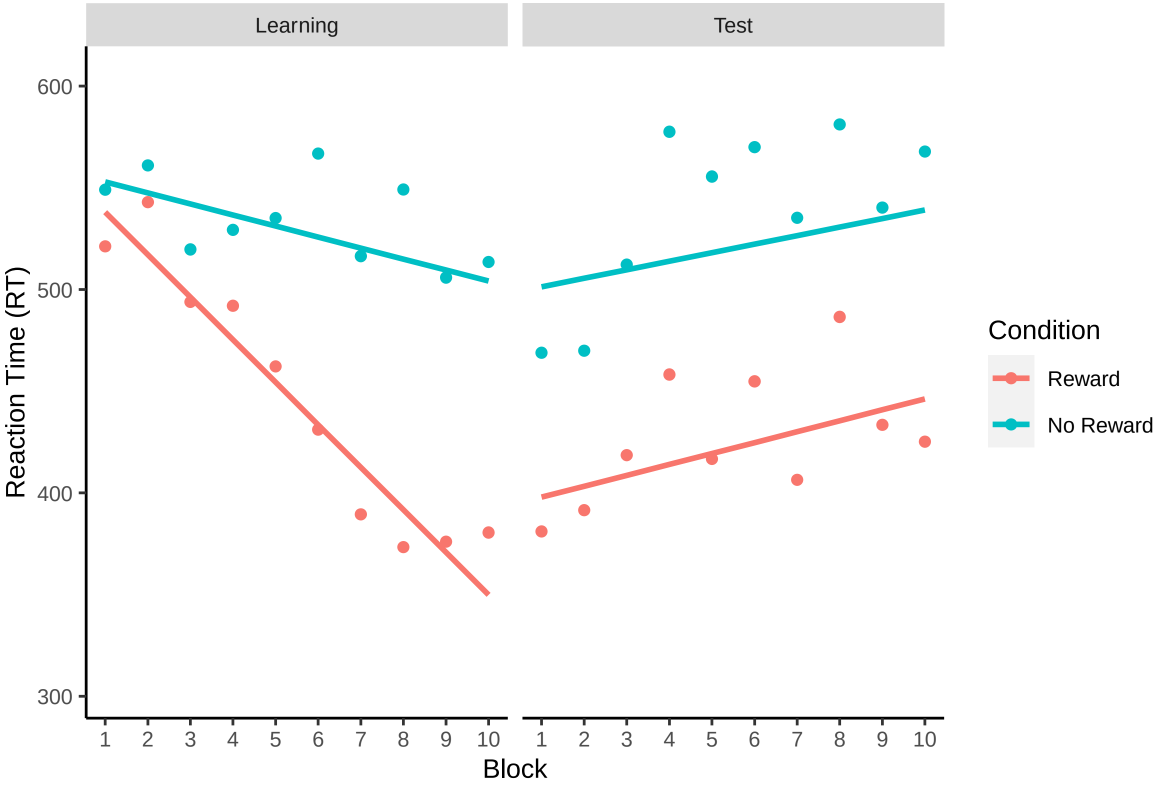

Figure 5. Reaction time plotted as a function of block and condition during the learning and test phase.

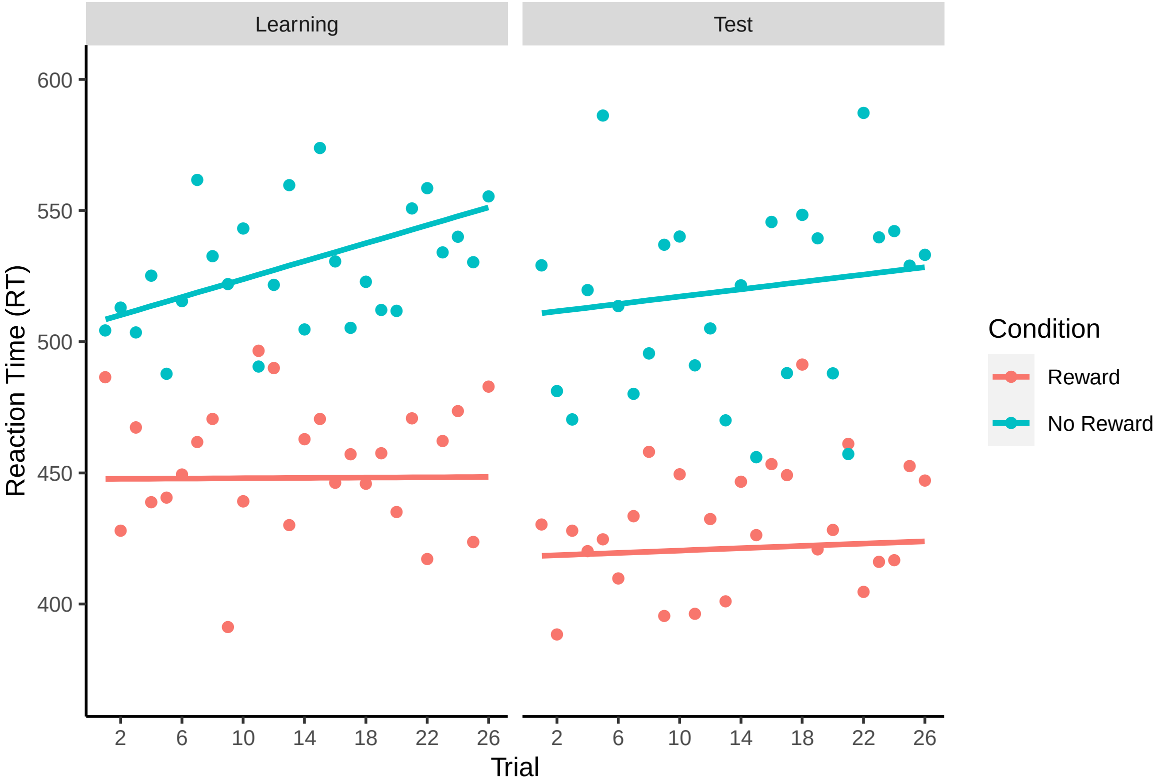

Figure 6. Reaction time plotted as a function of trial and condition during the learning and test phase.

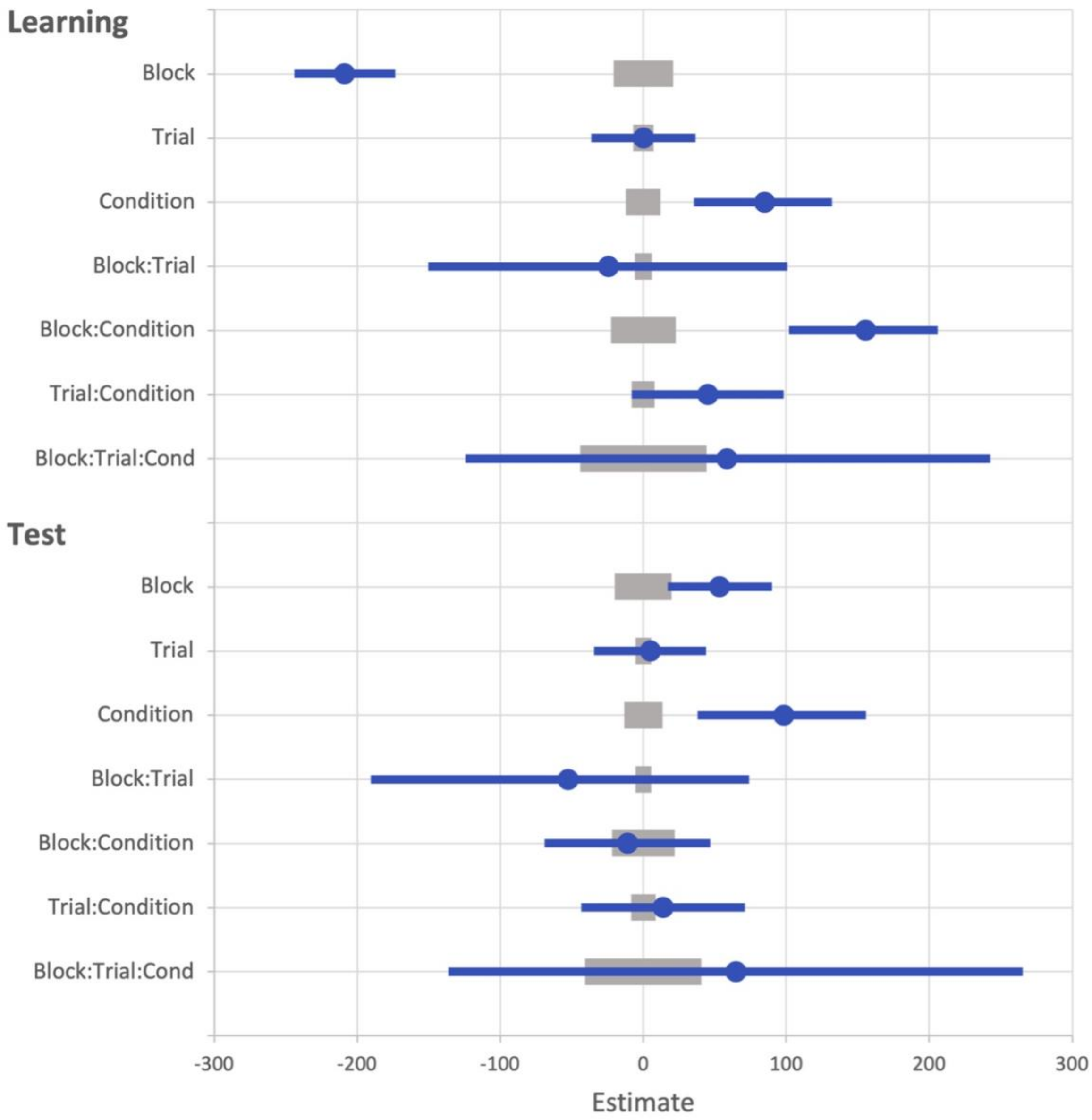

Figure 7. Mean point estimates and support intervals for each of the fixed effects from the generalized linear mixed effects model (GLMM) for reaction times (RTs) in Experiment 1. Grey boxes denote the null region (region of practical equivalence, *RPE*).

Correlations

BIS/BAS

To examine whether individual differences in the BIS/BAS scales could account for differences in reward history, the reward effect (reward coefficients for each participant for detections in the test phase) was correlated with the BIS scale and the three BAS scales (drive, fun-seeking, and reward responsiveness). The mean score for the BIS scale was 3.13 (*SD* = 0.53). The mean score for each of the BAS subscales were drive (*M* = 2.55, *SD* = 0.50), fun (*M* = 2.78, *SD* = 0.65), and reward (*M* = 3.45, *SD* = 0.45). There was no correlation between the VDAC effect and BIS (*r*(36) = -.24, *BF* = 0.55), drive (*r*(36) = -.20, *BF* = 0.39), fun (*r*(36) = 0.12, *BF* = 0.26), or reward (*r*(36) = -.013, *BF* = 0.20). There were also no correlations between RT and the BIS/BAS measures. There were no correlations between VDAC and any BIS/BAS scores in any of the subsequent Experiments, so the results are not further reported.

Working Memory

To examine the relationship between working memory and rewarded history, we correlated K (*M* = 3.60, *SD* = 0.81) and VDAC (reward coefficients from the test phase). There was no evidence of a correlation (*r*(36) = 0.12, *BF* = 0.26), suggesting that the benefit in performance towards the reward-associated feature was not related to working memory capacity. There were also no correlations between RTs and the BIS/BAS measures. There were no correlations between VDAC and any BIS/BAS scores in any of the subsequent Experiments (and K was not collected in Experiment 3), so the results are not further reported.

Discussion

In the learning phase of Experiment 1, there was evidence of both an overall effect of reward and an interaction between block and reward condition. These effects indicate that participants responded to a greater number of rewarded than non-rewarded targets and the difference between these conditions increased over time, demonstrating that participants successfully learned the reward association. The reaction time results were consistent with detections with faster RTs to rewarded than non-rewarded targets in the learning phase with the difference increasing over the course of each block.

During the test phase, there was evidence of an effect of reward suggesting that the bias to respond to rewarded targets relative to non-rewarded continued into the test phase despite no longer being rewarded. Critically, there was no interaction between condition and block or trial, suggesting that there was no reduction in this effect within a block or over the course of the entire test phase. During the learning phase, there was an effect of block and during the test phase there was an effect of both block and trial such that there was a decline in detections both within a block and over the course of each block. These results suggest that there was a vigilance decrement, as has been previously reported when sustaining attention for a prolonged time (Grier et al., 2003; O'Connell et al., 2009; Parasuraman et al., 1987; Parasuraman & Davies, 1977).

The results also demonstrated that there was a lasting impact of reward on RTs in the test phase. There was also no interaction between condition and block or trial suggesting that the effects on RT were not diminished. Overall, these results demonstrate that the effects of reward on sustained attention were not subject to extinction, consistent with Experiment 1 in Chapter II when the reward-associated feature remains task-relevant then reward related effects do not diminish.

Experiment 2

In Experiment 1 there was evidence of a continued effect of the reward-associated feature on sustained attention. In Experiment 2, a typical feature of VDAC experiments was investigated, the inclusion of absent trials. The inclusion of absent trials allows the effects of both selection and reward history to be examined as the difference between a previously selected but not rewarded feature can be compared to a novel feature that was not selected as a target during learning. It has been demonstrated that the ability to ignore distractors, is affected by the frequency that distractors are presented such that infrequent distractors are less effectively ignored than frequent ones (Geyer et al., 2008; Müller et al., 2009). In Chapter two Experiment 5, absent trials where shown to contribute to VDAC. Although, in this Experiment salient target was also contingent on observing VDAC. Therefore, it is possible that the inclusion of absent trials in this task may affect reward history and give a useful control to observe the effects of selection history in this task.

Method

Participants

Forty-one healthy participants (36 Female, M_{age} = 19.10, SD_{age} = 1.59) were recruited from the Psychological and Brain Sciences paid research participation pool at the University of California, Santa Barbara. Eight participants were excluded from the final analyses due to either a high false alarm rate or poor detection accuracy during the task resulting in a final sample of 29 participants (25 Female, M_{age} = 18.93, SD_{age} = 1.03). Participants were paid an average of $4.30 for momentary compensation for the reward task.

Procedure

Unless mentioned below, all procedures, stimuli, and tasks were the same as Experiment 1 (see Figure 1).

CTET: learning

Stimuli were the same as Experiment 1, but green [63, 129, 45] was included as a possible target color. During learning the targets were two of the following colorlist: red, blue, or green (counterbalanced among participants). One of the target colors was rewarded and one non-rewarded. The third color that was not presented as a target was also randomly presented as a non-target at the same frequency of target colors during learning.

CTET: test

During the test phase, participants continued to respond to target stimuli. In the current experiment, there was also the inclusion of absent trials where a third of targets were presented in a novel color that was not presented as a target during learning. This novel color was the color that was not presented as a target during learning (either red, blue, or green).

Design and Analysis

Both the learning and the test phase consisted of 10 blocks, each with 360 stimulus presentations. Of the 360 stimuli presentations, there were 30 long-duration targets. For the learning phase, there were 15 rewarded and 15 non-rewarded targets. In the test phase, there were 10 rewarded, 10 non-rewarded, and 10 absent trials. As there are 3 levels of the factor reward condition in the test phase, we specified contrasts for the GLMM with dummy coding where the no-reward condition was used as the reference level (intercept) to which the reward and absent conditions were compared to. This allowed for the examination of both reward history (the difference between reward and non-reward trials) and selection history (the difference between non-reward and absent trial). To quantify the combined contribution of reward and selection history we conducted an additional follow-up model with only reward and absent as levels for the factor reward condition.

Results

CTET: Learning

Detections

A general linear mixed effects model (GLMM) was used to examine detections with the fixed effects of block (1-10), trial (1-30), and reward condition (reward, non-rewarded, absent; see Figure 10). The GLMM revealed that there was an effect of block during the learning phase such that overall detections decreased a block order increased (*b* = -1.50, *SI* =

[-1.80, -1.21], *RPE* = ± 0.05, *BF* > 1000; see Figure 8). There was also evidence of an effect of trial such that overall detections decreased within a block over time (*b* = -0.45, *SI* = [-0.75, -0.16], *RPE* = ± 0.05, *BF* = 7.25; see Figure 9). There was an impact of condition such that participants detected a greater number of rewarded than non-rewarded targets (*b* = 0.88, *SI* = [0.37, 1.44], *RPE* = ± 0.05, *BF* = 2.99). There was no interaction between block and trial (*b* = -0.24, *SI* = [-1.32, 0.76], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.015). There was extreme evidence of an interaction between block and condition such that participants detections to non-rewarded targets decreased over each block relative to rewarded (*b* = 1.54, *SI* = [1.07, 1.99], *RPE* = ± 0.05, *BF* > 1000), suggesting that participants learned the association between color and reward. There was no interaction between trial and condition (*b* = -0.24, *SI* = [-0.71, -0.19], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.031). There was also no three-way interaction (*b* = -0.80, *SI* = [-2.39, 0.71], *RPE* = ± 0.05), with strong evidence in support of the null (*BF* = 0.031).

Reaction Time

Another GLMM was used to examine reaction time (RTs). See Figure 14 for point estimates. There was no evidence of an effect of block (*b* = 53.20 *SI* = [9.38, 99.98], *RPE* = ± 18.80; see Figure 12), there was substantial evidence in support of the null (*BF* = 0.29). There was no evidence of an effect of trial on RT (*b* = 30.93, *SI* = [-11.27, 72.63], *RPE* = ± 7.44; see Figure 13), there was very strong evidence in support of the null (*BF* = 0.034). There was evidence of an effect of reward condition on RTs such that participants were faster to respond to rewarded than non-rewarded targets (*b* = -99.20, *SI* = [-166.26, 33.95], *RPE* = ± 14.23, *BF* = 4.96). There was no interaction between block and trial (*b* = -22.99, *SI* = [-182.03, 124.23], *RPE* = ± 8.28), there was very strong evidence in support of the null, (*BF* =

0.015). There was an interaction between block and condition such that participants became faster the rewarded and slower to non-rewarded targets over each block (*b* = -156.40, *SI* = [-219.32, -96.35], *RPE* = ± 25.74, *BF* > 1000; see Figure 12). There was no interaction between trial and condition (*b* = -32.07, *SI* = [-94.80, 30.93], *RPE* = ± 7.87), there was very strong evidence in support of the null (*BF* = 0.015). There was no three-way interaction (*b* = 23.39, *SI* = [-79.75, 243.75], *RPE* = ± 48.50), there was decisive evidence in support of the null (*BF* < 0.01).

CTET: Test

Detections: reward and selection history

The GLMM revealed that there was evidence of an effect of block such that overall detections reduced over each block (*b* = -0.73, *SI* = [-1.10, -0.37], *RPE* = ± 0.05, *BF* = 508.29; see Figure 8). There was no effect of trial (*b* = -0.013, *SI* = [-0.38, 0.33], *RPE* = ± 0.05; see Figure 9), there was very strong evidence in support of the null (*BF* = 0.014). There was evidence of an effect of reward history (no-reward relative to reward) during the test phase such that there were a greater number of detections to rewarded than non-rewarded targets (*b* = 0.81, *SI* = [0.32, 1.31], *RPE* = ± 0.05, *BF* = 5.62). There was no evidence of an effect of selection history (no-reward relative to absent) during the test phase *b* = -0.32, *SI* = [-0.75, 0.14], *RPE* = ± 0.05), there was substantial evidence in support of the null (*BF* = 0.11). There was no interaction between block and trial (*b* = 0.75, *SI* = [-0.45, 2.04], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.047). There was no interaction between block and reward history (*b* = 0.019, *SI* = [-0.51, 0.55], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.013). There was also no interaction between block and selection history (*b* = 0.48, *SI* = [-0.03, 0.98], *RPE* = ± 0.05), there was substantial evidence in support of the null (*BF* = 0.16). There was no interaction between trial and reward history (*b* = -0.16, *SI* = [-0.68, 0.37], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.017). There was no interaction between trial and selection history (*b* = -0.26, *SI* = [-0.80, 0.24], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.027). There was no three-way interaction between block, trial, and reward history (*b* = 0.65, *SI* = [-1.36, 2.48], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.021). There was also no three-way interaction between block, trial, and selection history (*b* = -0.097, *SI* = [-1.99, 1.80], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.014).

Detections: combination of reward and selection history

The GLMM comparing the combination of reward and selection history (difference between rewarded and absent trials) revealed that there was evidence of an effect of block such that overall detections reduced over each block (*b* = -0.70, *SI* = [-1.10, -0.32], *RPE* = ± 0.05, *BF* = 48.32; see Figure 11 for point estimates). There was no effect of trial (*b* = -0.17, *SI* = [-0.57, 0.20], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.028). There was evidence of an effect of reward condition suggesting that participants had a higher number of detections to rewarded than novel-colored targets (*b* = -1.11, *SI* = [-1.56, -0.68], *RPE* = ± 0.05, *BF* = 645.78). There was no interaction between block and trial (*b* = 1.40, *SI* = [0.07, 2.79], *RPE* = ± 0.05), there was anecdotal evidence in support of the null (*BF* = 0.33). There was no interaction between block and condition (*b* = 0.46, *SI* = [-0.05, 0.99], *RPE* = ± 0.05), there was substantial evidence in support of the null (*BF* = 0.14). There was no interaction between trial and condition (*b* = -0.10, *SI* = [-0.61, 0.40], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.017). There was no three-way interaction (*b* = -0.74, *SI* = [-2.65, 1.05], *RPE* = ± 0.05), there very strong evidence in support of the null (*BF* = 0.028).

Reaction Time: reward and selection history

A similar GLMM was used to assess RTs during the test phase. There was evidence of an effect of block such that overall RTs to respond to targets reduced over each block (*b* = 167.00, *SI* = [108.56, 227.93], *RPE* = ± 32.46, *BF* > 1000; see Figure 12). There was no effect of trial (*b* = 47.34, *SI* = [-10.87, 109.82], *RPE* = ± 10.41; see Figure 13), there was strong evidence in support of the null (*BF* = 0.056). There was evidence of an effect of reward history during the test phase such that there were faster RTs to rewarded than non-rewarded targets (*b* = -72.61, *SI* = [-132.71, -15.60], *RPE* = ± 12.07, *BF* = 1.17). There was no evidence of an effect of selection history during the test phase *b* = 49.68, *SI* = [-14.21, 117.69], *RPE* = ± 14.54), there was strong evidence in support of the null (*BF* = 0.067). There was no interaction between block and trial (*b* = -49.91, *SI* = [-245.72, 146.25], *RPE* = ± 32.96), there was decisive evidence in support of the null (*BF* < 0.01). There was no interaction between block and reward history (*b* = -27.49, *SI* = [-114.92, 146.25], *RPE* = ± 32.96), there was decisive evidence in support of the null (*BF* < 0.01). There was evidence of an interaction block and selection history such that RTs were faster to non-rewarded compared to non-rewarded trials but that this difference became smaller over time (*b* = -123.82, *SI* = [-215.78, -37.63], *RPE* = ± 31.45, *BF* = 1.66). There was no interaction between trial and reward history (*b* = -0.81, *SI* = [-88.23, 86.26], *RPE* = ± 20.65), there was decisive evidence in support of the null (*BF* < 0.01). There was no interaction between trial and selection history (*b* = -29.53, *SI* = [-122.42, 63.55], *RPE* = ± 30.10), there was decisive evidence in support of the null (*BF* < 0.01). There was no three-way interaction between block, trial, and reward history (*b* = -58.38, *SI* = [-352.13, 235.83], *RPE* = ± 70.33), there was decisive evidence in support of the null (*BF* < 0.01). There was also no three-way interaction between block, trial, and selection history (*b* = -23.12, *SI* = [-314.38, 292.09], *RPE* = ± 76.25), there was decisive evidence in support of the null (*BF* < 0.01).

Reaction Time: combination of reward and selection history

The GLMM comparing reward versus absent revealed that there was evidence of an effect of block such that overall RTs reduced over each block (*b* = 139.31, *SI* = [85.59, 195.57], *RPE* = ± 34.01, *BF* > 1000; see Figure 15). There was no effect of trial (*b* = 46.50, *SI* = [-6.14, 103.13], *RPE* = ± 10.06), there was very strong evidence in support of the null (*BF* = 0.028). There was evidence of an effect of reward condition suggesting that RTs were faster to rewarded than to absent targets (*b* = 123.25, *SI* = [53.99, 194.23], *RPE* = ± 15.09, *BF* = 645.78). There was no interaction between block and trial (*b* = -107.09, *SI* = [-320.97, 91.40], *RPE* = ± 11.56), there was very anecdotal evidence in support of the null (*BF* = 0.33). There was no interaction between block and condition (*b* = -95.92, *SI* = [-182.26, 14.98], *RPE* = ± 35.97), there was substantial evidence in support of the null (*BF* = 0.14). There was no interaction between trial and condition (*b* = -29.03, *SI* = [-116.68, 52.06], *RPE* = ± 10.94), there was strong evidence in support of the null (*BF* = 0.017). There was no three-way interaction (*b* = 139.31, *SI* = [-260.99, 310.58], *RPE* = ± 76.77), there was very strong evidence in support of the null (*BF* = 0.028).

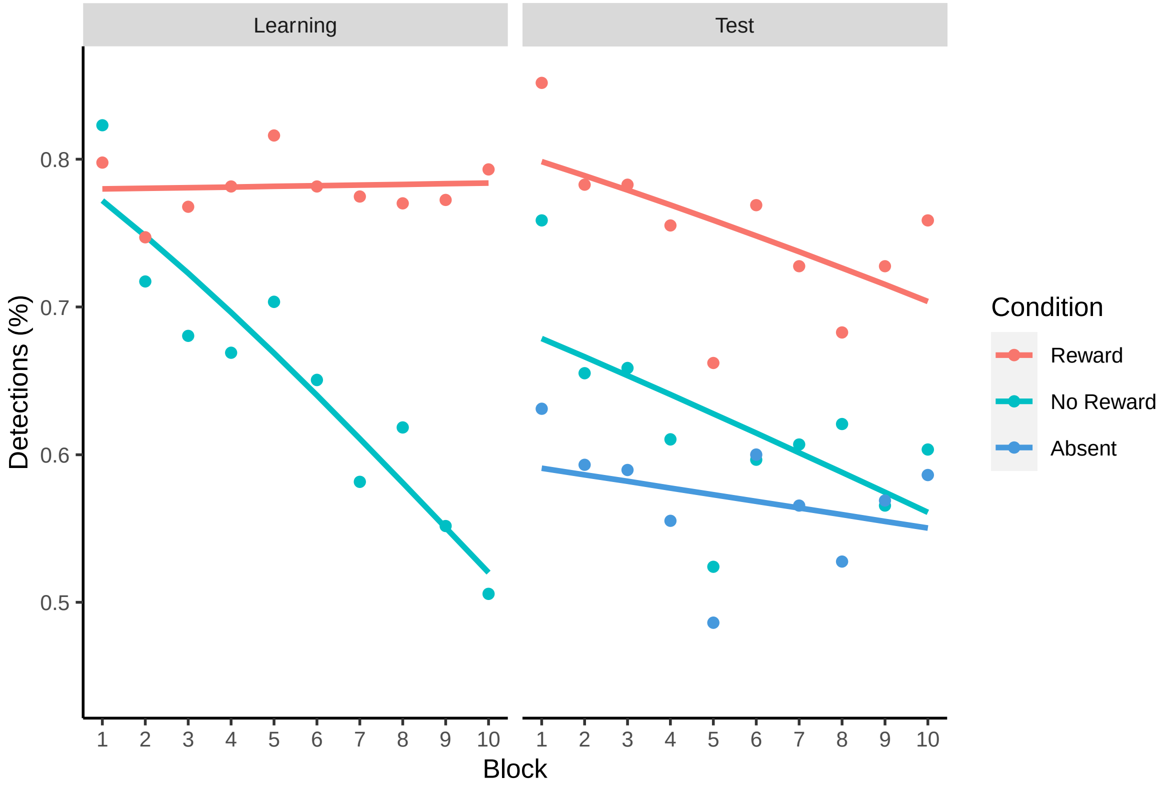

Figure 8. Detections plotted as a function of block and condition during the learning and test phase.

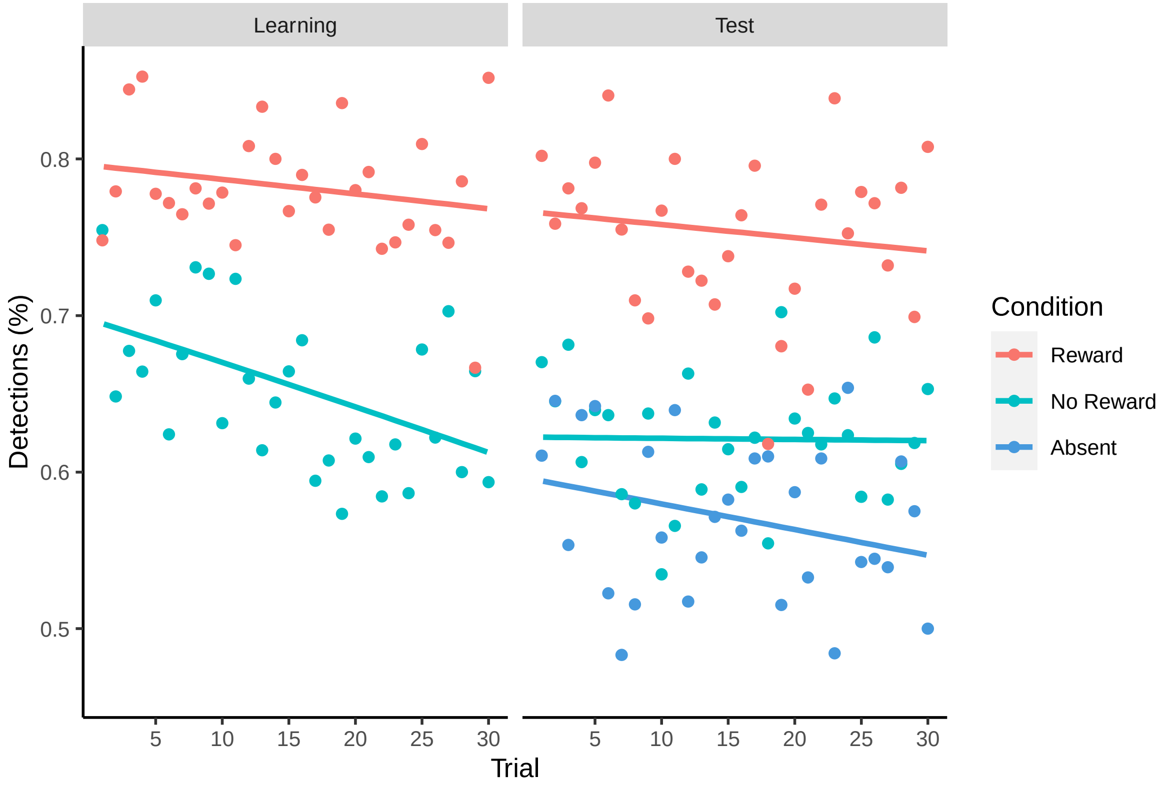

Figure 9. Detections plotted as a function of trial and condition during the learning and test phase.

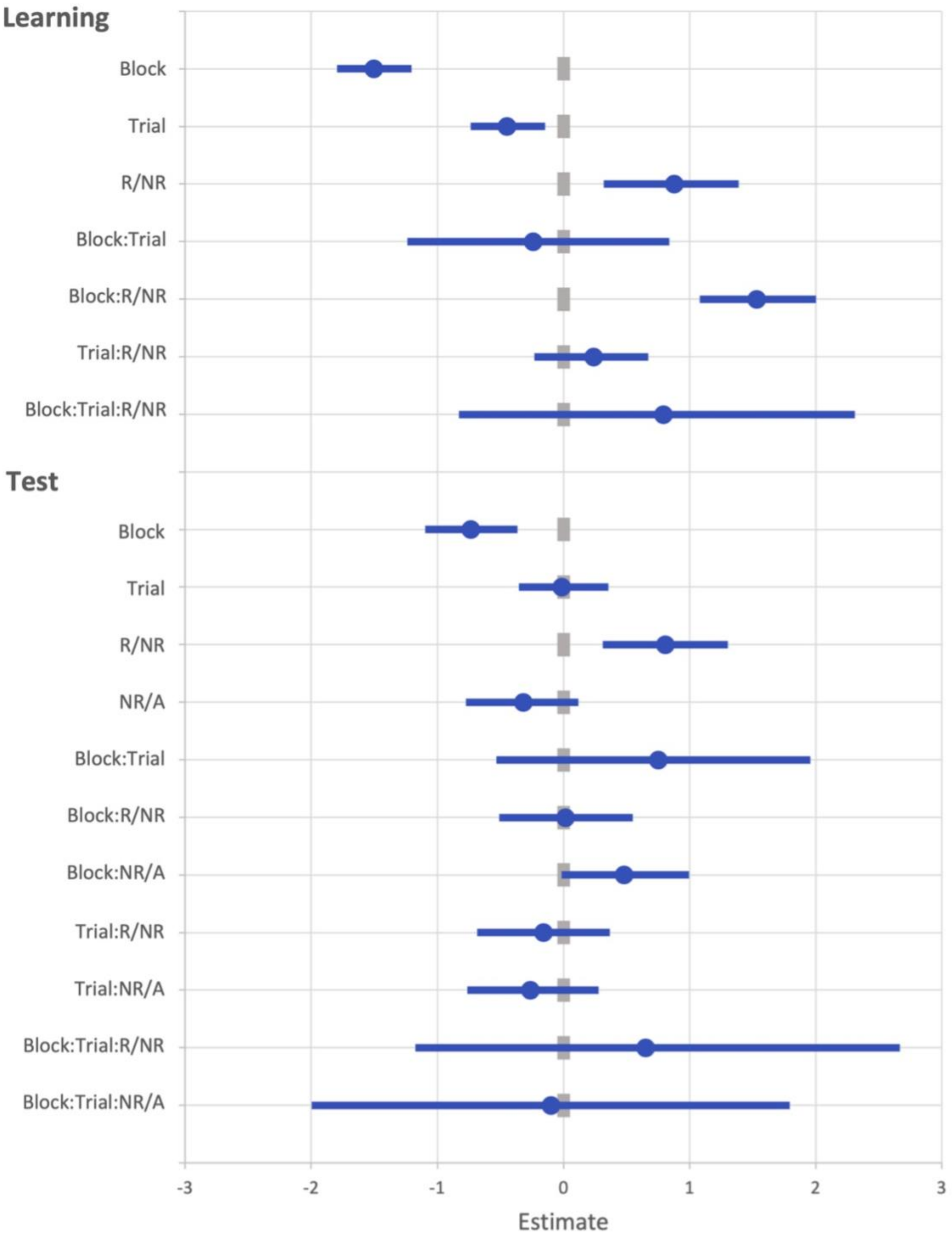

Figure 10. Mean point estimates and support intervals for each of the fixed effects from the generalized linear mixed effects model (GLMM) for detections in Experiment 2. Mean estimates are on the log odds scale. Grey boxes denote the null region (region of practical equivalence, *RPE*). R = Reward, NR = No-Reward.

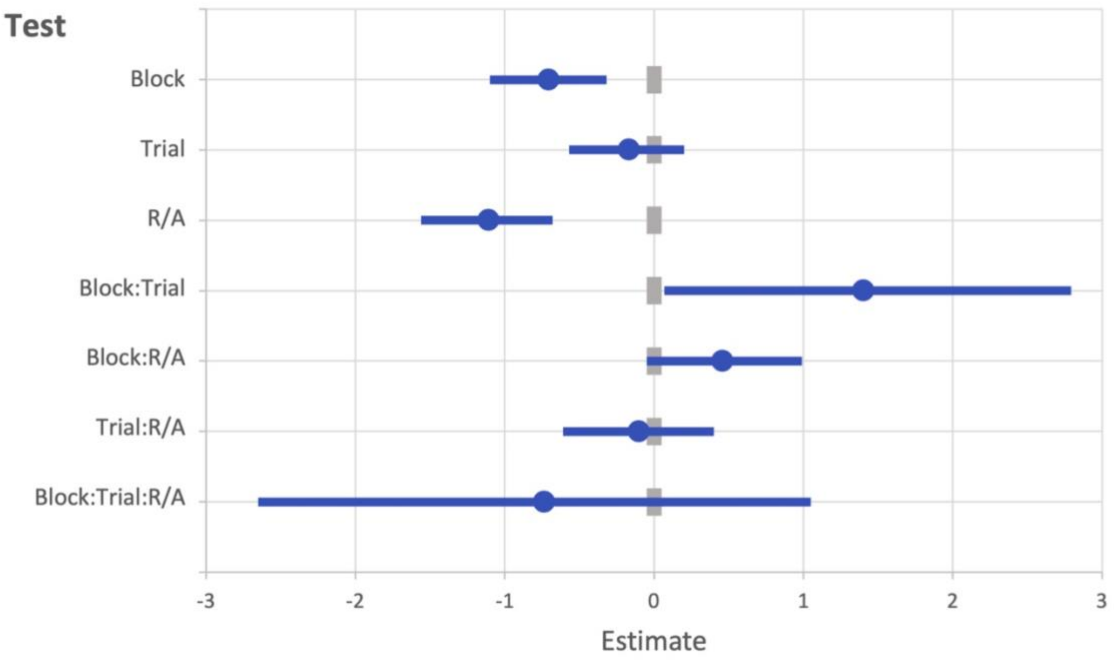

Figure 11. Mean point estimates and support intervals for each of the fixed effects for reward versus absent detections in the test phase of Experiment 2. Mean estimates are on the log odds scale. R = Reward, A = Absent.

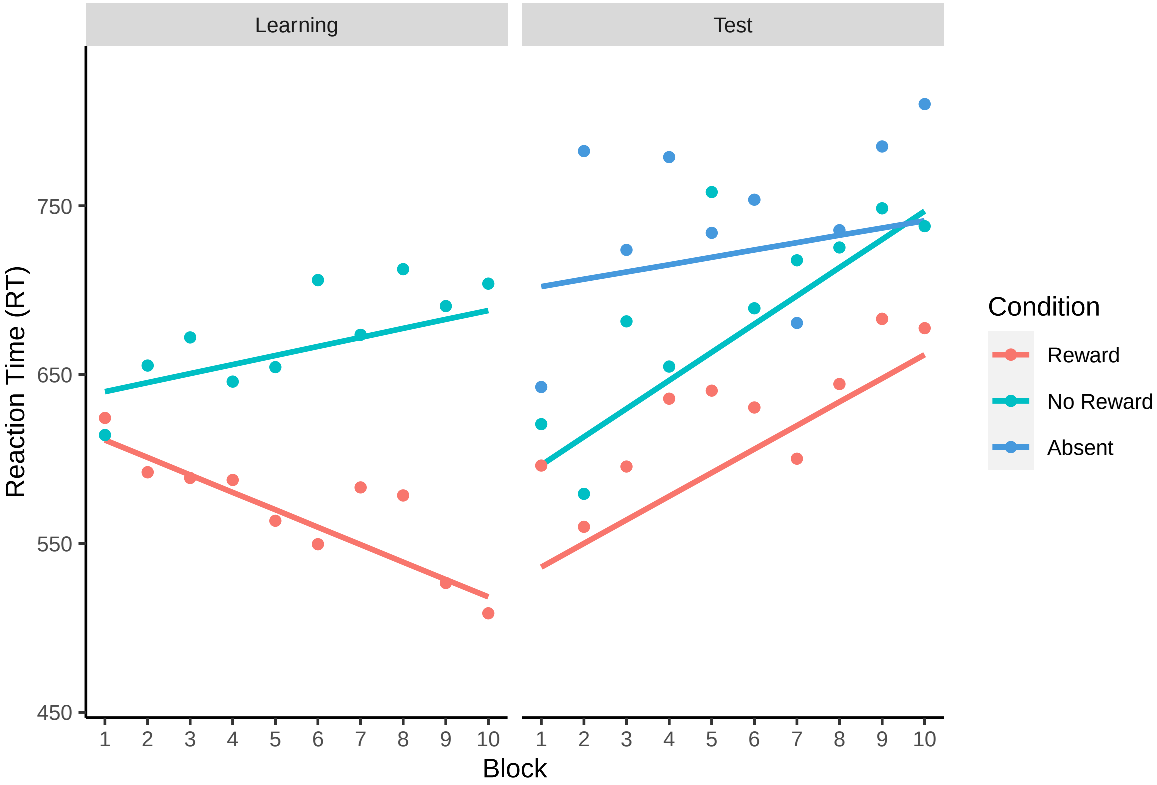

Figure 12. Reaction time plotted as a function of block and condition during the learning and test phase.

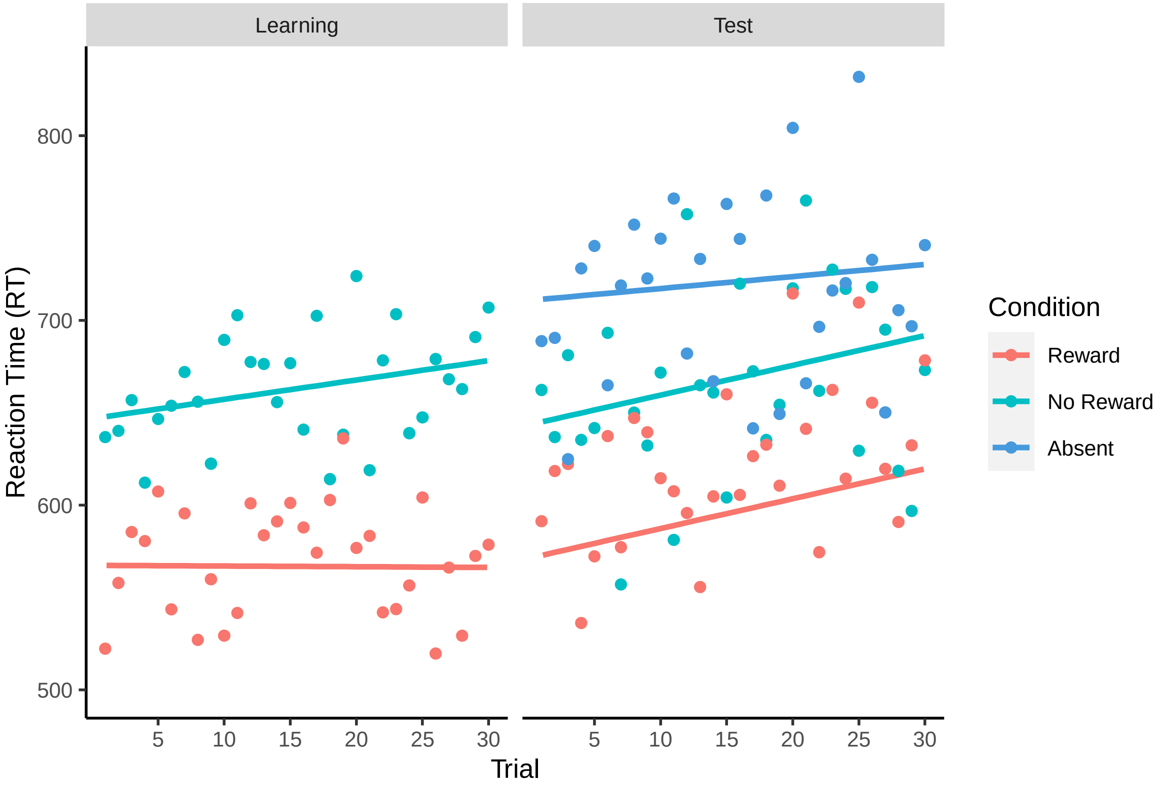

Figure 13. Reaction time plotted as a function of trial and condition during the learning and test phase.

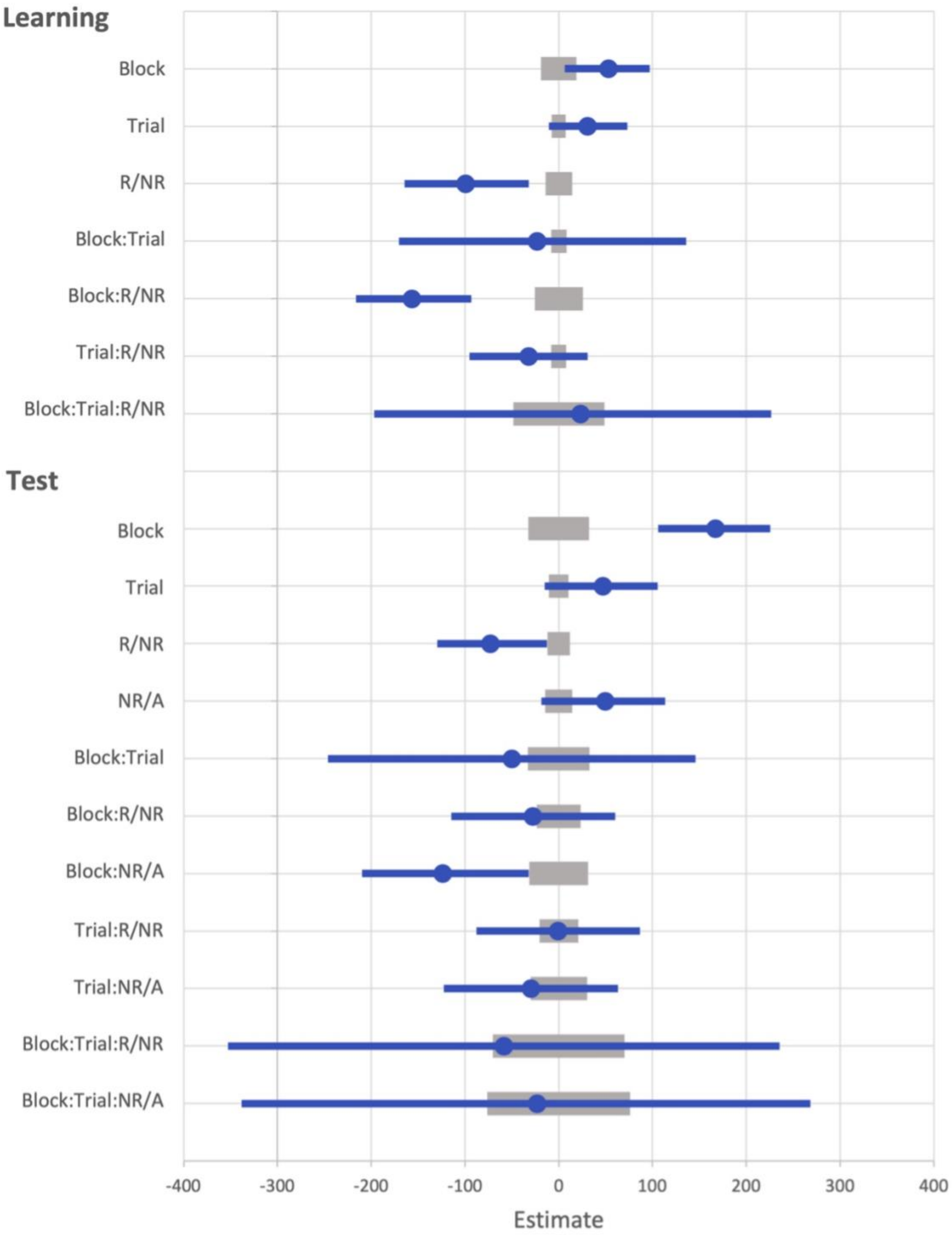

Figure 14. Mean point estimates and support intervals for each of the fixed effects from the generalized linear mixed effects model (GLMM) for reaction times (RTs) in Experiment 2. Grey boxes denote the null region (region of practical equivalence, *RPE*). R = Reward, NR = No-Reward.

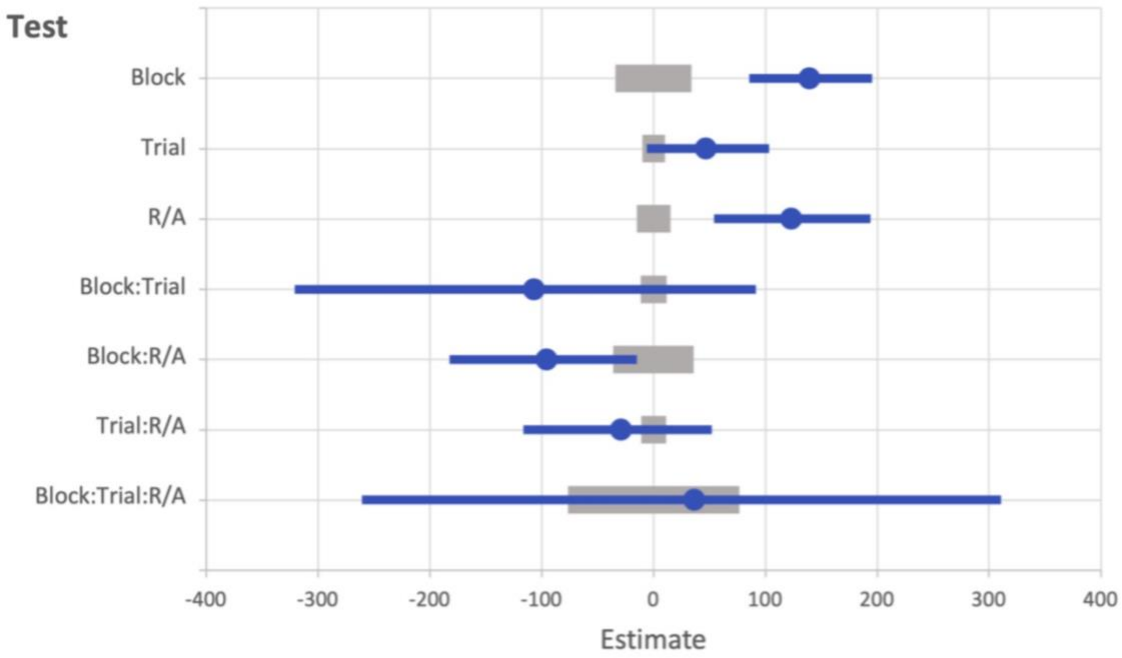

Figure 15. Mean point estimates and support intervals for each of the fixed effects for reward versus absent RTs in the test phase of Experiment 2. R = Reward, A = Absent.

Discussion

Consistent with the results from the learning phase in Experiment 1, there was an overall effect of reward condition and an interaction between block and reward condition such that detections were greater for rewarded than non-rewarded targets and this difference became larger over time. However, there was an effect of trial on detections during the learning phase suggesting that in this Experiment there was a vigilance decrement even though participants were being rewarded. The RT data followed the same pattern as detections with faster RTs to rewarded than non-rewarded targets that became faster over the course of each block during the learning phase.

During the test phase, there was evidence of an effect of reward history such that participants continued to respond to a greater number of rewarded compared to non-rewarded targets. Reward continued to bias attention in the test phase despite no longer being predictive of reward. There were no interactions with block or trial suggesting that this effect did not decrease over the course of the experiment. There was no evidence of an effect of selection history during the test phase i.e., there was no difference in detections between targets presented in the previously non-rewarded associated color and the novel color. This finding suggests that the effect of reward on sustained attention is unique to reward history alone and not due to previous experience with that feature during the learning phase. However, due to the nature of this task, the bias for participants to select the reward-associated feature a greater number of times in the learning phase could have confounded selection history with reward history. Nonetheless, participants did select i.e., made a response to the non-rewarded color ~65% of the time so it would be expected that there would still be a selection-driven effect when the non-reward associated feature remained task-relevant. During the test phase, there was an effect of block but not trial such that there was a decline in overall detections over the course of each block. However, it is surprising that there was not an effect of trial observed such that there were reduced detections across trials within a block as reported in previous studies and in Experiment 1.

The reaction time results were consistent with detections with a reward history effect present in reaction time data such that there were faster RTs to rewarded than non-rewarded targets in the test phase and this effect persisted over time. There was no evidence of a selection history effect on RTs. However, there was evidence that there was an interaction between selection history and block. This effect was such that participants were faster on non-rewarded trials compared to absent trials and this effect reduced over time, suggesting that any influence that selection history may have had on response times was diminished. There was no effect of block or trial on RTs suggesting that RTs remained constant throughout the test phase.

Overall, these results demonstrate that the effects of reward on sustained attention continued even when no longer rewarded and continued throughout the test phase. This Experiment also demonstrated that there was no impact of selection history as detections and RT did not differ between non-rewarded and absent targets, indicating that the frequency of exposure to the reward-associated feature did not influence the effect of reward on sustained attention.

Experiment 3

The purpose of Experiment 3 was to investigate whether placing the previously reward-associated feature on a non-target stimulus (i.e., a distractor) during the test phase would impair performance during the CTET, disrupting sustained attention. The distractor was either the reward-associated feature, non-reward associated feature, or a novel color (absent condition). The distance of the distractor was manipulated, so that it occurred either 3, 4, or 5 presentation positions prior to the target. It was expected that there would be a reduction in detections and an increase in RTs to targets when the prior distractor was rewarded compared to a non-rewarded or novel-colored distractor.

Method

Participants

Forty-six healthy participants (41 Female, M_{age} = 19.13, SD_{age} = 1.02) were recruited from the Psychological and Brain Sciences paid research participation pool at the University of California, Santa Barbara. Six participants were excluded from the final analyses due to either a high false alarm rate or poor accuracy during the task resulting in a final sample of 40 participants (25 Female, M_{age} = 19.33, SD_{age} = 1.06). Participants were paid an average of $5.64 for momentary compensation on the reward task.

Procedure

Participants did not complete the K task in this Experiment. However, unless mentioned below, all procedures, stimuli, and tasks were the same as Experiment 2.

Visual Search: learning

Stimuli were the same as Experiment 2, with targets at learning being two of the following colorlist: red, blue, or green. One of the target colors was rewarded and one non-rewarded. The third color that was not presented as a target was also randomly presented at the same frequency of targets during learning.

CTET: test

During the test phase, participants continued to respond to long-duration target stimuli. However, the features that were placed on targets during learning were presented as distractors at test. The distractor was presented either 3, 4, or 5 positions prior to a target. These positions were chosen because participants were given a time-window of two standard duration stimuli to respond to a target so the minimum distance of 3 positions prior to the target was required so that responses to the distractor and responses to the target were distinguishable. Distractors were presented as the previously reward-associated feature, previously non-reward associated feature, and a novel color (the third color that was not presented as a target during test).

Design and Analysis

Both the learning and the test phase consisted of 10 blocks, each with 432 stimulus presentations. Of the 432 stimuli presentations, there were 36 long-duration targets. For the learning phase, there were 18 rewarded and 18 non-rewarded targets. For the test phase, there were 12 rewarded, 12 non-rewarded, and 12 absent trials. Within each of the reward conditions in the test phase there were four presentations at each of the positions (3, 4, or 5). There were no differences between positions, so we collapsed over this condition.

Results

In this experiment, there were a large proportion of participants who responded to distractor stimuli. To examine these participants, participants were divided into sub-groups depending on whether they responded to the distractor stimuli or not. The upper bound of the confidence interval around 0 was used for detection accuracy in the test phase to assess which participants were responding to targets, distractors, and both. The cut-off of 8.62% for responding to targets and 10.87% for distractors. This resulted in a group of 28 participants who responded to only targets. There were 8 participants who responded to both targets and distractors and 2 who responded to only distractors but not targets. Due to the low number in this group, these participants were combined into one sub-group of 10 participants who responded to distractors. Data were analyzed by running a general linear mixed model on all participants, the target sub-group, and the distractor sub-group. The following metrics were examined: target detections, target response times, and distractor detections (mistakenly responding to a standard duration stimulus presented in a previous target color).

CTET: Learning

A separate general linear mixed effects model (GLMM) was used to examine detections with the fixed effects of block (1-10), trial (1-36), and reward condition (reward, non-rewarded). A separate GLMM was conducted for all participants, the target sub-group, and the distractor sub-group (See Figure 16. for mean point estimates)

Detections: all participants

The GLMM which included all participants revealed that there was an effect of block during the learning phase such that overall detections decreased a block order increased (b = -1.75, SI = [-1.99, -1.51], RPE = ± 0.05, BF > 1000; see Figure 20). There was also evidence of an effect of trial such that overall detections decreased within a block as trial order increased (*b* = -0.64, *SI* = [-0.89, -0.40], *RPE* = ± 0.05, *BF* > 1000; see Figure 21). There was an impact of reward condition such that participants detected more rewarded than non-rewarded targets (*b* = 1.75, *SI* = [0.49, 1.45], *RPE* = ± 0.05, *BF* > 1000). There was no interaction between block and trial (*b* = 0.89, *SI* = [0.05, 1.78], *RPE* = ± 0.05), there was substantial evidence in support of the null (*BF* = 0.32). There was extreme evidence of an interaction between block and condition such that detections to non-rewarded targets decreased and rewarded increased over the course of each block (*b* = 3.25, *SI* = [2.85, 3.64], *RPE* = ± 0.05, *BF* > 1000), suggesting that participants learned the association between color and reward. There was no interaction between trial and condition (*b* = -0.033, *SI* = [-0.44, 0.37], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.011). There was also no three-way interaction (*b* = -0.74, *SI* = [-2.04, 0.60], *RPE* = ± 0.05), with strong evidence in support of the null (*BF* = 0.030).

Detections: Target sub-group

The GLMM which included participants that only responded to targets during the test phase revealed that there was an effect of block during the learning phase such that overall detections decreased a block order increased (*b* = -1.22, *SI* = [-151, -.92], *RPE* = ± 0.05, *BF* > 1000; see Figure 22). There was also evidence of an effect of trial such that overall detections decreased within a block as trial order increased (*b* = -0.64, *SI* = [-0.94, -0.36], *RPE* = ± 0.05, *BF* > 1000; see Figure 23). There was an impact of reward condition such that participants detected more rewarded than non-rewarded targets (*b* = 0.97, *SI* = [0.49, 1.45], *RPE* = ± 0.05, *BF* = 46.66). There was no interaction between block and trial (*b* = 0.77, *SI* = [-0.29, 1.73], *RPE* = ± 0.05), with strong evidence in support of the null (*BF* = 0.074). There was extreme evidence of an interaction between block and condition such that detections to non-rewarded targets decreased and rewarded targets increased over the course of each block (*b* = 2.72, *SI* =

[2.28, 3.18], *RPE* = ± 0.05, *BF* > 1000). There was no interaction between trial and condition (*b* = -0.058, *SI* = [-0.48, 0.36], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.013). There was also no three-way interaction (*b* = -0.51, *SI* = [-2.08, 0.95], *RPE* = ± 0.05), with very strong evidence in support of the null (*BF* = 0.019).

Detections: Distractor sub-group

The GLMM which included participants that responded to distractors during the test phase revealed that there was an effect of block during the learning phase such that overall detections decreased a block order increased (*b* = -3.08, *SI* = [-3.57, -2.61], *RPE* = ± 0.05, *BF* > 1000; see Figure 24). There was also evidence of an effect of trial such that overall detections decreased within a block as trial order increased (*b* = -0.74, *SI* = [-1.18, -0.29], *RPE* = ± 0.05, *BF* = 13.13; see Figure 25). There was an impact of reward condition such that participants detected more rewarded than non-rewarded targets (*b* = 4.09, *SI* = [3.42, 4.76], *RPE* = ± 0.05, *BF* > 1000). There was no interaction between block and trial (*b* = 1.11, *SI* = [-0.45, 2.76], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.079). There was extreme evidence of an interaction between block and condition such that detections to non-rewarded targets decreased relative to rewarded over the course of each block (*b* = 6.00, *SI* = [5.06, 7.04], *RPE* = ± 0.05, *BF* > 1000). There was no interaction between trial and condition (*b* = 0.074, *SI* = [-0.91, 1.05], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.04). There was also no three-way interaction (*b* = -2.08, *SI* = [-5.55, 1.26], *RPE* = ± 0.05), with strong evidence in support of the null (*BF* = 0.083).

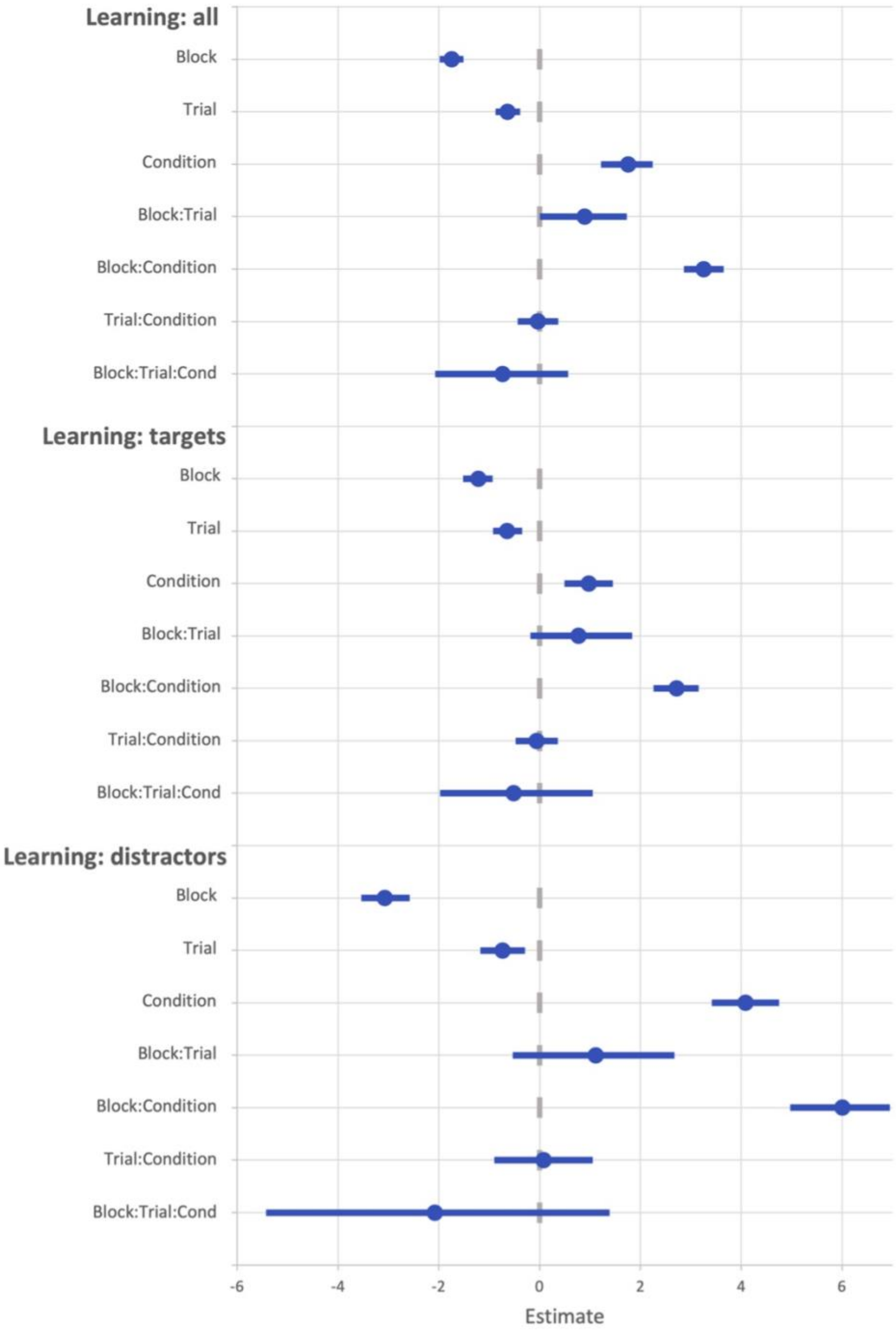

Figure 16. Mean point estimates and support intervals for each of the fixed effects from the generalized linear mixed effects model's (GLMM's) for detections during learning in Experiment 3. Mean estimates are on the log odds scale. Grey boxes denote the null region (region of practical equivalence, *RPE*).

A separate general linear mixed effects model (GLMM) was used to examine reaction times with the fixed effects of block (1-10), trial (1-36), and reward condition (reward, non-rewarded). A separate GLMM was conducted for the target sub-group, and the distractor sub-group (See Figure 17. for mean point estimates)

Reaction Time: all participants

The GLMM which included all participants revealed that there was no effect of block during the learning phase (*b* = -27.44, *SI* = [-65.46, 7.67], *RPE* = ± 26.76; see Figure 28), there was decisive evidence in support of the null (*BF* < 0.01). There was no effect of trial (*b* = 29.70, *SI* = [-4.97, 66.85, *RPE* = ± 8.31; see Figure 29), there was strong evidence in support of the null (*BF* = 0.051). There was an impact of reward condition such that RTs were faster to rewarded than non-rewarded targets (*b* = -132.49, *SI* = [-194.66, -70.93], *RPE* = ± 15.78, *BF* = 180.74). There was no interaction between block and trial (*b* = 8.52, *SI* = [-120.63, 137.63], *RPE* = ± 9.00), there was decisive evidence in support of the null (*BF* < 0.01). There was extreme evidence of an interaction between block and condition such that RTs to became faster to rewarded relative to non-rewarded targets (*b* = -210.80, *SI* = [-260.42, -163.17], *RPE* = ± 27.24, *BF* > 1000). There was no interaction between trial and condition (*b* = -30.37, *SI* = [-76.28, 15.70], *RPE* = ± 12.56), there was very strong evidence in support of the null (*BF* = 0.017). There was also no three-way interaction (*b* = -11.00, *SI* = [-168.98, 159.71], *RPE* = ± 69.15), with decisive evidence in support of the null (*BF* < 0.01).

Reaction Time: target sub-group

The GLMM which included participants that only responded to targets during the test phase revealed that there was no effect of block (*b* = -35.04, *SI* = [-75.49, 5.76], *RPE* = ± 26.34; see Figure 30), there was very strong evidence in support of the null (*BF* = 0.023). There was no evidence of an effect of trial (*b* = 23.76, *SI* = [-13.59, 64.05, *RPE* = ± 8.45; see Figure 31), there was very strong evidence in support of the null (*BF* = 0.019). There was no evidence of an effect of reward condition on RTs in the target group (*b* = -69.75, *SI* = [-

131.03, -10.93], *RPE* = ± 13.41), there was anecdotal evidence in support of the null (*BF* = 0.52). There was no interaction between block and trial (*b* = -28.64, *SI* = [-167.22, 109.82], *RPE* = ± 8.36), there was decisive evidence in support of the null (*BF* < 0.01). There was extreme evidence of an interaction between block and reward condition such that RTs became faster to rewarded compared to non-rewarded targets over the course of each block (*b* = -192.44, *SI* = [-246.37, -140.83], *RPE* = ± 26.35 *BF* > 1000). There was no interaction between trial and condition (*b* = -0.058, *SI* = [-0.48, 0.36], *RPE* = ± 0.05), there was decisive evidence in support of the null (*BF* < 0.01). There was also no three-way interaction (*b* = -25.33, *SI* = [-211.17, 160.46], *RPE* = ± 51.44), with decisive evidence in support of the null (*BF* < 0.01).

Reaction Time: distractor sub-group

The GLMM which included participants that responded to distractors during the test phase revealed that there was no effect of block (*b* = 77.59, *SI* = [-18.25, 179.88], *RPE* = ± 31.25), there was strong evidence in support of the null (*BF* = 0.058). There was no evidence of an effect of trial (*b* = 77.59, *SI* = [-18.25, 179.88], *RPE* = ± 31.25), there was strong evidence in support of the null (*BF* = 0.21). There was an impact of reward condition such that RTs were faster to rewarded compared to non-rewarded targets (*b* = -333.75, *SI* = [-417.35, -252.70], *RPE* = ± 9.10, *BF* > 1000). There was no interaction between block and trial (*b* = 209.07, *SI* = [-108.30, 521.18], *RPE* = ± 11.81), there was strong evidence in support of the null (*BF* = 0.043). There was extreme evidence of an interaction between block and condition such that RTs became faster to rewarded relative to non-rewarded targets over the course of each block (*b* = -398.04, *SI* = [-517.42, -278.53], *RPE* = ± 21.39, *BF* > 1000). There was no interaction between trial and condition (*b* = -136.27, *SI* = [-253.99, -24.17], *RPE* = ± 6.91), there was strong evidence in support of the null (*BF* = 0.083). There was also no three-way interaction (*b* = -67.84, *SI* = [-477.32, 344.84], *RPE* = ± 112.24), with decisive evidence in support of the null (*BF* < 0.01).

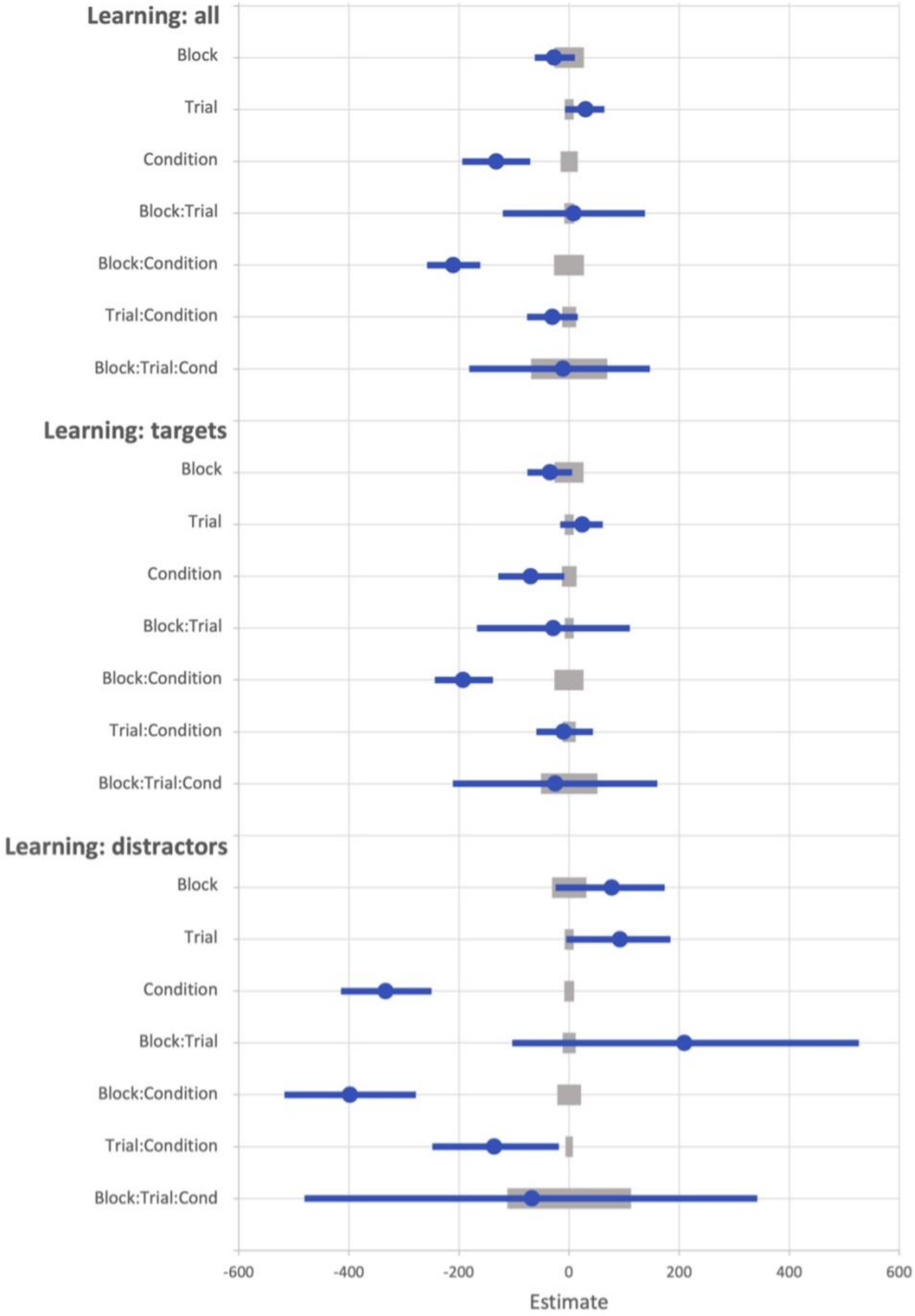

Figure 17. Mean point estimates and support intervals for each of the fixed effects from the generalized linear mixed effects model's (GLMM) for reaction time during learning in Experiment 3. Grey boxes denote the null region (region of practical equivalence, *RPE*).

CTET: Test

Target Detections

A separate general linear mixed effects model (GLMM) was used to examine detections of target stimuli during the test phase with the fixed effects of block (1-10), trial (1-36), and reward condition (reward, non-rewarded, absent). A separate GLMM was conducted for all participants, the target sub-group, and the distractor sub-group (See Figure 18. for mean point estimates for the main model and Figure 19 for the model assessing reward versus absent).

Target detections: reward and selection history – all participants

The GLMM revealed that there was evidence of an effect of block such that overall detections reduced over each block (*b* = -0.67, *SI* = [-0.96, -0.39], *RPE* = ± 0.05, *BF* > 1000; see Figure 20 and 21). There was an effect of trial such that detections decreased within a block (*b* = -0.59, *SI* = [-0.89, -0.31], *RPE* = ± 0.05, *BF* = 303.37). There was no evidence of an effect of reward history (reward relative to no-reward) during the test phase (*b* = -0.097, *SI* = [-0.23, 0.03], *RPE* = ± 0.05) there was strong evidence in support of the null (*BF* = 0.035). There was no evidence of an effect of selection history (no-reward relative to absent) during the test phase *b* = -0.0086, *SI* = [-0.15, 0.13], *RPE* = ± 0.05), there was decisive evidence in support of the null (*BF* < 0.01). There was no interaction between block and trial (*b* = 1.09, *SI* = [0.11, 2.13], *RPE* = ± 0.05), there was anecdotal evidence in support of the null (*BF* = 0.42). There was no interaction between block and reward history (*b* = 0.13, *SI* = [-0.27, 0.57], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.013). There was also no interaction between block and selection history (*b* = -0.0034, *SI* = [-0.44, 0.43], *RPE* = ± 0.05), there was decisive evidence in support of the null (*BF* < 0.01). There was no interaction between trial and reward history (*b* = 0.095, *SI* = [-0.34, 0.53], *RPE* = ±

0.05), there was very strong evidence in support of the null (*BF* = 0.011). There was no interaction between trial and selection history (*b* = 0.0016, *SI* = [-0.43, 0.43], *RPE* = ± 0.05), there was decisive evidence in support of the null (*BF* < 0.01). There was no three-way interaction between block, trial, and reward history (*b* = -0.25, *SI* = [-1.65, 1.27], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.012). There was also no three-way interaction between block, trial, and selection history (*b* = 0.68, *SI* = [-0.73, 2.18], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.021).

Target detections: combination of reward and selection history – all participants

The GLMM comparing the combination of reward and selection history (difference between rewarded and absent trials) revealed that there was evidence of an effect of block such that overall detections reduced over each block (*b* = -0.53, *SI* = [-0.83, -0.25], *RPE* = ± 0.05, *BF* = 93.10). There was an effect of trial such that detections decrease over the course of each trial (*b* = -0.50, *SI* = [-0.79, -0.22], *RPE* = ± 0.05, *BF* = 39.33). There was no evidence of an effect of reward condition (*b* = 0.025, *SI* = [-0.05, 0.24], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.025). There was no interaction between block and trial (*b* = 0.84, *SI* = [-0.12, 1.86], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.011). There was no interaction between block and condition (*b* = -0.13, *SI* = [-0.53, 0.26], *RPE* = ± 0.05), there was very strong in support of the null (*BF* = 0.013). There was no interaction between trial and condition (*b* = -0.091, *SI* = [-0.48, 0.3], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.013). There was no three-way interaction (*b* = 0.92, *SI* = [-0.44, 2.37], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.047).

Target detections: reward and selection history – target sub-group

The GLMM revealed that there was evidence of an effect of block such that overall target detections reduced over each block (*b* = -0.82, *SI* = [-1.15, -0.49], *RPE* = ± 0.05, *BF* > 1000; see Figure 22). There was an effect of trial such that detections decreased within a block (*b* = -0.68, *SI* = [-1.00, -0.36], *RPE* = ± 0.05, *BF* = 969.55; see Figure 23). There was no evidence of an effect of reward history (*b* = -0.048, *SI* = [-0.18, 0.10], *RPE* = ± 0.05), there was decisive evidence in support of the null (*BF* < 0.01). There was no evidence of an effect of selection history during the test phase (*b* = -0.013, *SI* = [-0.16, 0.14], *RPE* = ± 0.05), there was decisive evidence in support of the null (*BF* < 0.01). There was no interaction between block and trial (*b* = 0.75, *SI* = [-0.34, 1.92], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.055). There was no interaction between block and reward history (*b* = 0.14, *SI* = [-0.31, 0.63], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.014). There was also no interaction between block and selection history (*b* = 0.064, *SI* = [-0.39, 0.55], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.011). There was no interaction between trial and reward history (*b* = 0.19, *SI* = [-0.27, 0.64], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.018). There was no interaction between trial and selection history (*b* = 0.083 *SI* = [-1.54, 1.85], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.012). There was no three-way interaction between block, trial, and reward history (*b* = 0.16, *SI* = [-1.54, 1.85], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.012). There was also no three-way interaction between block, trial, and selection history (*b* = 0.92, *SI* = [-0.79, 2.60], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.031).

Target detections: combination of reward and selection history – target sub-group

The GLMM comparing the combination of reward and selection history (difference between rewarded and absent trials) revealed that there was evidence of an effect of block such that overall detections reduced over each block (*b* = -0.67, *SI* = [-1.00, -0.36], *RPE* = ± 0.05, *BF* = 222.34). There was an effect of trial such that detections decrease over the course of each trial (*b* = -0.50, *SI* = [-0.82, -0.18], *RPE* = ± 0.05, *BF* = 8.46). There was no evidence of an effect of reward condition (*b* = 0.034, *SI* = [-0.11, 0.18], *RPE* = ± 0.05), there was decisive evidence in support of the null (*BF* < 0.01). There was no interaction between block and trial (*b* = 0.91, *SI* = [-0.16, 2.04], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.11). There was no interaction between block and condition (*b* = -0.076, *SI* = [-0.55, 0.40], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.014). There was no interaction between trial and condition (*b* = -0.098, *SI* = [-0.53, 0.37], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.015). There was no three-way interaction (*b* = 0.76, *SI* = [-0.87, 2.37], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.029).

Target detections: reward and selection history – distractor sub-group

The GLMM revealed that was no evidence of an effect of block (*b* = -0.27, *SI* = [-0.83, 0.37], *RPE* = ± 0.05; see Figure 24) there was strong evidence in support of the null (*BF* = 0.038). There was no effect of trial (*b* = -0.27, *SI* = [-0.88, 0.31], *RPE* = ± 0.05; see Figure 25), there was strong evidence in support of the null (*BF* = 0.047). There was no evidence of an effect of reward history (*b* = -0.15, *SI* = [-0.51, 0.26], *RPE* = ± 0.05) there was strong evidence in support of the null (*BF* = 0.043). There was no evidence of an effect of selection history (no-reward relative to absent) during the test phase (*b* = 0.11, *SI* = [-0.26, 0.51], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.036). There was evidence of an interaction between block and trial such that the decrement in detections within a block reduced as block order increased (*b* = 2.84, *SI* = [0.75, 4.92], *RPE* = ± 0.05, *BF* = 2.08). There was no interaction between block and reward history (*b* = 0.14, *SI* = [-0.70, 1.04], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.028). There was also no interaction between block and selection history (*b* = -0.21, *SI* = [-1.10, 0.63], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.028). There was no interaction between trial and reward history (*b* = -0.054, *SI* = [-0.89, 0.77], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.025). There was no interaction between trial and selection history (*b* = -0.48, *SI* = [-1.37, 0.37], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.051). There was no three-way interaction between block, trial, and reward history (*b* = -2.85, *SI* = [-5.93, 0.13], *RPE* = ± 0.05), there was substantial evidence in support of the null (*BF* = 0.21). There was also no three-way interaction between block, trial, and selection history (*b* = -1.14, *SI* = [-4.04, 1.82], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.038).

Target detections: combination of reward and selection history – distractor sub-group

The GLMM comparing the combination of reward and selection history (difference between rewarded and absent trials) showed that there was no evidence of an effect of block (*b* = -0.67, *SI* = [-0.64, 0.50], *RPE* = ± 0.05) there was very strong evidence in support of the null (*BF* = 0.029). There was no effect of trial (*b* = -0.32, *SI* = [-0.93, 0.26], *RPE* = ± 0.05), there was strong evidence for the null (*BF* = 0.057). There was no evidence of an effect of reward condition (*b* = 0.23, *SI* = [-0.19, 0.68], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.075). There was no interaction between block and trial (*b* = 0.014, *SI* = [-1.94, 1.96], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.031). There was no interaction between block and condition (*b* = -0.35, *SI* = [-1.20, 0.47], *RPE* = ± 0.05), there was strong in support of the null (*BF* = 0.044). There was no interaction between trial and condition (*b* = -0.42, *SI* = [-1.22, 0.41], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.053). There was no three-way interaction (*b* = 1.69, *SI* = [-1.16, 4.67], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.065)

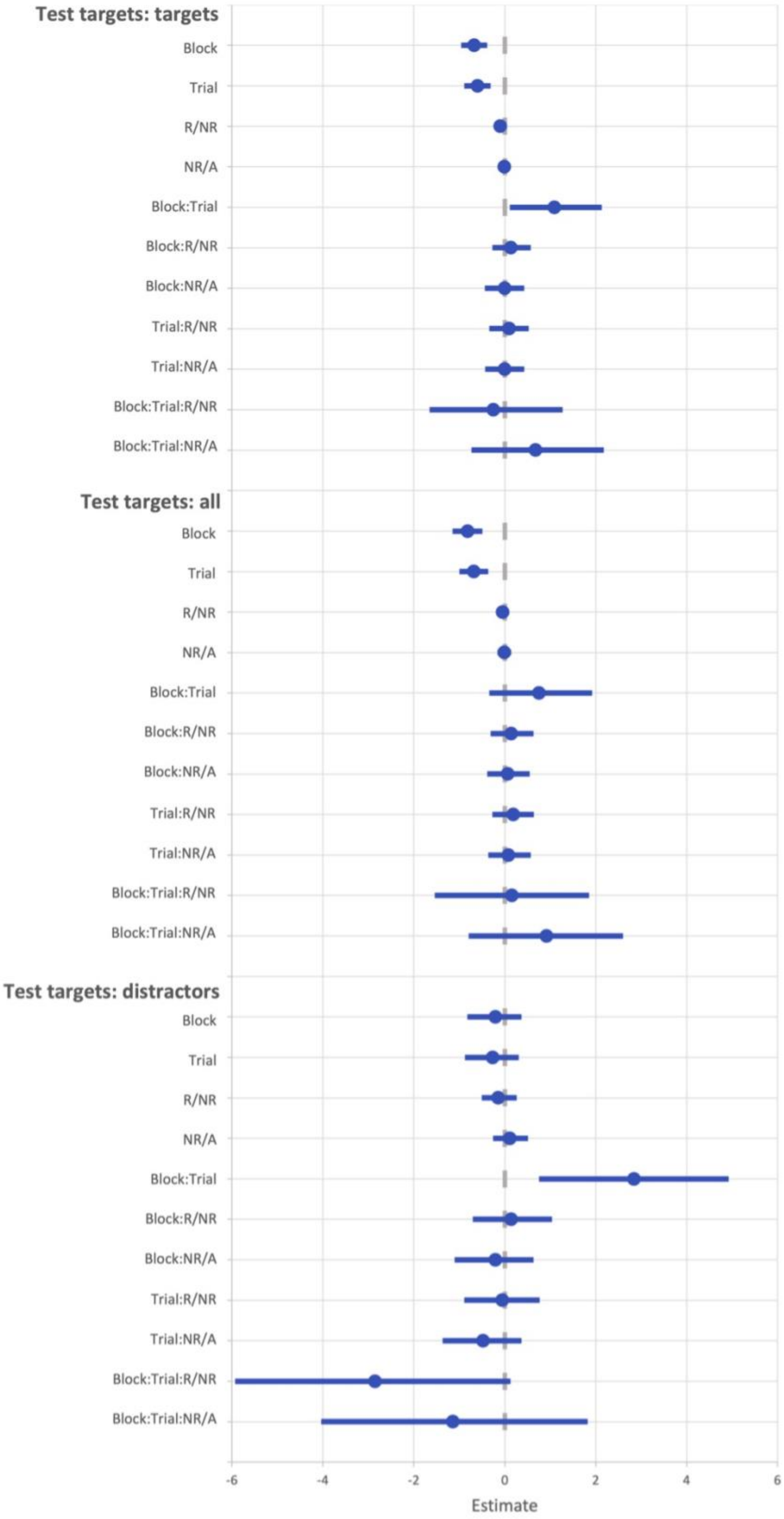

Figure 18. Mean point estimates and support intervals for each of the fixed effects from the generalized linear mixed effects model's (GLMM) for target detections during the test phase in Experiment 3. Mean estimates are on the log odds scale. Grey boxes denote the null region (region of practical equivalence, *RPE*).

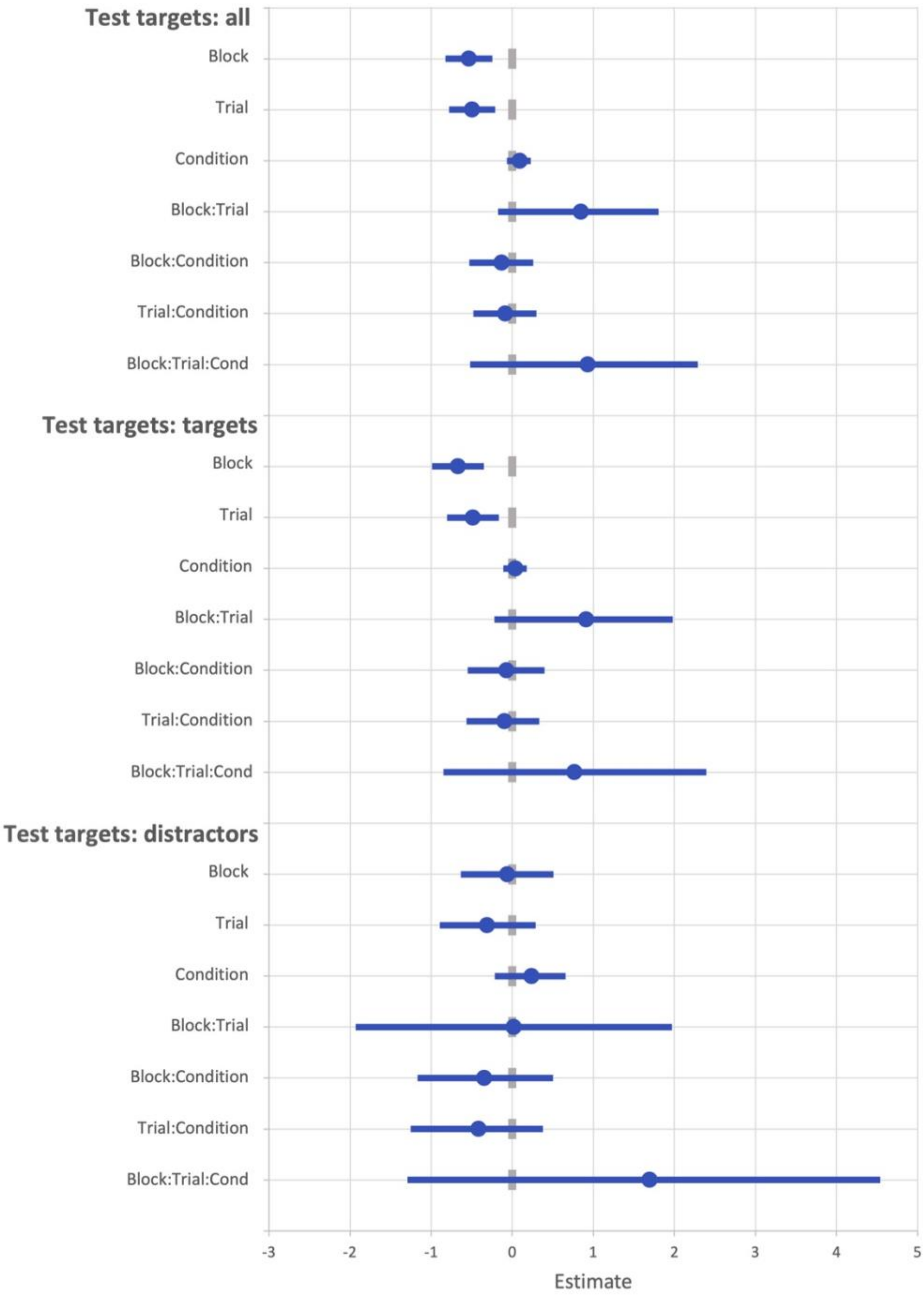

Figure 19. Mean point estimates and support intervals for each of the fixed effects from the generalized linear mixed effects model (GLMM) examining reward versus absent for target detections during the test phase in Experiment 3. Mean estimates are on the log odds scale. Grey boxes denote the null region (region of practical equivalence, *RPE*).

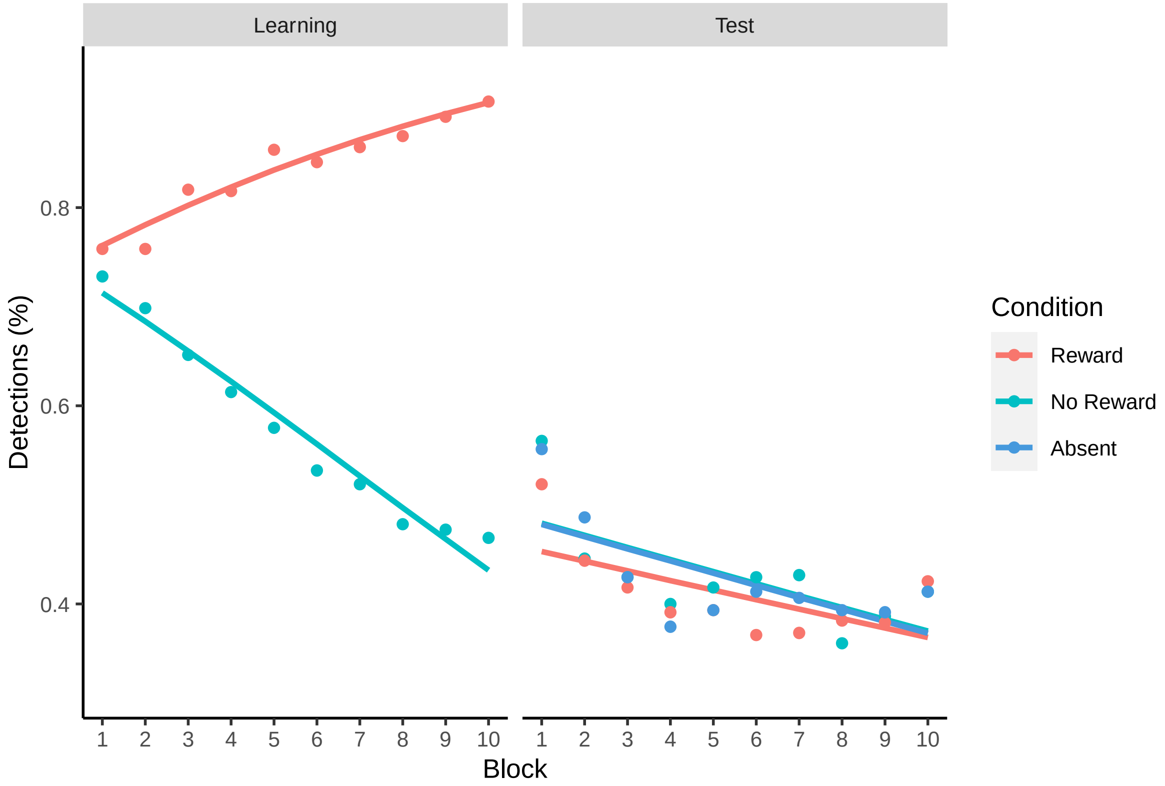

Figure 20. Detections for all participants plotted as a function of block and condition

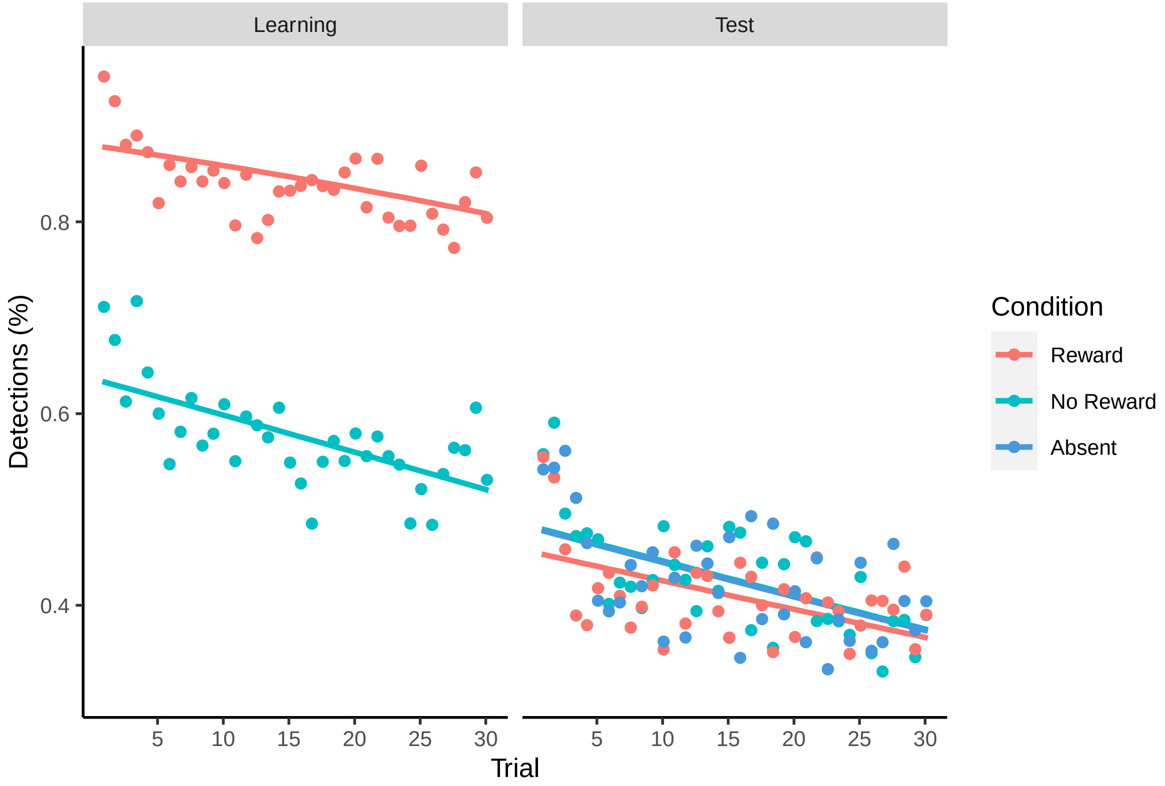

Figure 21. Detections for all participants plotted as a function of trial and condition

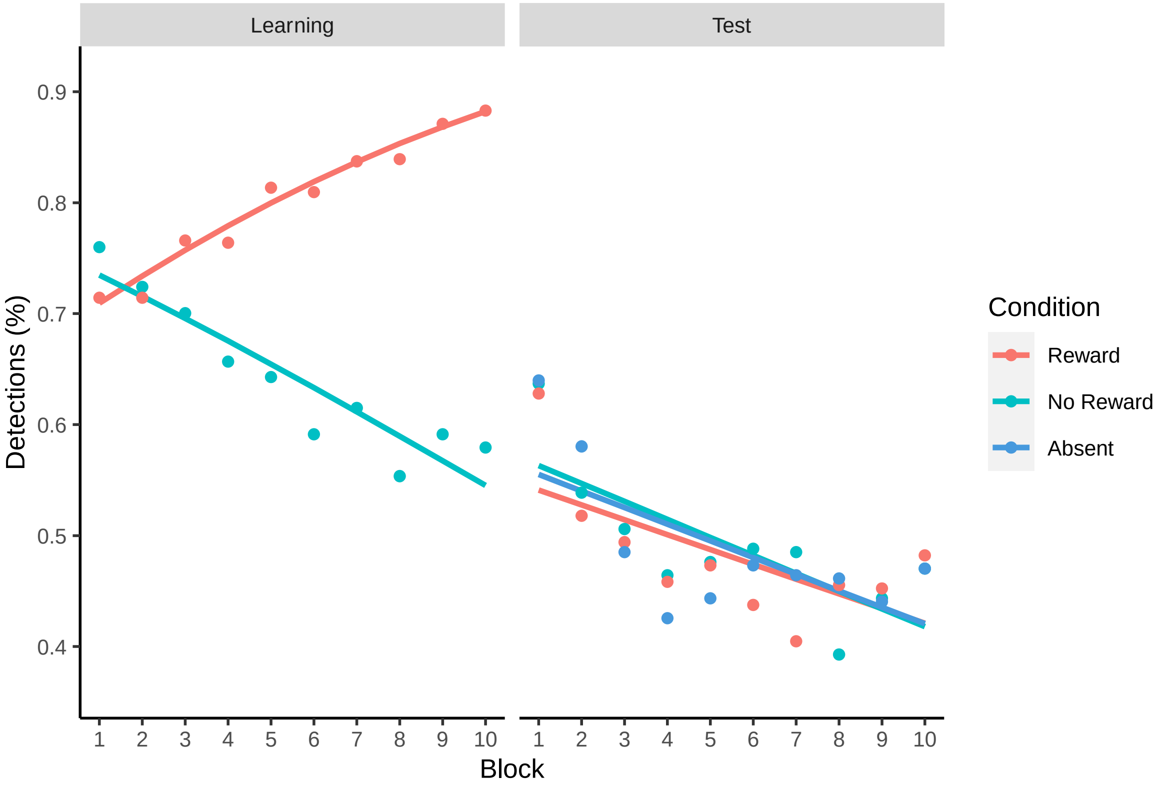

Figure 22. Detections for the target sub-group plotted as a function of block and condition

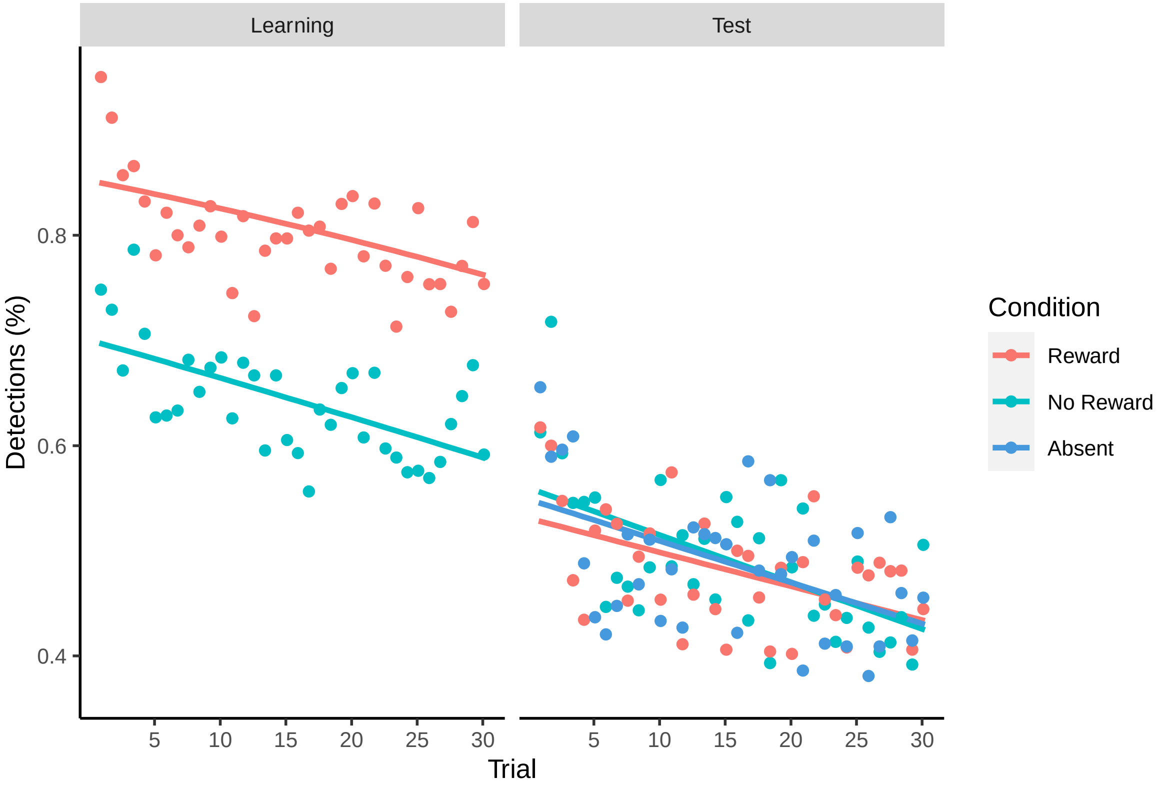

Figure 23. Detections for the target sub-group plotted as a function of trial and condition

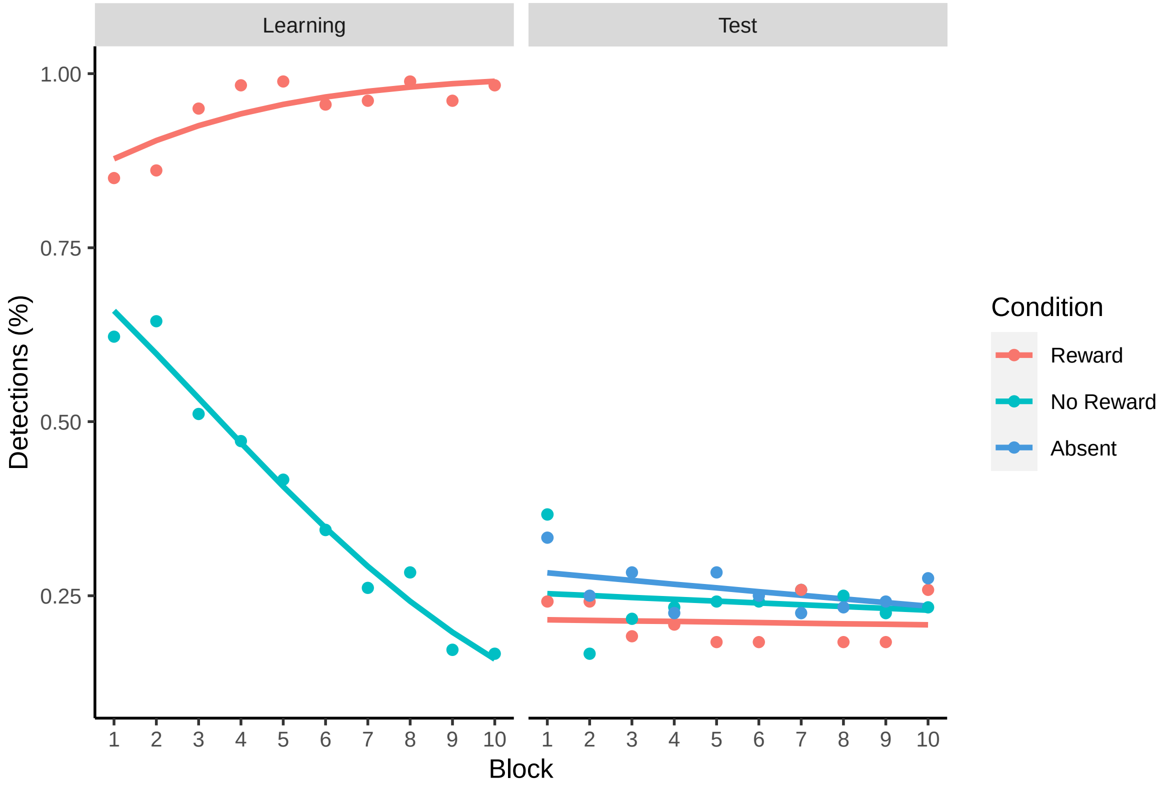

Figure 24. Detections for the distractor sub-group plotted as a function of trial and condition

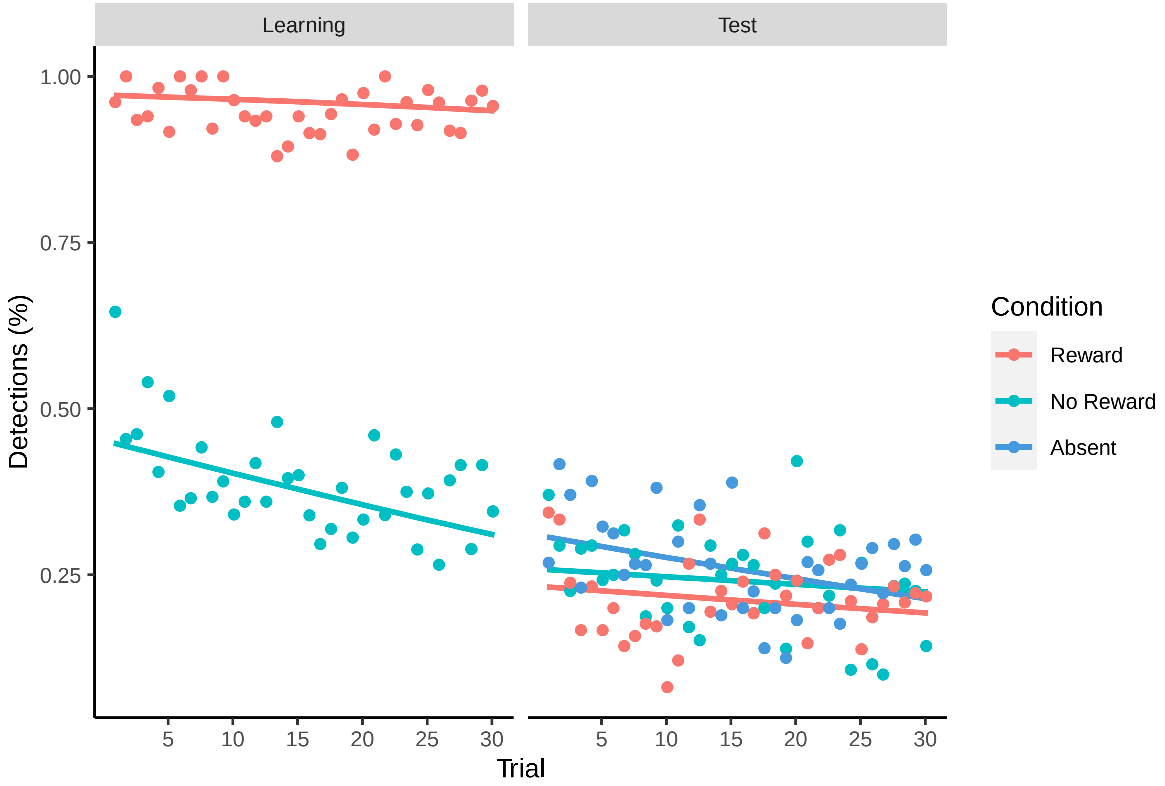

Figure 25. Detections for the distractor sub-group plotted as a function of block and condition

Target Reaction Times

A separate general linear mixed effects model (GLMM) was used to examine reaction times during the test phase with the fixed effects of block (1-10), trial (1-36), and reward condition (reward, non-rewarded, absent). A separate GLMM was conducted for all participants, the target sub-group, and the distractor sub-group (See Figure 26. for mean point estimates for the main model and Figure 27 for the model assessing reward versus absent).

Target Reaction Times: reward and selection history – all participants

The GLMM revealed that there was no effect of block (*b* = 38.41 *SI* = [-8.85, 85.24], *RPE* = ± 16.23; see Figure 28), there was strong evidence in support of the null (*BF* = 0.053). There was no effect of trial (*b* = 40.60, *SI* = [-4.06, 88.22], *RPE* = ± 39.31; see Figure 29), there was decisive evidence in support of the null (*BF* < 0.01). There was no evidence of an effect of reward history (*b* = -1.56, *SI* = [-23.05, 21.95], *RPE* = ± 6.21), there was strong evidence in support of the null (*BF* = 0.083). There was no evidence of an effect of selection history (*b* = -7.34, *SI* = [-33.87, 17.09], *RPE* = ± 59.48), there was decisive evidence in support of the null (*BF* < 0.01). There was no interaction between block and trial (*b* = -37.68, *SI* = [-203.77, 115.42], *RPE* = ± 59.48), there was decisive evidence in support of the null (*BF* < 0.01). There was no interaction between block and reward history (*b* = -35.96, *SI* = [-103.77, 32.54], *RPE* = ± 38.64), there was decisive evidence in support of the null (*BF* < 0.01). There was also no interaction between block and selection history (*b* = -67.12, *SI* = [-135.34, -3.45], *RPE* = ± 33.24), there was strong evidence in support of the null (*BF* = 0.075). There was no interaction between trial and reward history (*b* = 1.30, *SI* = [-67.86, 70.21], *RPE* = ± 35.24), there was decisive evidence in support of the null (*BF* < 0.01). There was no interaction between trial and selection history (*b* = 13.65, *SI* = [-55.42, 82.73], *RPE* = ± 23.53), there was decisive evidence in support of the null (*BF* < 0.01). There was no three-way interaction between block, trial, and reward history (b = -103.10, *SI* = [-337.86, 133.18], *RPE* = ± 547.73), there was decisive evidence in support of the null (*BF* < 0.01). There was also no three-way interaction between block, trial, and selection history (b = -83.27, *SI* = [-317.86, 151.90], *RPE* = ± 445.32), there was decisive evidence in support of the null (*BF* < 0.01).

Target Reaction Times: combination of reward and selection history – all participants

The GLMM comparing the combination of reward and selection history (difference between rewarded and absent trials) revealed that there was no effect of block (b = 2.63, *SI* = [-45.14, 46.62], *RPE* = ± 18.81), there was decisive evidence in support of the null (*BF* < 0.01). There was no effect of trial (b = 42.07 *SI* = [-6.43, 90.15], *RPE* = ± 37.78), there was very strong evidence in support of the null (*BF* = 0.019). There was no evidence of an effect of reward condition (b = -5.17, *SI* = [-33.60], *RPE* = ± 10.33, there was decisive evidence in support of the null (*BF* < 0.01). There was no interaction between block and trial (b = -138.86, *SI* = [-299.33, 11.08], *RPE* = ± 36.78), there was strong evidence in support of the null (*BF* = 0.097). There was no interaction between block and condition (b = -31.55, *SI* = [-92.80, 30.53], *RPE* = ± 39.61), there was decisive evidence in support of the null (*BF* < 0.01). There was no interaction between trial and condition (b = 12.25, *SI* = [-49.76, 79.28], *RPE* = ± 39.61), there was very decisive evidence in support of the null (*BF* < 0.01). There was no three-way interaction (b = 22.28, *SI* = [-201.10, 245.38], *RPE* = ± 15.15), there was decisive evidence in support of the null (*BF* < 0.01).

Target Reaction Times: reward and selection history – target sub-group

The GLMM revealed that there was an effect of block such that overall RTs increased throughout the test phase (b = 61.42 *SI* = [15.90, 106.03], *RPE* = ± 14.42, *BF* = 1.14; see Figure 30). There was no effect of trial (b = 42.47, *SI* = [-3.09, 91.08], *RPE* = ± 10.60; see

Figure 31), there was strong evidence in support of the null (*BF* = 0.10). There was no evidence of an effect of reward history (*b* = 1.18, *SI* = [-22.57, 26.87], *RPE* = ± 6.23), there was decisive evidence in support of the null (*BF* < 0.01). There was no evidence of an effect of selection history (*b* = -2.49, *SI* = [-28.32, 21.29], *RPE* = ± 5.01), there was decisive evidence in support of the null (*BF* < 0.01). There was no interaction between block and trial (*b* = -43.99, *SI* = [-209.36, 121.32], *RPE* = ± 31.20), there was decisive evidence in support of the null (*BF* < 0.01). There was no interaction between block and reward history (*b* = -13.18, *SI* = [-77.19, 56.29], *RPE* = ± 23.81), there was decisive evidence in support of the null (*BF* < 0.01). There was also no interaction between block and selection history (*b* = -46.86, *SI* = [-116.63, 17.82], *RPE* = ± 15.93), there was strong evidence in support of the null (*BF* = 0.031). There was no interaction between trial and reward history (*b* = -10.25, *SI* = [-81.15, 60.58], *RPE* = ± 24.00), there was decisive evidence in support of the null (*BF* < 0.01). There was no interaction between trial and selection history (*b* = 6.02, *SI* = [-59.01, 76.50], *RPE* = ± 12.01), there was decisive evidence in support of the null (*BF* < 0.01). There was no three-way interaction between block, trial, and reward history (*b* = -31.44 *SI* = [-270.93, 209.60], *RPE* = ± 52.98), there was decisive evidence in support of the null (*BF* < 0.01). There was also no three-way interaction between block, trial, and selection history (*b* = -51.14, *SI* = [-290.93, 209.60], *RPE* = ± 72.53), there was decisive evidence in support of the null (*BF* < 0.01).

Target Reaction Times: combination of reward and selection history – target sub-group

The GLMM comparing the combination of reward and selection history (difference between rewarded and absent trials) revealed that there was no effect of block (*b* = 48.70, *SI* = [3.73, 96.53], *RPE* = ± 15.15), there was substantial evidence in support of the null (*BF* = 0.19). There was no effect of trial (*b* = 33.09, *SI* = [-16.01, 81.68], *RPE* = ± 8.76), there was strong evidence in support of the null (*BF* = 0.039). There was no evidence of an effect of reward condition (*b* = -3.71, *SI* = [-31.27, 21.83], *RPE* = ± 6.50), there was decisive evidence in support of the null (*BF* < 0.01). There was no interaction between block and trial (*b* = -74.88, *SI* = [-238.94, 77.63], *RPE* = ± 8.76), there was very strong evidence in support of the null (*BF* = 0.018). There was no interaction between block and condition (*b* = -34.00, *SI* = [-101.47, 28.84], *RPE* = ± 18.82), there was very strong evidence support of the null (*BF* = 0.015). There was no interaction between trial and condition (*b* = 15.38, *SI* = [-52.81, 83.57], *RPE* = ± 13.40), there was very decisive evidence in support of the null (*BF* < 0.01). There was no three-way interaction (*b* = -18.19, *SI* = [-231.83, 215.37], *RPE* = ± 65.76), there decisive evidence in support of the null (*BF* < 0.01).

Target Reaction Times: reward and selection history – distractor sub-group

The GLMM revealed there was no effect of block (*b* = 34.97, *SI* = [-100.15, 180.06], *RPE* = ± 10.32; see Figure 32), there was very strong evidence in support of the null (*BF* = 0.023). There was no effect of trial (*b* = 11.43 *SI* = [-126.93, 149.59], *RPE* = ± 79.04; see Figure 33), there was decisive evidence in support of the null (*BF* < 0.01). There was no evidence of an effect of reward history (*b* = -23.24, *SI* = [-118.67, 57.80], *RPE* = ± 5.60), there was very strong evidence in support of the null (*BF* = 0.022). There was no evidence of an effect of selection history (no-reward relative to absent) during the test phase (*b* = -13.11, *SI* = [-115.79, 109.37], *RPE* = ± 17.15), there was very strong evidence in support of the null (*BF* = 0.023). There was no interaction between block and trial (*b* = 0.44, *SI* = [-474.25, 477.35], *RPE* = ± 121.36), there was very strong evidence in support of the null (*BF* = 0.013). There was no interaction between block and reward history (*b* = -176.86, *SI* = [-386.46, 22.18], *RPE* = ± 75.13), there was strong evidence in support of the null (*BF* = 0.082). There was also no interaction between block and selection history (*b* = -198.97, *SI* =

[-408.19, 0.62], *RPE* = ± 69.51), there was substantial evidence in support of the null (*BF* = 0.15). There was no interaction between trial and reward history (*b* = 90.44, *SI* = [-111.97, 309.87], *RPE* = ± 58.42), there was very strong evidence in support of the null (*BF* = 0.02). There was no interaction between trial and selection history (*b* = 102.20, *SI* = [-92.46, 308.79], *RPE* = ± 39.58), there was very strong evidence in support of the null (*BF* = 0.023). There was no three-way interaction between block, trial, and reward history (*b* = -446.93, *SI* = [-1119.04, 238.50], *RPE* = ± 1200.97), there was decisive evidence in support of the null (*BF* < 0.01). There was also no three-way interaction between block, trial, and selection history (*b* = 965.40, *SI* = [-1042.20, 321.58], *RPE* = ± 965.40), there was decisive evidence in support of the null (*BF* < 0.01).

Target Reaction Times: combination of reward and selection history – distractor sub-group

The GLMM comparing the combination of reward and selection history revealed that there was no effect of block (*b* = -144.75, *SI* = [-281.63, 215.37], *RPE* = ± 18.04), there was substantial evidence in support of the null (*BF* = 0.37). There was no effect of trial (*b* = 99.37, *SI* = [-32.22, 237.93], *RPE* = ± 74.56), there was strong evidence in support of the null (*BF* = 0.044). There was no evidence of an effect of reward condition (*b* = 26.21, *SI* = [-96.05, 157.78], *RPE* = ± 18.96), there was strong evidence in support of the null (*BF* = 0.032). There was no interaction between block and trial (*b* = -445.80, *SI* = [-905.37, -2.51], *RPE* = ± 71.61), there was decisive evidence in support of the null (*BF* < 0.01). There was no interaction between block and condition (*b* = -18.50, *SI* = [-21.40, 160.71], *RPE* = ± 28.26), there was decisive evidence in support of the null (*BF* < 0.01). There was no interaction between trial and condition (*b* = 11.58, *SI* = [-166.84, 203.22], *RPE* = ± 75.52), there was very strong evidence in support of the null (*BF* = 0.016). There was no three-way interaction (*b* = 105.46, *SI* = [-498.42, 705.95], *RPE* = ± 282.52, there was decisive evidence in support of the null (*BF* < 0.01).

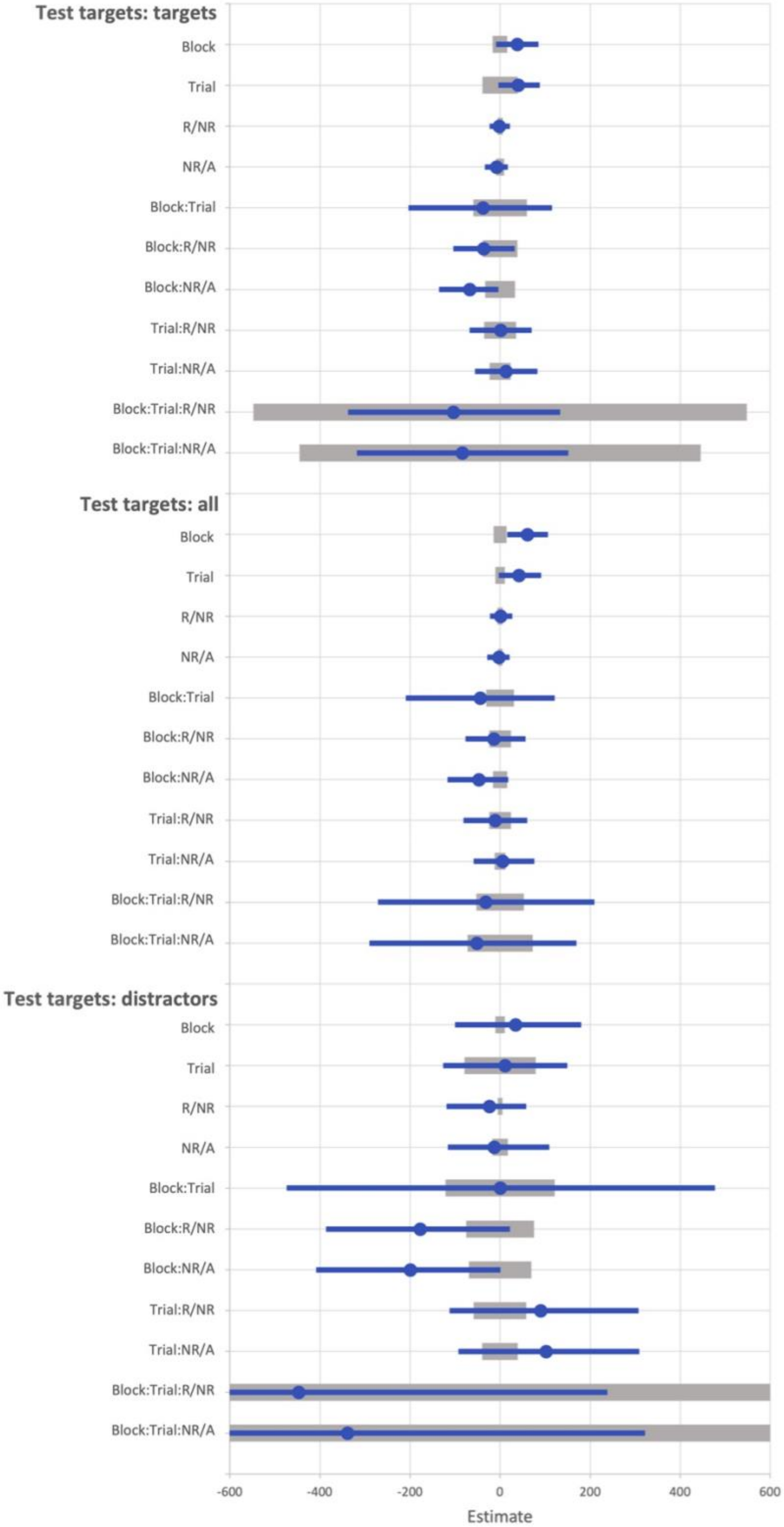

Figure 26. Mean point estimates and support intervals for each of the fixed effects from the generalized linear mixed effects model's (GLMM) for target RTs during the test phase in Experiment 3. Grey boxes denote the null region (region of practical equivalence, *RPE*).

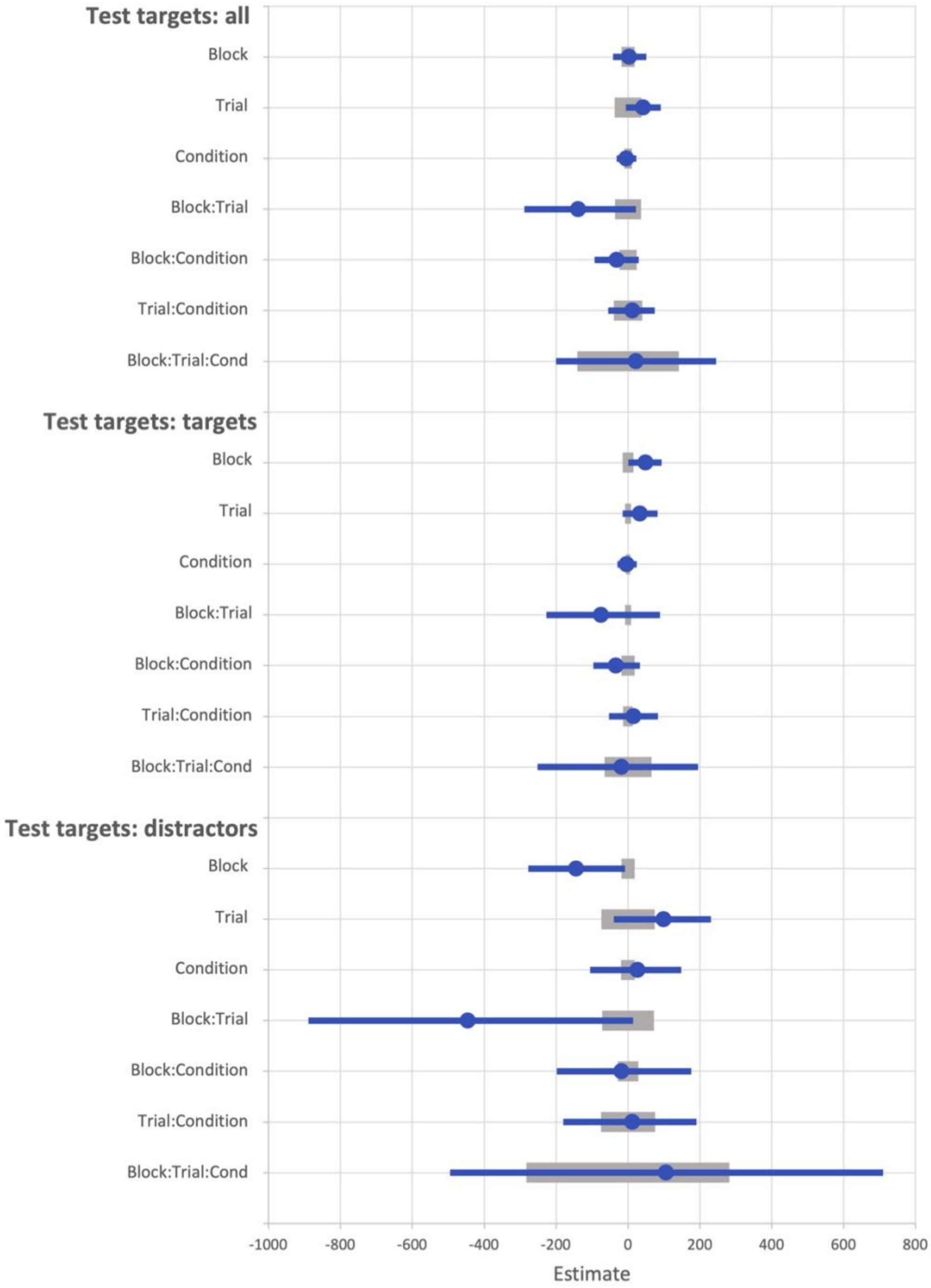

Figure 27. Mean point estimates and support intervals for each of the fixed effects from the generalized linear mixed effects model (GLMM) examining reward versus absent for target RTs during the test phase in Experiment 3. Grey boxes denote the null region (region of practical equivalence, *RPE*).

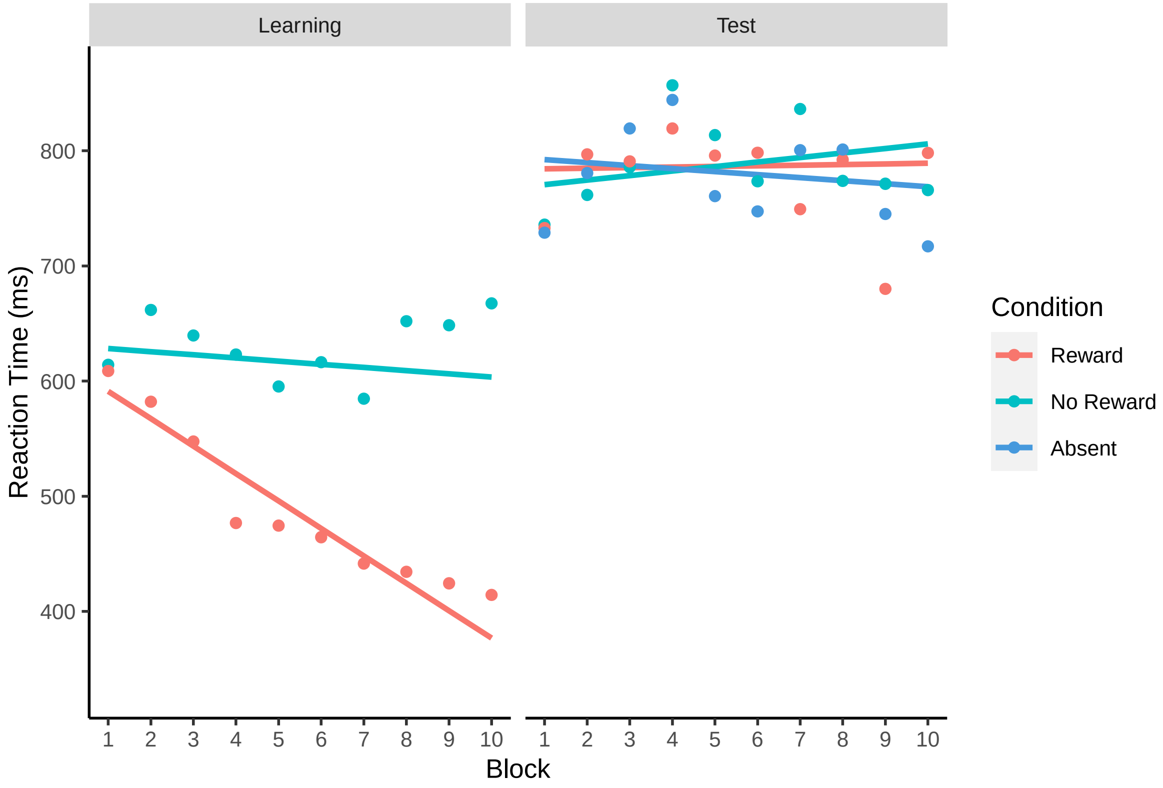

Figure 28. RTs for all participants plotted as a function of block and condition

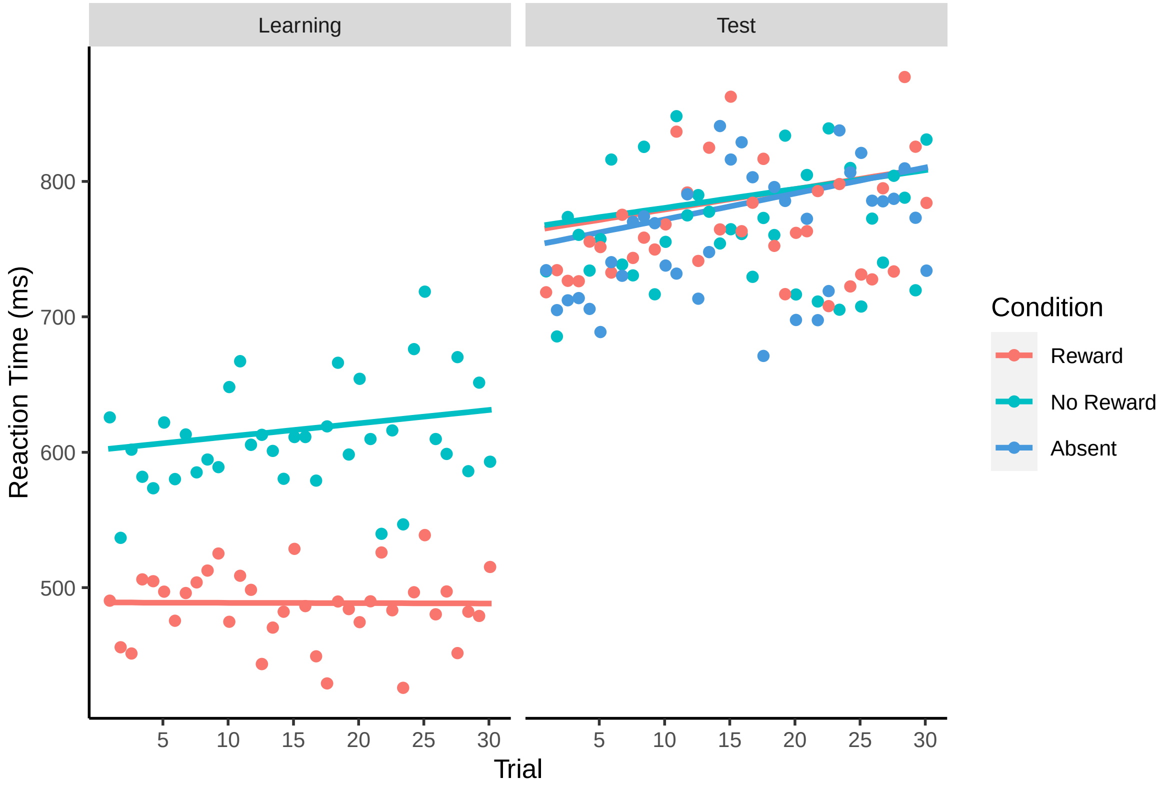

Figure 29. RTs for all participants plotted as a function of trial and condition

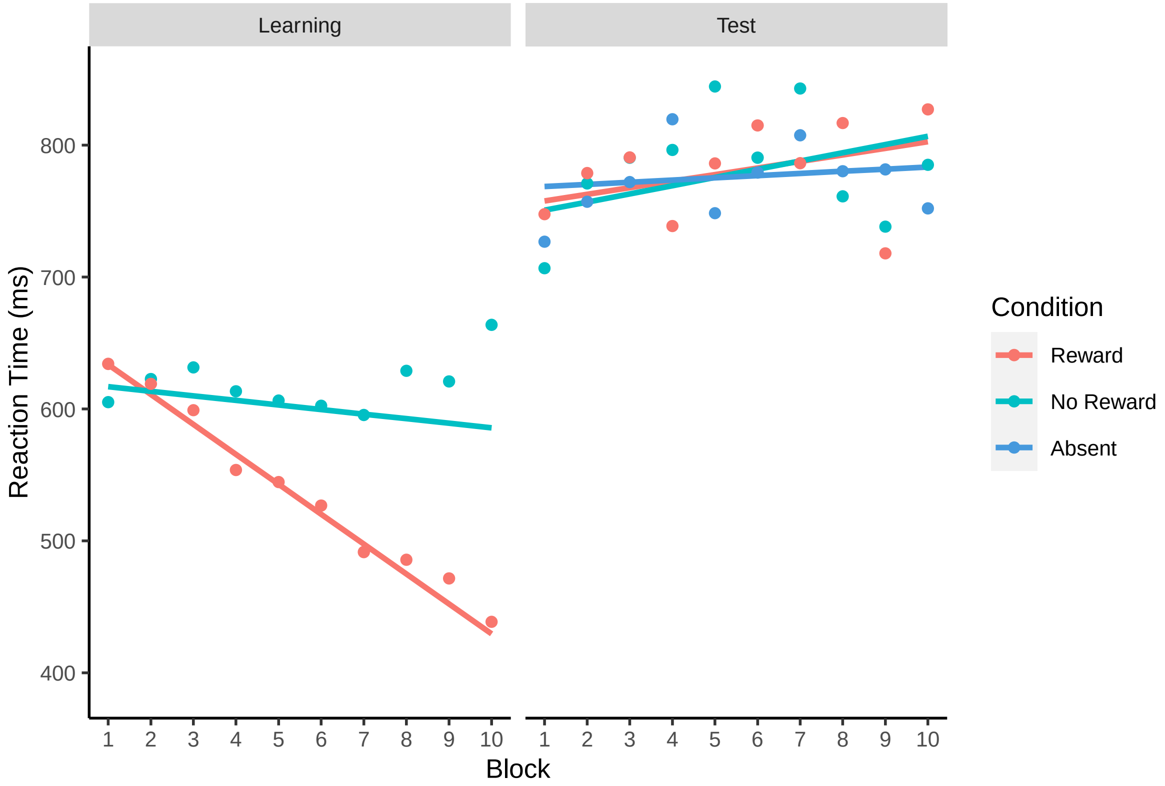

Figure 30. RTs for the target sub-group plotted as a function of block and condition

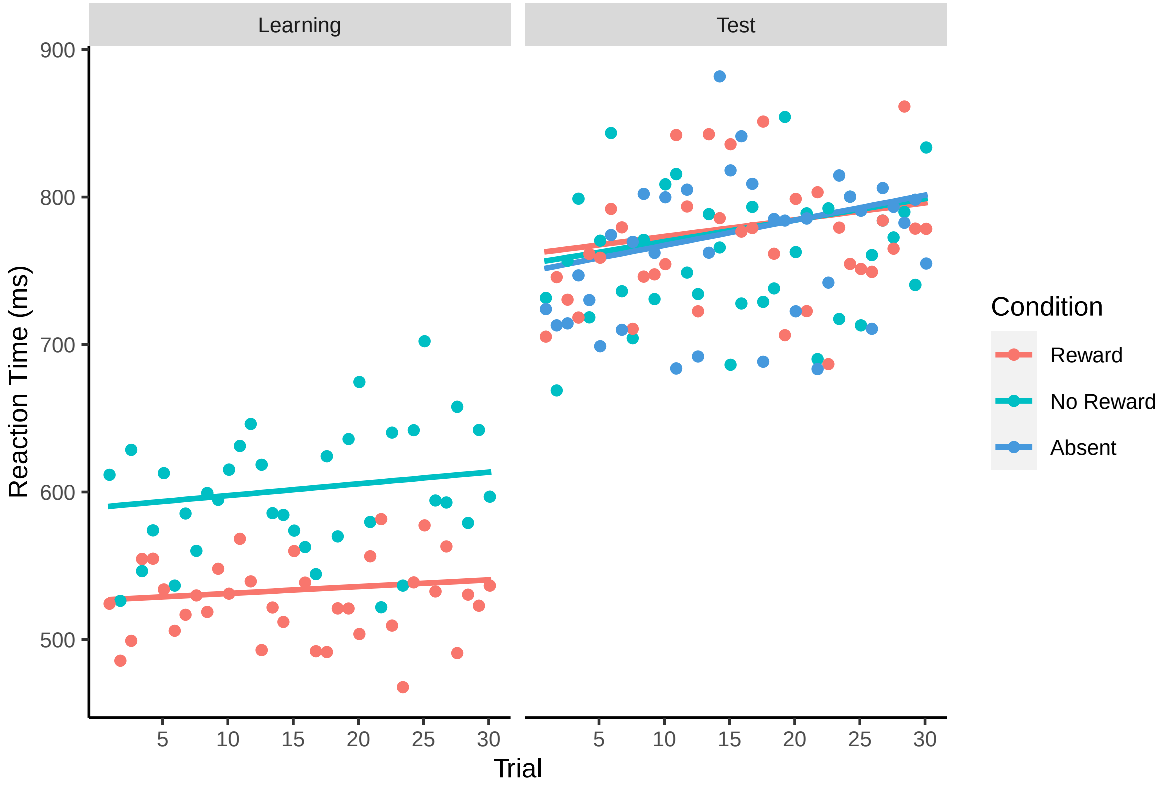

Figure 31. RTs for target sub-group participants plotted as a function of trial and condition

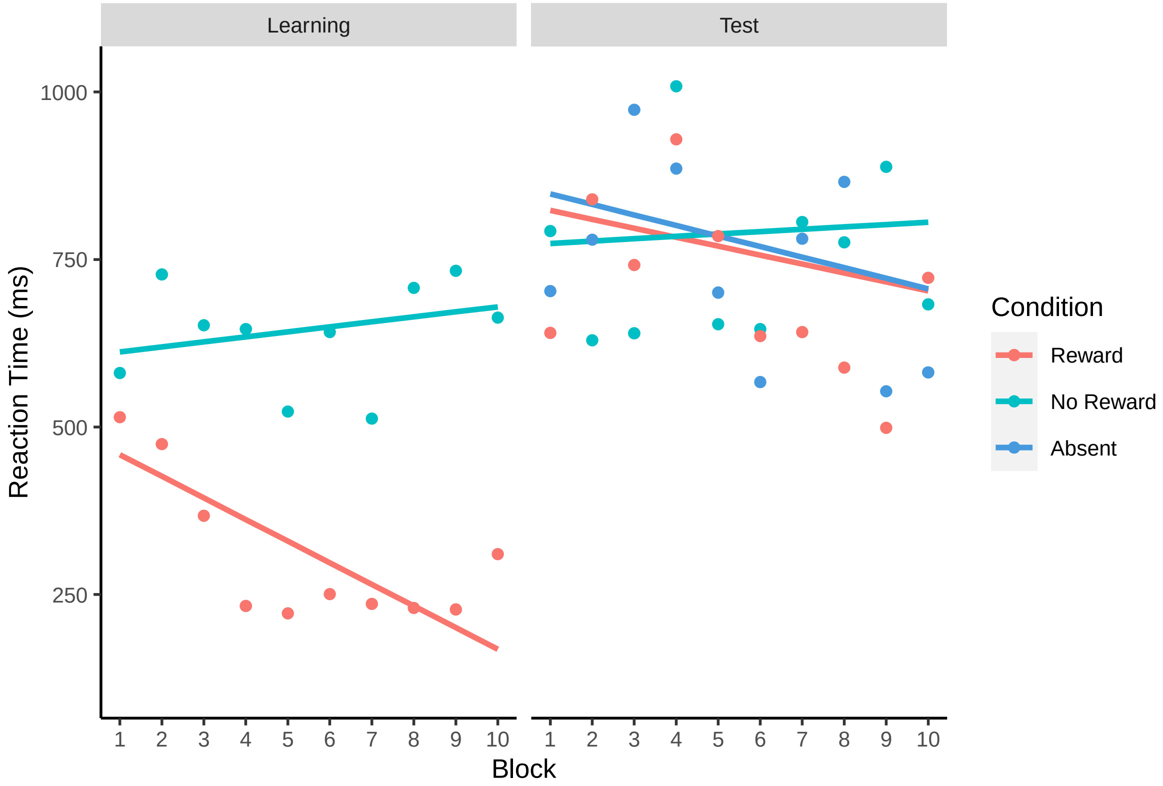

Figure 32. RTs for the distractor sub-group plotted as a function of block and condition

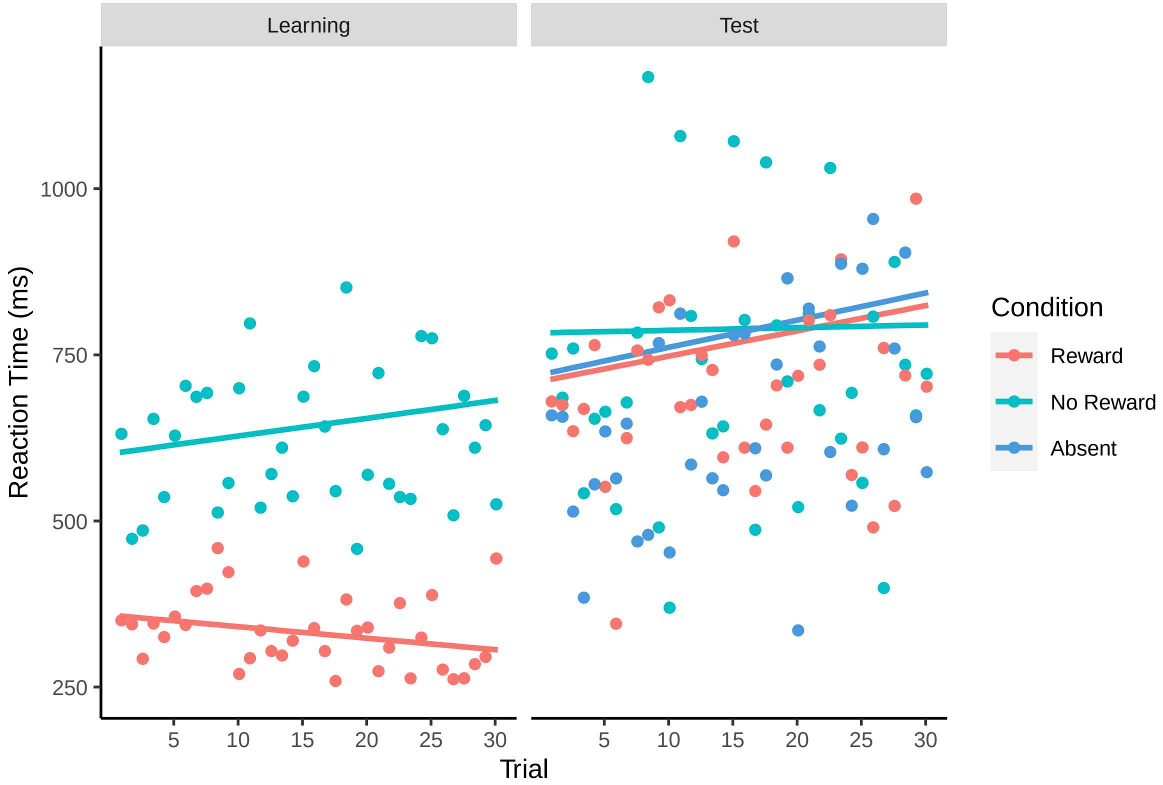

Figure 33. RTs for distractor sub-group participants plotted as a function of trial and condition

Distractor Detections

A separate general linear mixed effects model (GLMM) was used to examine responses to distractors during the test phase with the fixed effects of block (1-10), trial (1-36), and reward condition (reward, non-rewarded, absent). A separate GLMM was conducted for all participants, the target sub-group, and the distractor sub-group (See Figure 34. for mean point estimates for the main model and Figure 35. for the model assessing reward versus absent).

Distractor detections: reward and selection history – all participants

The GLMM revealed that there was no effect of block (*b* = -0.15, *SI* = [-0.75, 0.41], *RPE* = ± 0.05; see Figure 36), there was strong evidence in support of the null (*BF* = 0.033). There was no effect of trial (*b* = -0.18, *SI* = [-0.73, 0.38], *RPE* = ± 0.05; see Figure 37), there was strong evidence in support of the null (*BF* = 0.035). There was evidence of an effect of reward history such that participants responded to a greater number of previously rewarded distractors than previously non-rewarded distractors (*b* = 1.21, *SI* = [0.53, 1.89], *RPE* = ± 0.05, *BF* = 4.82). There was no evidence of an effect of selection history during the test phase (*b* = -0.35, *SI* = [-0.79, 0.05], *RPE* = ± 0.05), there was substantial evidence in support of the null (*BF* = 0.15). There was no interaction between block and trial (*b* = 2.21, *SI* = [0.20, 4.25], *RPE* = ± 0.05), there was anecdotal evidence in support of the null (*BF* = 0.46). There was no interaction between block and reward history (*b* = -0.35, *SI* = [-1.15, 0.39], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.036). There was also no interaction between block and selection history (*b* = 1.04, *SI* = [0.19, 1.91], *RPE* = ± 0.05), there was anecdotal evidence in support of the null (*BF* = 0.89). There was no interaction between trial and reward history (*b* = -0.18, *SI* = [-0.85, 0.79], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.024). There was no interaction between trial and selection history (*b* = -0.032, *SI* = [-0.85, 0.79], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.024). There was no three-way interaction between block, trial, and reward history (*b* = -0.28, *SI* = [-2.81, 2.27], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.022. There was also no three-way interaction between block, trial, and selection history (*b* = -0.63, *SI* = [-3.43, 2.21], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.028).

Distractor detections: combination of reward and selection history – all participants

The GLMM comparing the combination of reward and selection history (difference between rewarded and absent trials) revealed that there was no effect of block (*b* = -0.50, *SI* = [-0.96, -0.06], *RPE* = ± 0.05), there was anecdotal evidence in support of the null (*BF* = 0.53). There was no effect of trial (*b* = -0.36, *SI* = [-0.79, 0.08], *RPE* = ± 0.05), there was anecdotal evidence in support of the null (*BF* = 0.11). There was evidence of an effect of reward such that participants responded to a greater number of previously rewarded distractors compared to distractors presented in a novel color (*b* = -1.56, *SI* = [-2.22, -0.91], *RPE* = ± 0.05, *BF* = 45.23). There was evidence of an interaction between block and trial (*b* = 1.93, *SI* = [0.39, 3.51], *RPE* = ± 0.05, *BF* = 1.16). There was an interaction between block and condition such that the difference in responses to rewarded and absent distractors decreased with the course of each block (*b* = 1.39, *SI* = [0.063, 2.13], *RPE* = ± 0.05, *BF* = 53.53). There was no interaction between trial and condition (*b* = 0.14, *SI* = [-0.57, 0.86], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.028). There was no three-way interaction (*b* = -0.33, *SI* = [-2.80, 2.17], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.029).

Distractor detections: reward and selection history – target sub-group

The GLMM revealed that there was no effect of block (*b* = -0.47, *SI* = [-1.22, 0.32], *RPE* = ± 0.05; see Figure 38), there was strong evidence in support of the null (*BF* = 0.088). There was no effect of trial (*b* = -0.50, *SI* = [-1.27, 0.31], *RPE* = ± 0.05; see Figure 39), there was strong evidence in support of the null (*BF* = 0.095). There was no evidence of an effect of reward history on the target only group suggesting that they did not respond to more previously rewarded distractors than previously non-rewarded distractors (*b* = 0.10, *SI* = [-0.32, 0.52], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.04). There was no evidence of an effect of selection history (no-reward relative to absent) during the test phase (*b* = -0.24, *SI* = [-0.71, 0.20], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.067). There was an interaction between block and trial (*b* = 5.15, *SI* = [2.49, 7.78], *RPE* = ± 0.05, *BF* = 35.61). There was no interaction between block and reward history (*b* = -0.70, *SI* = [-1.77, 0.43], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.08). There was also no interaction between block and selection history (*b* = 1.19, *SI* = [-0.67, 1.65], *RPE* = ± 0.05), there was substantial evidence in support of the null (*BF* = 0.28). There was no interaction between trial and reward history (*b* = 0.24, *SI* = [-0.86, 1.33], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.039). There was no interaction between trial and selection history (*b* = 0.51, *SI* = [-0.67, 1.65], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.055). There was no three-way interaction between block, trial, and reward history (*b* = 0.17, *SI* = [-3.48, 3.82], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.036). There was also no three-way interaction between block, trial, and selection history (*b* = -2.54, *SI* = [-6.37, 1.47], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.085).

Distractor detections: combination of reward and selection history – target sub-group

The GLMM comparing the combination of reward and selection history (difference between rewarded and absent trials) that there was an effect of block such that detections decreased as a function of block (*b* = -1.16, *SI* = [-1.89, -0.47], *RPE* = ± 0.05, *BF* = 7.58). There was no effect of trial (*b* = -0.26, *SI* = [-0.96, 0.46], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.051). There was no evidence of an effect of reward in the target group (*b* = -0.35, *SI* = [-0.77, 0.07], *RPE* = ± 0.05), there was substantial evidence in support of the *BF* = 0.14). There was evidence of an interaction between block and trial such that the vigilance decrement was greater in earlier compared to later blocks (*b* = 5.26, *SI* = [2.85, 7.71], *RPE* = ± 0.05, *BF* = 132.22). There was an interaction between block and condition such that the difference in responses to rewarded and absent distractors decreased with the course of each block (*b* = 1.88, *SI* = [0.82, 2.96], *RPE* = ± 0.05, *BF* = 13.08). There was no interaction between trial and condition (*b* = 0.26, *SI* = [-0.83, 1.33], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.05). There was no three-way interaction (*b* = -2.64, *SI* = [-6.16, 1.11], *RPE* = ± 0.05), there was substantial evidence in support of the null (*BF* = 0.12).

Distractor detections: reward and selection history – distractor sub-group

The GLMM revealed that there was no effect of block (*b* = 0.45, *SI* = [-0.35, 1.21], *RPE* = ± 0.05; see Figure 40), there was strong evidence in support of the null (*BF* = 0.051). There was no effect of trial (*b* = 0.43, *SI* = [-0.38, 1.20], *RPE* = ± 0.05; see Figure 41), there was strong evidence in support of the null (*BF* = 0.077). There was evidence of an effect of reward history such that participants responded to a greater number of previously rewarded distractors than previously non-rewarded distractors (*b* = 4.63, *SI* = [3.69, 5.72], *RPE* = ± 0.05, *BF* > 1000). There was no evidence of an effect of selection history (no-reward relative to absent) during the test phase (*b* = -0.058, *SI* = [-0.77, 0.54], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.068). There was no interaction between block and trial (*b* = -1.04, *SI* = [-3.72, 1.75], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.063). There was no interaction between block and reward history (*b* = -0.71, *SI* = [-1.76, 0.30], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.091). There was also no interaction between block and selection history (*b* = 0.61, *SI* = [-0.52, 1.78], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.063). There was no interaction between trial and reward history (*b* = -0.76, *SI* = [-1.81, 0.25], *RPE* = ± 0.05), there was substantial evidence in support of the null (*BF* = 0.11). There was no interaction between trial and selection history (*b* = -0.80, *SI* = [-1.89, 0.35], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.096). There was no three-way interaction between block, trial, and reward history (*b* = 1.50, *SI* = [-1.96, 4.90], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.047). There was also no three-way interaction between block, trial, and selection history (*b* = 1.61, *SI* = [-2.29, 5.71], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.051).

Distractor detections: combination of reward and selection history – distractor sub-group

The GLMM comparing the combination of reward and selection history (difference between rewarded and absent trials) revealed that there was no effect of block (*b* = -0.26, *SI* = [-0.79, 0.29], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.044). There was no effect of trial (*b* = -0.33, *SI* = [-0.91, 0.21], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.064). There was evidence of an effect of reward such that participants responded to a greater number of rewarded distractors compared to distractors presented in a novel color (*b* = -4.56, *SI* = [-5.74, -3.57], *RPE* = ± 0.05, *BF* > 1000). There was no evidence of an interaction between block and trial (*b* = 0.48, *SI* = [-1.36, 2.27], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.033). There was an interaction between block and condition such that the difference in responses to rewarded and absent distractors decreased with the course of each block (*b* = 1.31, *SI* = [0.36, 2.23], *RPE* = ± 0.05, *BF* = 2.16). There was no interaction between trial and condition (*b* = -0.03, *SI* = [-0.94, 0.89], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.034). There was no three-way interaction (*b* = 0.075, *SI* = [-6.16, 1.11], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.036).

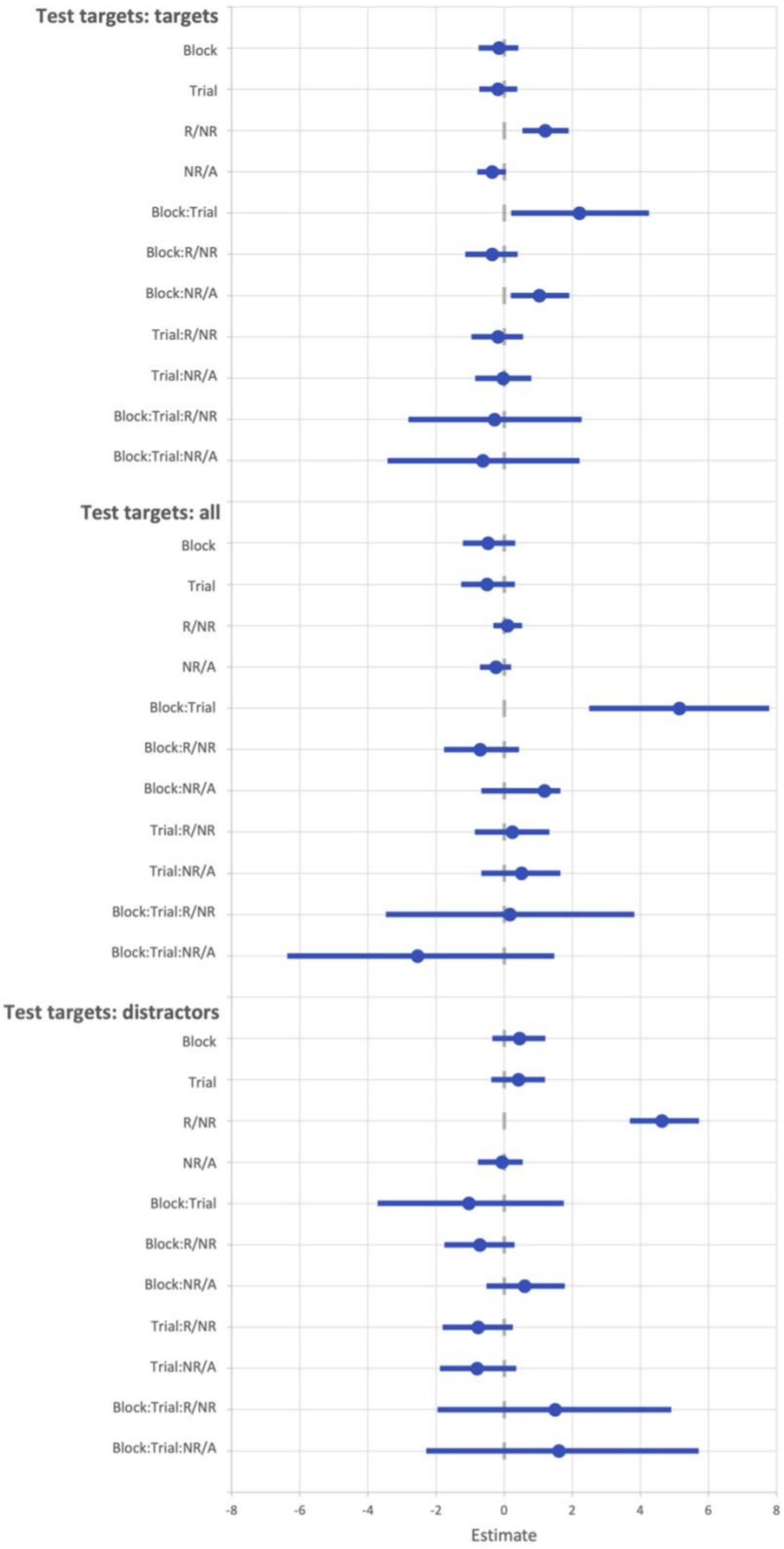

Figure 34. Mean point estimates and support intervals for each of the fixed effects from the generalized linear mixed effects model's (GLMM) for distractor detections during the test phase in Experiment 3. Mean estimates are on the log odds scale. Grey boxes denote the null region (region of practical equivalence, *RPE*).

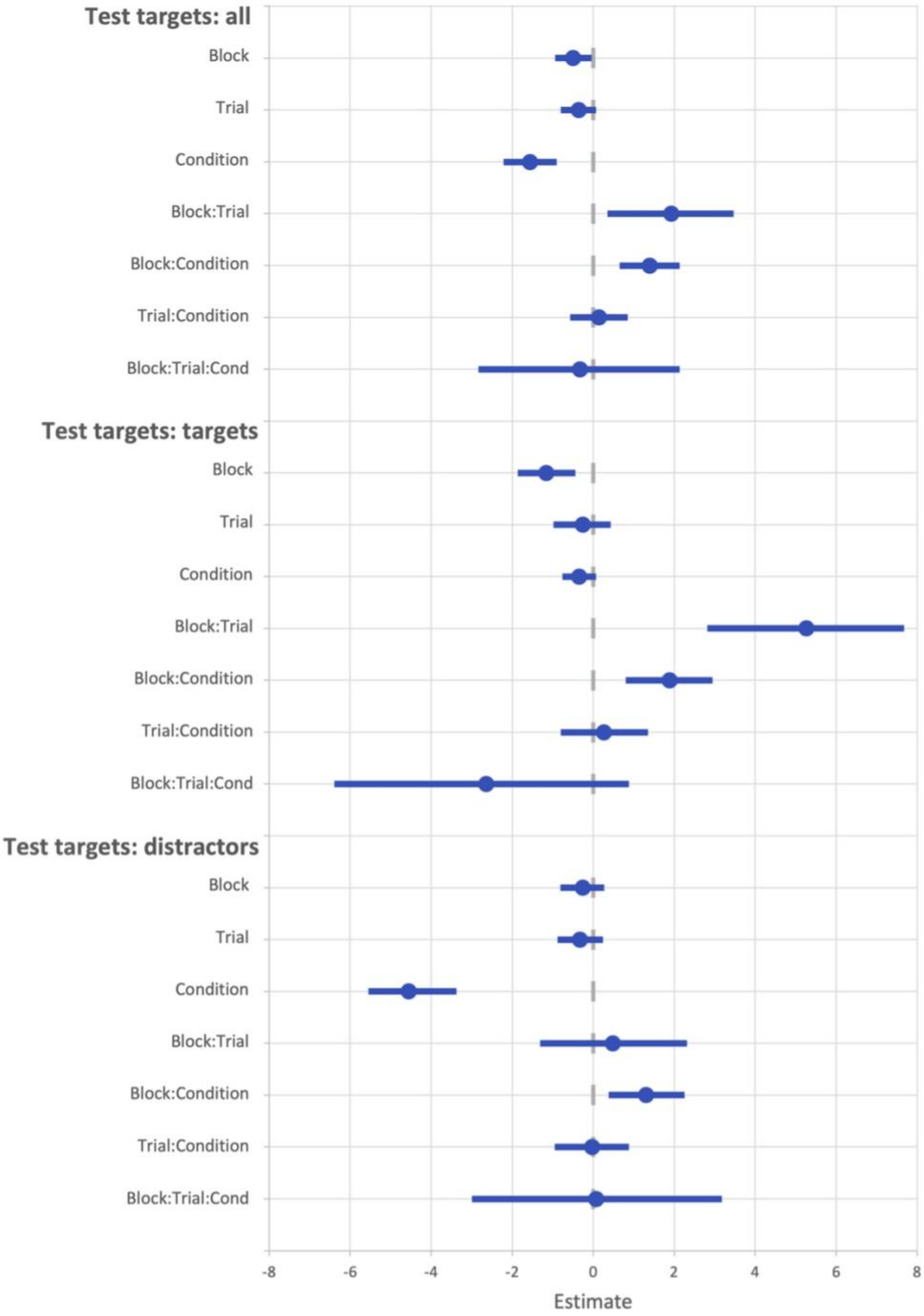

Figure 35. Mean point estimates and support intervals for each of the fixed effects from the generalized linear mixed effects model (GLMM) examining reward versus absent for distractor detections during the test phase in Experiment 3. Mean estimates are on the log odds scale. Grey boxes denote the null region (region of practical equivalence, *RPE*).

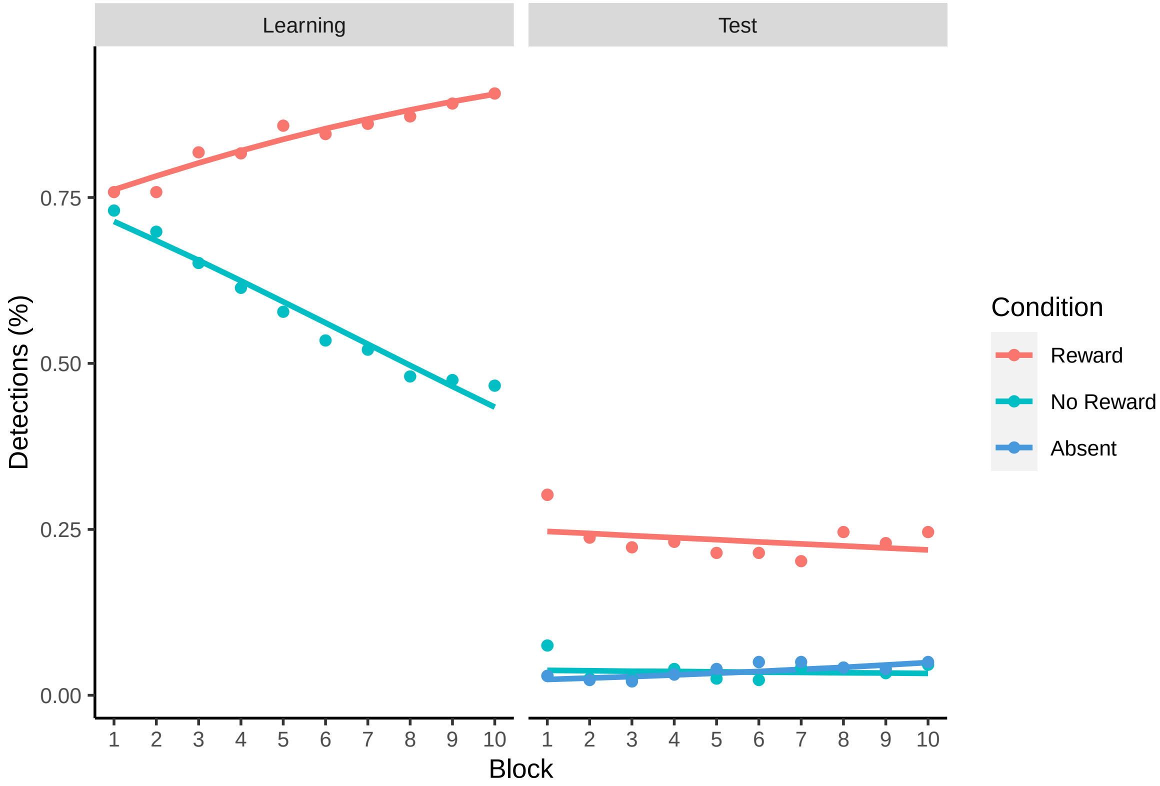

Figure 36. Distractor detections for all participants plotted as a function of block and condition

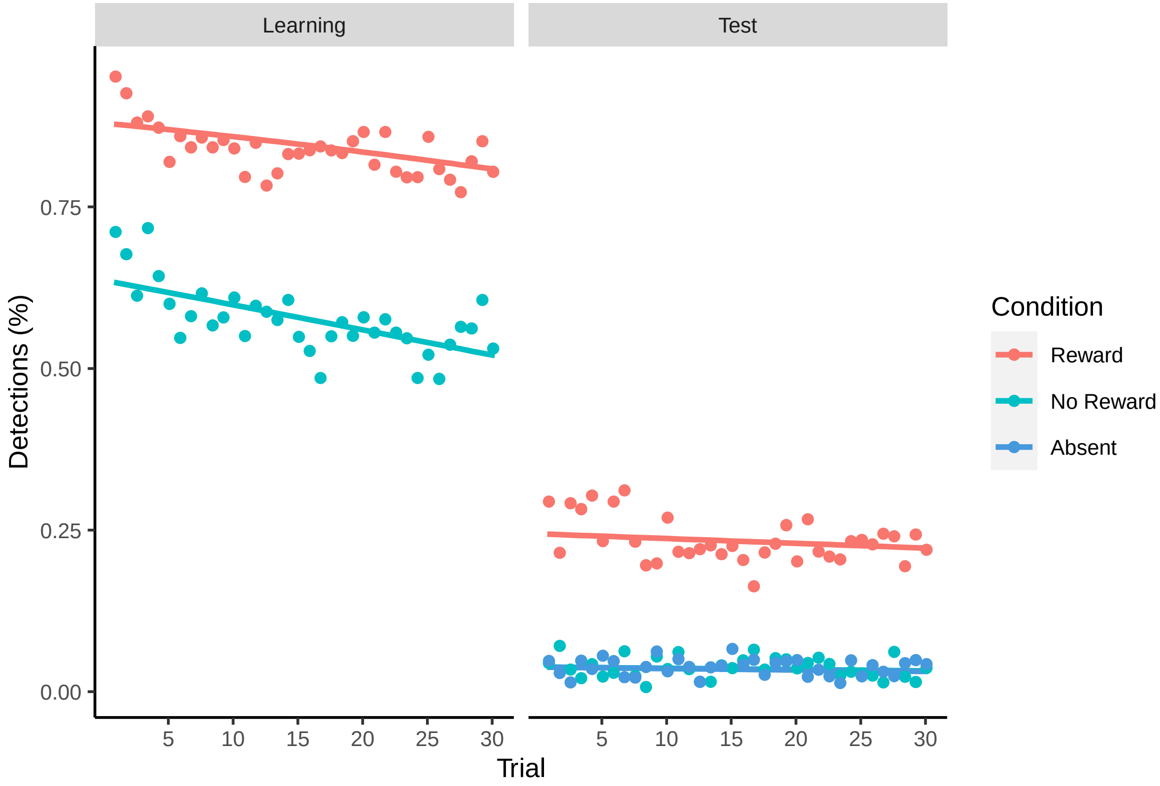

Figure 37. Distractor detections for all participants plotted as a function of block and condition

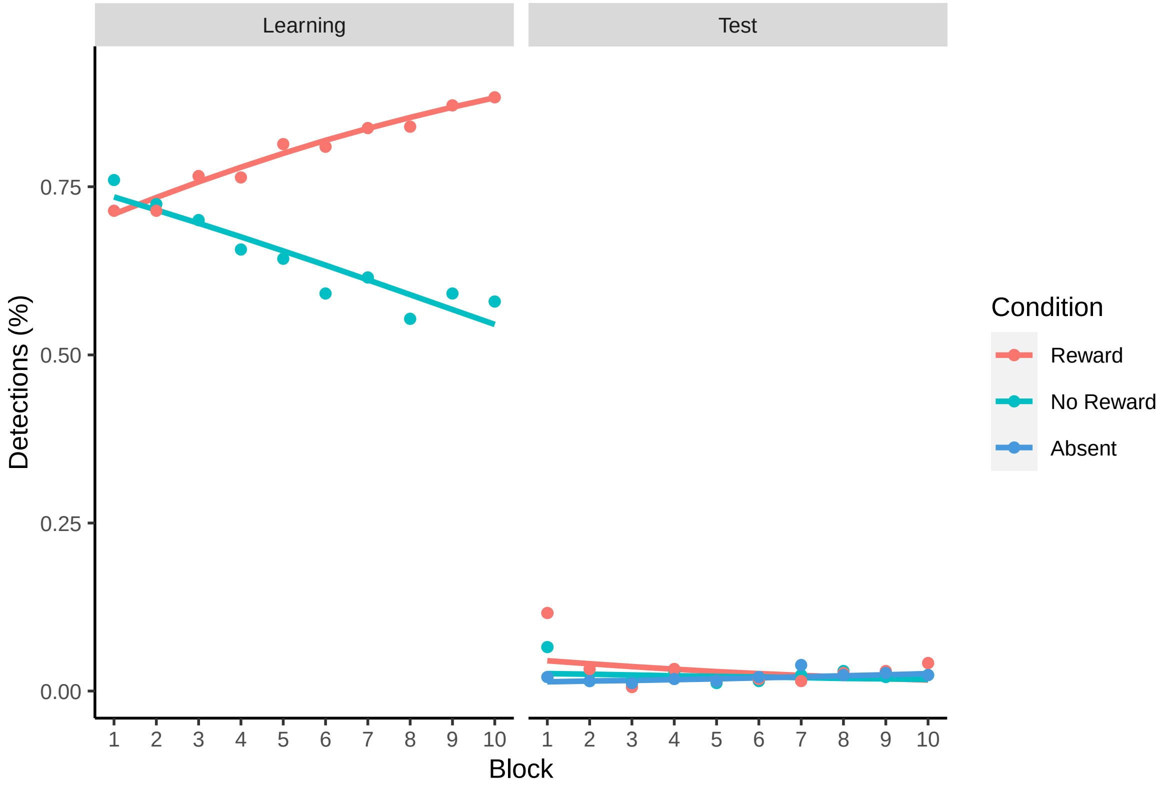

Figure 38. Distractor detections the target sub-group plotted as a function of block and condition

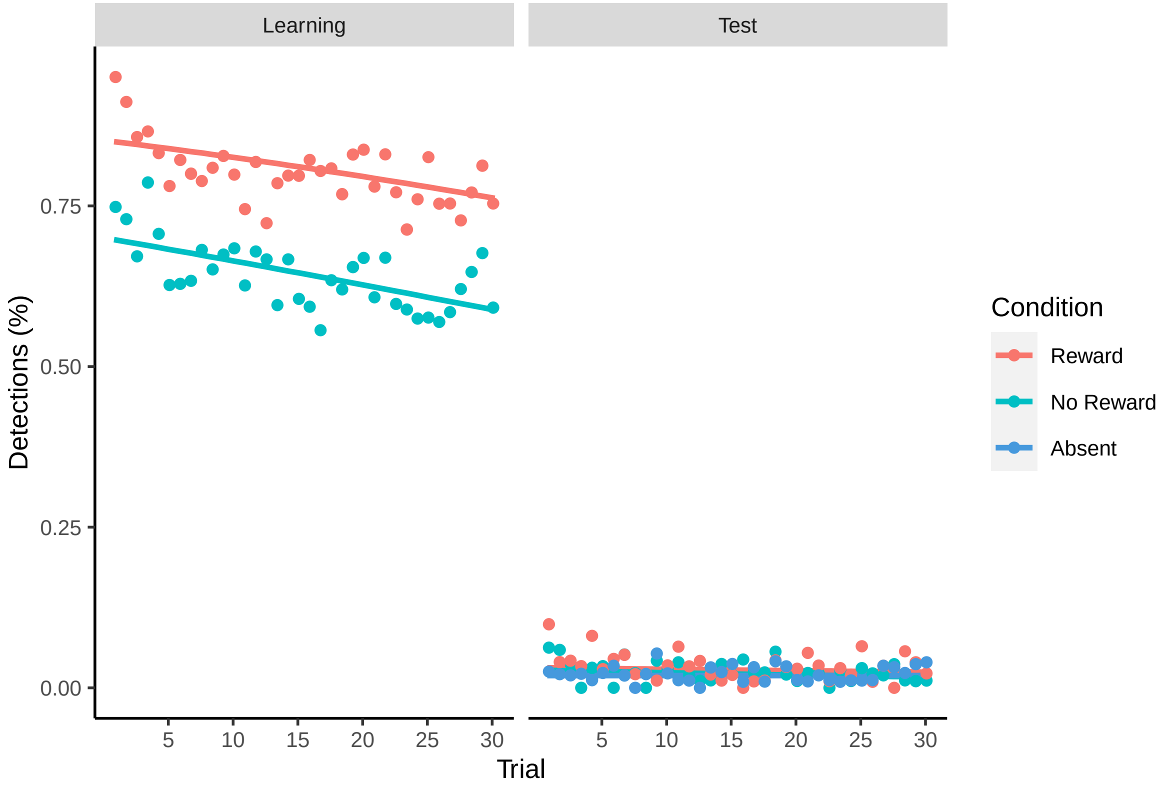

Figure 39. Distractor detections for the target sub-group plotted as a function of block and condition

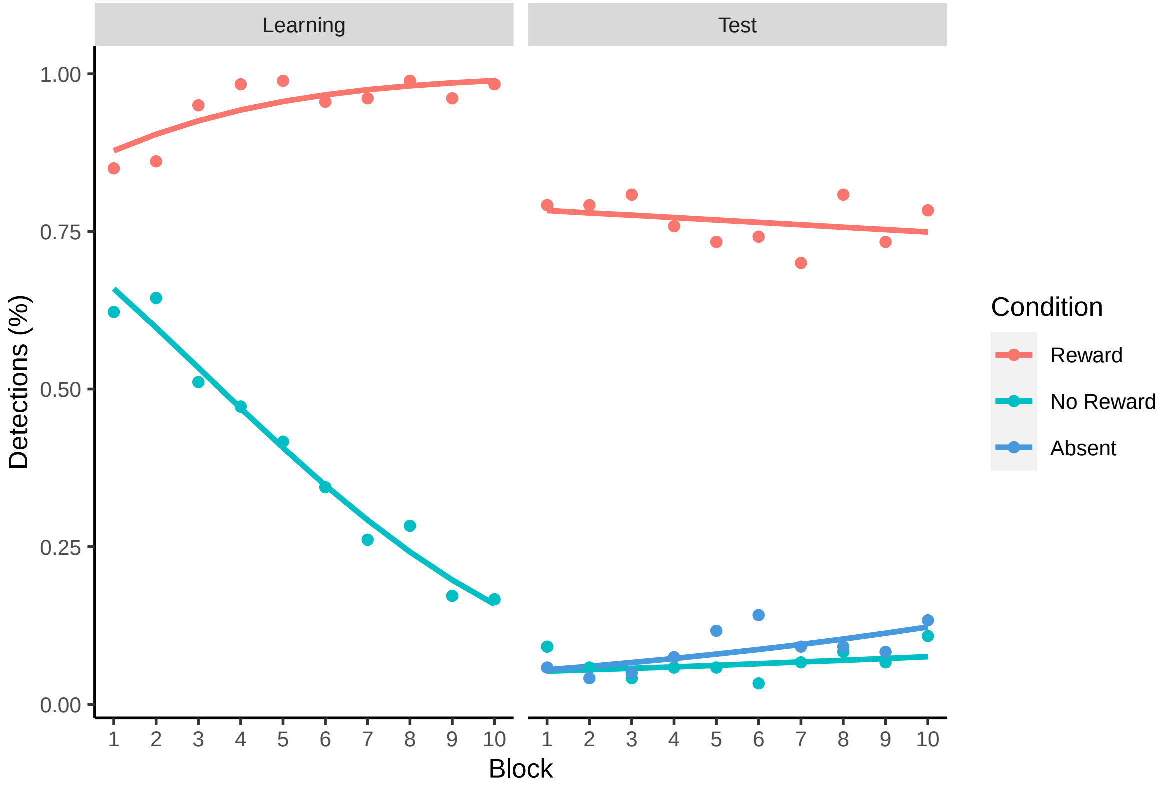

Figure 40. Distractor detections the distractor sub-group plotted as a function of block and condition

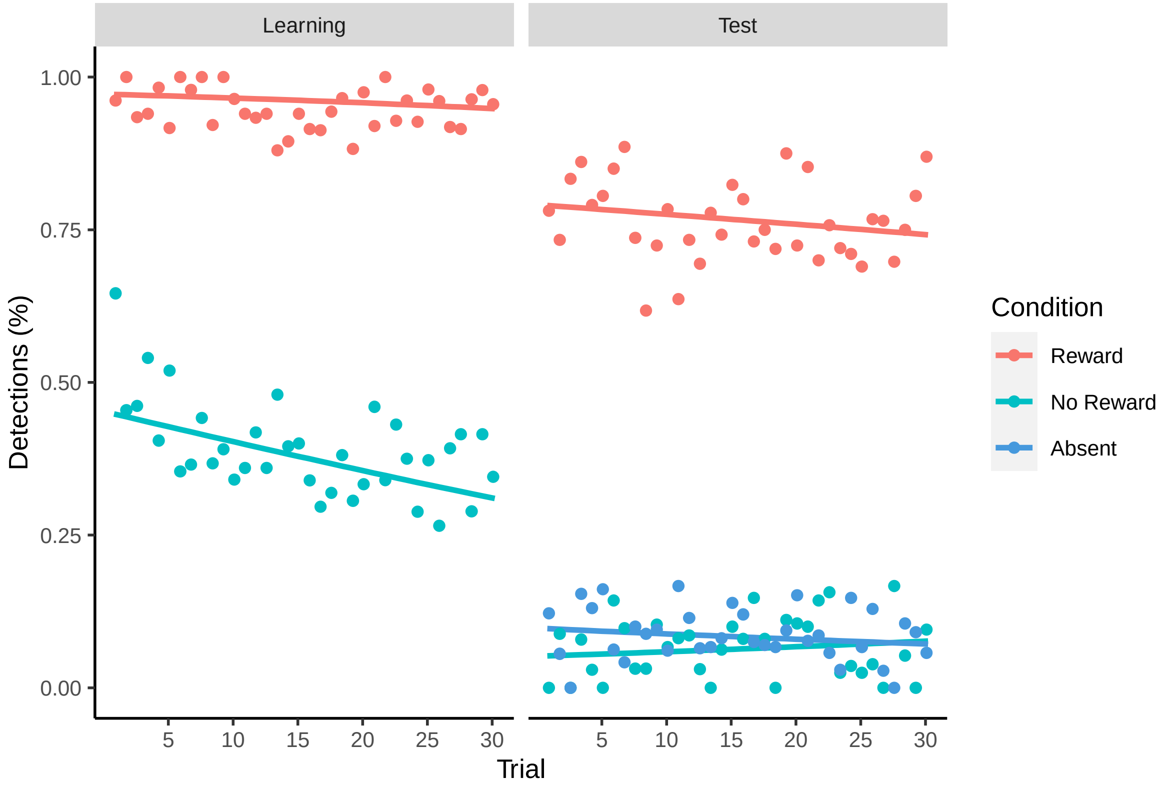

Figure 41. Distractor detections the distractor sub-group plotted as a function of trial and condition

Discussion

There was evidence of an effect of reward and an interaction between block and condition in the learning phase across all participants and the two sub-groups. This effect was such that participants responded to a greater number of rewarded relative to non-rewarded targets. However, the Bayes Factor for the effect of reward condition was substantially larger in the group that responded to distractors in the test phase (*BF* = 1780000) than in the group that responded to targets only (*BF* = 47). There was an effect of both block and trial across all sub-groups indicating that detections decreased over time. RTs during the learning phase indicated that there was an overall effect of reward in the distractor sub-group and not the target sub-group. However, the interaction between condition and reward was present in both groups suggesting that the learning of the reward association was also present in the reaction time data.

During the test phase, there was no effect of the reward-associated distractor on detections of long-duration targets across all groups. This indicates that a previously reward-associated feature did not disrupt sustained attention relative to when a non-reward association distractor was present or when a distractor was absent. This could be due to task-relevance, if the distractor is presented on a non-target, it is no longer relevant to current goals and does not impact sustained attention. It's also possible that the distance between the distractor and the target was too long to cause disruption to fail to respond to the target. This possibility needs to be explored in future research. During the test phase, there was a performance decrement in the target sub-group but not the distractor sub-group. Although, this effect is most likely driven by the distractor group having poorer performance to targets resulting in a floor effect. There were also no effect of reward condition on response times to targets in the test phase.

When examining responses to distractor stimuli, it was found that 10 out of the 40 participants were consistently responding to distractor stimuli as if they were targets. Results demonstrated that there was an effect of reward history on distractor detections in the distractor sub-group but not the target sub-group. Interestingly, 8 out of the 10 participants also responded to targets throughout the task suggesting that they did understand that the goal of the task was to respond to the long-duration stimuli. Why do these participants continue to respond to the reward-associated color when it is not the target? It's possible that the rewarded stimulus was perceived to be long-duration target to these individuals. This is consistent with the idea that items that signal a high reward are perceived to last for a longer time (Failing & Theeuwes, 2016). Furthermore, these results are consistent with Chapter II where it was demonstrated that when a reward-associated feature is presented as a distractor instead of a target it was only possible to observe VDAC under certain conditions i.e., when a salient singleton was present. However, this finding was specific to visual search tasks.

General Discussion

Previous research has shown that reward-associated stimuli can involuntarily capture attention during a selective attention task (Anderson et al., 2011; Anderson & Halpern, 2017; Anderson & Yantis, 2013; Failing & Theeuwes, 2014; MacLean et al., 2016; MacLean & Giesbrecht, 2015a, 2015b). However, it remains unclear whether reward-associated stimuli can impact other forms of attention such as sustained attention. In the present study, how reward and selection history impact sustained attention was investigated. In all experiments, during the learning phase, there was an effect of reward condition and an interaction between reward and block, indicating that participants successfully learned the reward association as the difference in both detections and RTs between rewarded and non-rewarded targets increased with each block. During the test phase, there was evidence of an effect of reward history in Experiments 1 and 2. When the reward-associated feature remained task-relevant during the test phase target detections continued to be biased to reward-associated features. However, in Experiment 3 there was no effect of VDAC when the reward-associated feature was presented on a distractor, target detection performance was not influenced by prior distractor type. However, it was found that reward history influenced distractor responses such that participants continued to respond to a greater number of rewarded distractors relative to non-rewarded and absent-colored distractors.

When reward history was observed during the test phase, no reduction in this effect across blocks or within a block was observed. These results are consistent with previous reports suggesting that when the reward-associated feature remains task-relevant such as when continuing to appear on a target then reward-associations are not extinguished (Milner et al., 2023). These findings are also in line with previous research that has demonstrated that when rewards are available sustained attention is improved (Bergum & Lehr, 1964; Esterman et al., 2014; Horne & Pettitt, 1985; Massar et al., 2016). However, the difference in the current set of studies is that it demonstrates that rewarded features continued to be prioritized in visual attention even when no longer rewarded. It is the nature of sustained attention tasks to be difficult. Therefore, it’s possible that any cue such as color that signaled the presence of a target in this current task would be utilized and continued to be utilized by participants to reduce attentional effort.

However, when examining whether presenting the reward association feature as a distractor prior to a target in the RSVP stream there was no evidence of a capture effect disrupting target performance. Performance was much lower in the test phase of Experiment 3 likely due to the task being more difficult as color could no longer be used as a cue to detect targets. These findings are consistent with Bachman et al., (2021) who did not find evidence of VDAC when the reward-associated feature was presented as a distractor during a sustained attention task. However, one limitation of the current study was that the distractor appeared 3, 4, or 5 positions before the target (2.4-4s). This was done so that the distractor response time window did not overlap with the onset of the target. However, this interval may have been too large to cause a miss of a target. Consequently, 10 out of the 40 participants consistently responded to previously rewarded distractors throughout the test phase. Eight out of the 10 also responded reliably to targets suggesting that they did understand the task and were not solely using color to respond to targets. It’s possible that for these participants that the reward-associated feature gained salience such that it was *perceived* to be of a longer duration. This idea would support research that has shown that previously rewarded stimuli are perceived to last for a longer duration of time (Failing & Theeuwes, 2016). Further research is needed to explore this possibility.

In Experiments 2 and 3 there was the opportunity to assess selection history as there were non-rewarded trials and absent trials which were presented in a novel color that had not been selected at test. No effect of selection history was found in Experiment 2 where the previously selected features remained on a target during the test phase. This result suggests that the benefits in performance in the sustained attention task are unique to reward history and not due to selection history influences alone. Although, as previously mentioned selection of the rewarded and non-rewarded target were not equal during the learning phase as participants detected a greater number of rewarded than non-rewarded targets. However, participants made a response to the non-rewarded color on average 65% of the time so it would be expected there would still be a selection-driven effect. In Experiment 3 there was also no evidence of an effect of selection history, which is not surprising as there was no evidence for selection history.

Our results are consistent with previous reports demonstrating that reward can influence attentional priority when spatial shifts of attention are not required (Failing & Theeuwes, 2015; le Pelley et al., 2017, 2019). However, previous research has failed to find evidence of an effect of value-driven attention capture when the primary task required no spatial shifts of attention (Bachman et al., 2021). However, it is important to note the differences between this study and ours, the distractor was presented at a location outside of the RSVP stream where attention was focused. As distractors were both irrelevant to completing the task and in a task-irrelevant location that was outside of participants current focus these distractors could possibly be more easily suppressed. Whereas in a visual search task, each location has the possibility of containing a task-relevant stimulus in any one trial so allocation of attention would not be suppressed at certain locations.

Across all Experiments either an effect of block and/or trial was observed during the learning and test phase indicating that performance on the task declined over time, supporting previous findings (O'Connell et al., 2009). This finding is consistent with previous research that has shown that decrements to sustained attention with time-on-task are insensitive to reward over time (Esterman et al., 2014). Although, reward boosts performance there is still a decline in performance over time regardless of reward condition, consistent with the idea that some aspects of performance are due to motivational lapses as supported by Underload theory while other aspects of sustained attention such as the vigilance decrement cannot be overcome by motivational factors such as reward supporting Resource theory.

In summary, these experiments replicated prior findings that reward can improve performance during sustained attention tasks (Bergum & Lehr, 1964; Esterman et al., 2014; Horne & Pettitt, 1985; Massar et al., 2016). Furthermore, it was demonstrated that these reward-associations can continue to benefit sustained attention even when no longer rewarded and do not appear to be subject to extinction. However, it was found that there was no evidence of VDAC when previously rewarded features were presented on a distractor. Although, it appeared that the reward-associated distractors were still prioritized in visual attention.

Chapter IV: Generalizability across environments

Introduction

Typical VDAC paradigms have shown that features associated with reward can automatically capture attention (Anderson et al., 2011b, 2016; Anderson & Halpern, 2017; Anderson & Yantis, 2012a, 2013). However, this finding is specific to a set of largely homogenous tasks, and it is currently unclear whether such biases can generalize to other contexts within the lab but also beyond the lab into our everyday lives. It has been demonstrated that reward-associations can generalize when learning occurs in one task and test is in another unrelated task. Reward associations learned in the typical VDAC paradigm were found to have a larger flanker effect when the flanker was a previously reward-associated feature compared to a low-reward associated or neutral distractor (Anderson et al., 2012). This demonstrates that VDAC was able to generalize even though the stimuli, attentional set, and response requirements of the task differ between learning and test. In addition, the typical VDAC paradigm places the target features from learning on a different shape at test (e.g., on a circle at learning, diamond at test) demonstrating that these associations do generalize at least to some extent (Anderson et al., 2011a, 2011b, 2016; Anderson & Yantis, 2013).

After learning that a stimulus feature results in a rewarding outcome participants would be presented with similar features in the real world between the learning and the test phase. How is it possible for these attentional biases to persist when there are competing associations being formed outside of the lab between the two phases? It is possible that VDAC only occurs in the environment, context, or specific task in which the association was learned. Further research does suggest that the context evokes a specific set of stimulus associations that only bias attention in the specific context that they were learned. A study by Anderson (2015) used the typical VDAC paradigm where targets were always defined by two different colors in the learning phase. The difference in this study was that the visual search display was presented in two different contexts: a forest scene and a city scene. One color e.g., red was always rewarded when in the forest scene, and the other color e.g., green was always rewarded in the city scene. The author then examined distraction in the test phase by examining RTs when the red or green distractor was presented in either of the two scenes. Results showed that when the distractor appeared in the context in which it had previously been rewarded, RTs were slower than when that colored distractor was presented in the unrewarded context. However, it is possible that these findings are not due to a failure of generalizing the reward-associations across contexts but instead could be due to reward being associated with the combination of the scene and color that were rewarded. Once this combination of rewarded scene and color feature is presented at test, distraction occurs as evident by slower RTs under these conditions. Therefore, research thus far has been unclear on whether VDAC is able to generalize to other tasks.

This chapter will address whether attention capture by rewarded features will bias attention in other contexts that differ from that of learning. To investigate this, typical VDAC features from the learning task will be used to assess whether the reward associated feature will then impact performance in a second sustained attention task (Experiment 1). The second experiment will examine whether rewarded features can bias attention in a naturalistic visual search display with real objects.

Experiment 1

The purpose of Experiment 1 was to investigate whether reward-associations with a color feature learned in a visual search task would affect attentional priority in another task completed a week later. The second task was a sustained attention task where targets and non-targets were surrounded by colored borders. It was expected that the reward-associated feature from learning would improve performance when placed on a target during the sustained attention task.

Method

Participants

Forty-three healthy participants (24 Female, M_{age} = 18.72, SD_{age} = 1.05) were recruited from the Psychological and Brain Sciences paid research participation pool at the University of California, Santa Barbara. Eight participants were excluded from the final analyses due to either a high false alarm rate or poor accuracy during the task resulting in a final sample of 35 participants (21 Female, M_{age} = 18.83, SD_{age} = 1.12). Participants were paid an average of $13.94 for momentary compensation on the reward task.

Visual Search: learning

Stimuli were the same as Experiment 1 in Chapter two (See Figure 1a). Targets were two of the following colors: red, blue, green. One color resulting in a 5¢ with an 80% probability and the other color resulted in no-reward. Color mapping was counterbalanced between participants.

CTET: test

During the test phase participants completed the continuous temporal expectancy task (CTET see Chapter III Figure 1; O'Connell et al., 2009). Participants responded to long duration stimuli within an RSVP stream, all stimuli were surrounded with a different colored border. A third of the targets were presented in the reward-associated color from learning, another third were presented in the non-reward associated color, and the final third were in a novel color (the third color that was not used as a target during the learning phase).

Procedure

Participants attended two experimental sessions separated by exactly 1 week. In the initial session participants first completed a demographic questionnaire and the behavioral inhibition system (BIS) and behavioral activation system (BAS) scales (Carver & White, 1994). Participants then performed a change detection task designed to measure visual working memory capacity. Finally, participants completed the learning phase of the visual search task. In the second session, participants completed the test phase of the CTET followed by a post-questionnaire.

Design and Analysis

In the learning phase, there were 10 blocks each consisting of 80 trials. There was a total of 400 rewarded and 400 non-rewarded trials. The test phase consisted of 10 blocks, each with 360 stimulus presentations. Of the 360 stimuli presentations, there were 30 long-duration targets. For the test phase, there were 10 rewarded, 10 non-rewarded, and 10 absent trials.

Results

Visual search: Learning

Accuracy

A general linear mixed effects model (GLMM) was used to assess accuracy during the visual search task with the fixed effects of trial (1-800) and reward condition (reward, non-rewarded; See Figure 2). There was no effect of trial on accuracy (*b* = 0.11 *SI* = [-0.11, 0.31], *RPE* = ± 0.05; see Fig. 1), there was very strong evidence in support of the null (*BF* = 0.018). There was evidence of an effect of reward condition such that accuracy was higher on rewarded than non-rewarded trials (*b* = -0.38, *SI* = [0.19, 0.58], *RPE* = ± 0.05, *BF* = 130.92). The interaction between trial and reward condition was probable such that responses became more accurate to rewarded relative to non-rewarded trials over time (*b* = -1.11, *SI* = [0.80, 1.43], *RPE* = ± 0.05, *BF* > 1000).

Reaction Time

A similar GLMM was used to examine reaction time on correct trials during the learning phase (see Fig. 5). The effect of trial was not probable (*b* = -10.41, *SI* = [-18.71, -2.01], *RPE* = ± 4.73, *BF* = 0.21; see Fig. 4). An effect of reward condition was probable such that RTs were faster to rewarded than non-rewarded trials (*b* = -29.96, *SI* = [-43.03, -17.32], *RPE* = ± 2.81, *BF* = 144.39. The interaction between trial and reward condition was probable such that RT decreased at a faster rate for rewarded than non-rewarded target features (*b* = -37.27, *SI* = [-48.87, -25.42], *RPE* = ± 5.43, *BF* > 1000).

CTET: test

Detections: reward and selection history

The GLMM revealed that there was no evidence of an effect of block (*b* = 0.41, *SI* = 0.08, 0.76), *RPE* = ± 0.05), there was anecdotal evidence for the null (*BF* = 0.83) There was no effect of trial (*b* = -0.36, *SI* = [-0.71, -0.04], *RPE* = ± 0.05), there was substantial evidence in support of the null (*BF* = 0.38). There was evidence of an effect of reward history (no-reward relative to reward) during the test phase such that there were a greater number of detections to previously rewarded than previously non-rewarded targets (*b* = 0.54, *SI* = [0.21, 0.90], *RPE* = ± 0.05, *BF* = 4.22). There was no evidence of an effect of selection history (no-reward relative to absent) during the test phase (*b* = 0.054, *SI* = [-0.29, 0.04], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.10). There was no interaction between block and trial (*b* = 0.97, *SI* = [-0.19, 2.19], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.10). There was no interaction between block and reward history (*b* = -0.21, *SI* = [-0.70, 0.28], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.021). There was also no interaction between block and selection history (*b* = -0.20, *SI* = [-0.71, 0.31], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.02). There was no interaction between trial and reward history (*b* = -0.31, *SI* = [-0.83, 0.18], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.037). There was no interaction between trial and selection history (*b* = -0.20, *SI* = [-0.71, 0.28], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.019). There was no three-way interaction between block, trial, and reward history (*b* = -0.091, *SI* = [-1.80, 1.77], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.014). There was also no three-way interaction between block, trial, and selection history (*b* = -0.21, *SI* = [-1.87, 1.59], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.014).

Detections: combination of reward and selection history

The GLMM comparing the combination of reward and selection history (difference between rewarded and absent trials) revealed that there was no effect of block (*b* = 0.20, *SI* = [-0.15, 0.54], *RPE* = ± 0.05; see Figure 3), there was strong evidence in support of the null (*BF* = 0.036). There was an effect of trial such that overall detections decreased within a block over the course of each trial (*b* = -0.67, *SI* = [-1.04, -0.31], *RPE* = ± 0.05), *BF* =

120.58). There was evidence of an effect of reward condition suggesting that participants had a higher number of detections to rewarded than novel-colored targets (*b* = -0.49, *SI* = [-0.86, -0.14], *RPE* = ± 0.05, *BF* = 1.28). There was no interaction between block and trial (*b* = 0.88, *SI* = [-0.33, 2.18], *RPE* = ± 0.05), there was strong evidence in support of the null (*BF* = 0.068). There was no interaction between block and condition (*b* = 0.0088, *SI* = [-0.47, 0.48], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.014). There was no interaction between trial and condition (*b* = 0.11, *SI* = [-0.37, 0.62], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.016). There was no three-way interaction (*b* = -0.12, *SI* = [-1.77, 1.54], *RPE* = ± 0.05), there was very strong evidence in support of the null (*BF* = 0.016).

Reaction Time: reward and selection history

The GLMM on RTs revealed that there was evidence of an effect of block such that RTs became slower over the course of the test phase (*b* = -121.73, *SI* = [-174.58, -71.79], *RPE* = ± 36.84, *BF* = 221.61). There was no effect of trial (*b* = -10.44, *SI* = [-59.98, 39.09], *RPE* = ± 9.76), there was decisive evidence in support of the null (*BF* < 0.01). There was no evidence of an effect of reward history (*b* = -30.22, *SI* = [-67.49, 7.66], *RPE* = ± 8.98), there was strong evidence in support of the null (*BF* = 0.069). There was no evidence of an effect of selection history during the test phase (*b* = -4.20, *SI* = [-39.71, 34.23], *RPE* = ± 9.51), there was decisive evidence in support of the null (*BF* < 0.01). There was no interaction between block and trial (*b* = -65.04, *SI* = [-250.07, 106.27], *RPE* = ± 30.68), there was decisive evidence in support of the null (*BF* < 0.01). There was no interaction between block and reward history (*b* = 5.80, *SI* = [-64.85, 76.54], *RPE* = ± 26.75), there was decisive evidence in support of the null (*BF* < 0.01. There was also no interaction between block and selection history (*b* = -4.86, *SI* = [-82.67, 73.41], *RPE* = ± 27.07), there was decisive evidence in support of the null (*BF* < 0.01). There was no interaction between trial and reward history (*b* = 64.35, *SI* = [-11.22, 139.22], *RPE* = ± 24.32), there was strong evidence in support of the null (*BF* = 0.055). There was no interaction between trial and selection history (*b* = 15.39, *SI* = [-60.51, 91.60], *RPE* = ± 27.61, there was decisive evidence in support of the null (*BF* < 0.01). There was no three-way interaction between block, trial, and reward history (*b* = -21.57, *SI* = [-285.97, 223.05], *RPE* = ± 61.44), there was decisive evidence in support of the null (*BF* < 0.01). There was also no three-way interaction between block, trial, and selection history (*b* = 88.83, *SI* = [-179.20, 256.31], *RPE* = ± 64.25), there was decisive evidence in support of the null (*BF* < 0.01).

Reaction Time: combination of reward and selection history

The GLMM comparing the combination of reward and selection history revealed that there was an effect of block such that overall RTs became faster over the course of each block (*b* = -115.93, *SI* = [-166.95, -67.17], *RPE* = ± 35.07, *BF* = 299.12; see Figure 6). There was no effect of trial (*b* = 54.56, *SI* = [6.41, 106.08], *RPE* = ± 10.20), there was substantial evidence for the null (*BF* = 0.35). There was no evidence of an effect of reward condition (*b* = 26.70, *SI* = [-0.51, 55.53], *RPE* = ± 4.76), there was substantial evidence for the null (*BF* = 0.17). There was no interaction between block and trial (*b* = -86.54, *SI* = [-250.76, 93.62], *RPE* = ± 9.03), there was very strong evidence in support of the null (*BF* = 0.015). There was no interaction between block and condition (*b* = -9.82, *SI* = [-76.82, 57.43], *RPE* = ± 42.09), there was decisive evidence in support of the null (*BF* < 0.01). There was no interaction between trial and condition (*b* = -49.21, *SI* = [-115.75, 18.39], *RPE* = ± 16.47), there was strong evidence in support of the null (*BF* = 0.056). There was no three-way interaction (*b* = 111.86, *SI* = [-103.66, 324.59], *RPE* = ± 32.13), there was very strong evidence in support of the null (*BF* = 0.023).

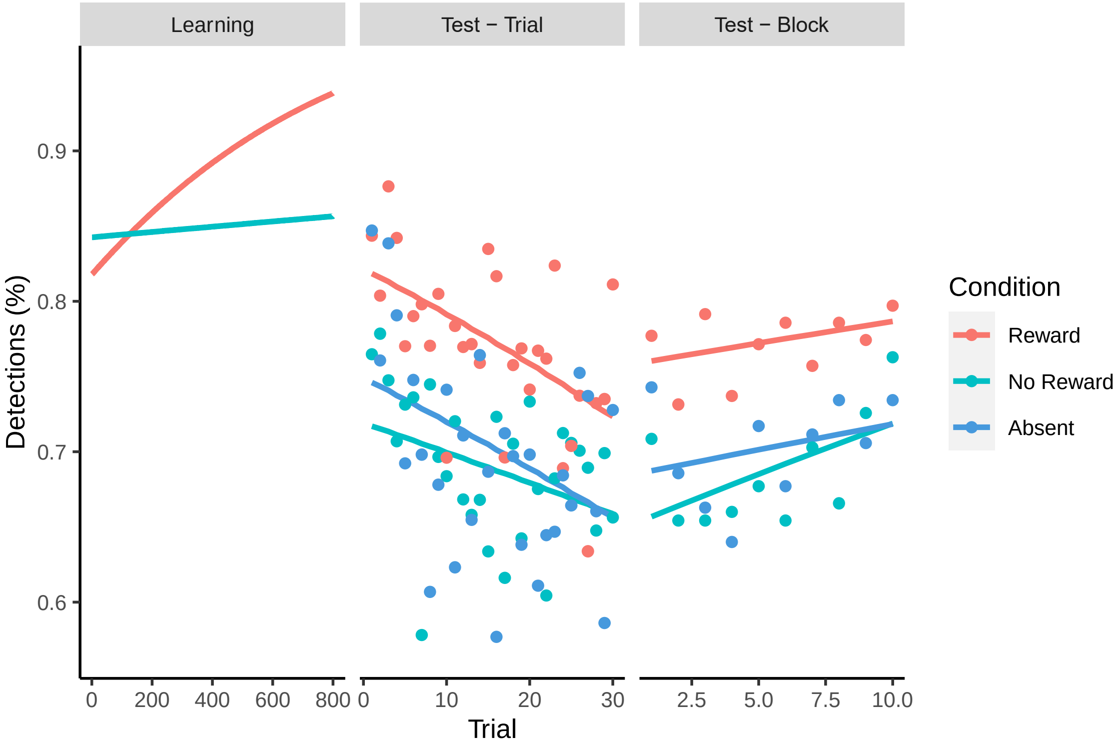

Figure 1. Detections plotted as a function of block and condition during the learning and test phase.

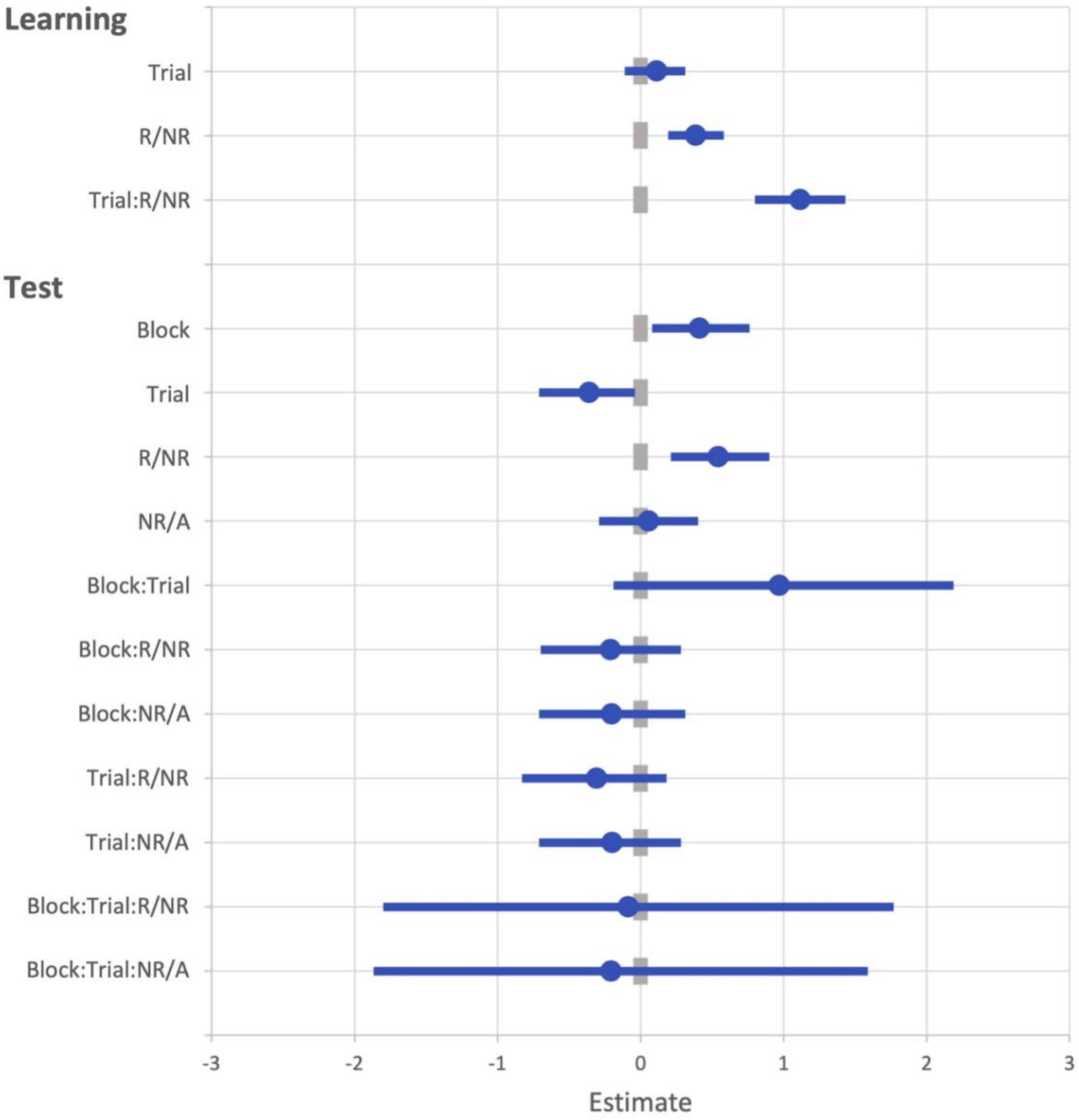

Figure 2. Mean point estimates and support intervals for each of the fixed effects from the generalized linear mixed effects model (GLMM) for accuracy during learning and detections during test in Experiment 1. Mean estimates are on the log odds scale. Grey boxes denote the null region (region of practical equivalence, *RPE*). R = Reward, NR = No-Reward.

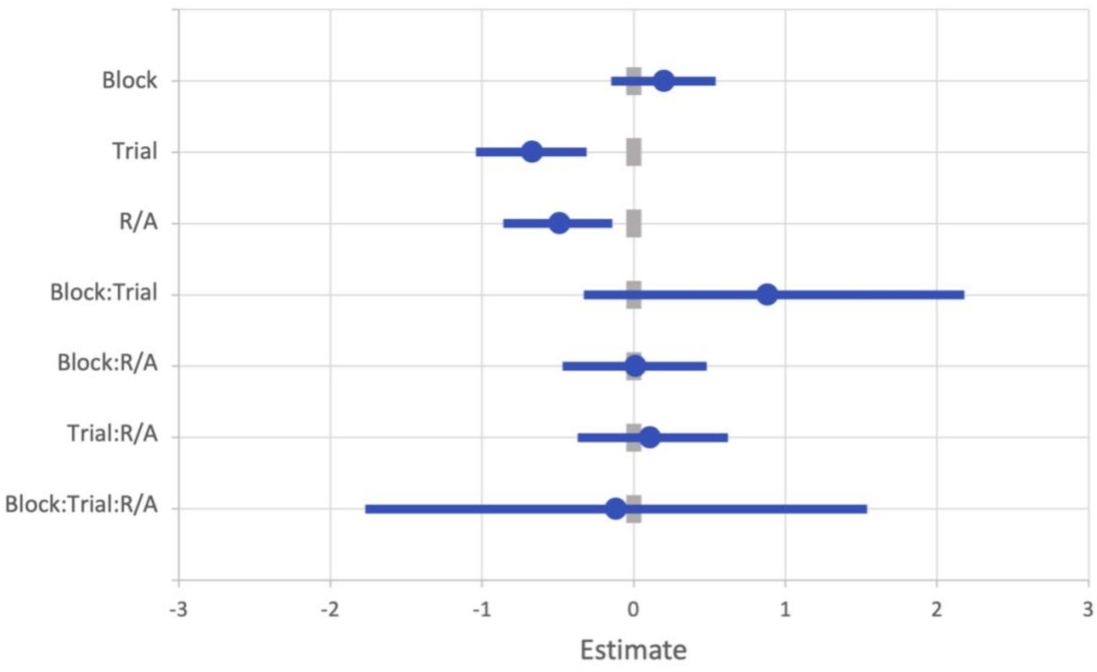

Figure 3. Mean point estimates and support intervals for each of the fixed effects for reward versus absent RTs in the test phase of Experiment 1. Mean estimates are on the log odds scale. R = Reward, A = Absent.

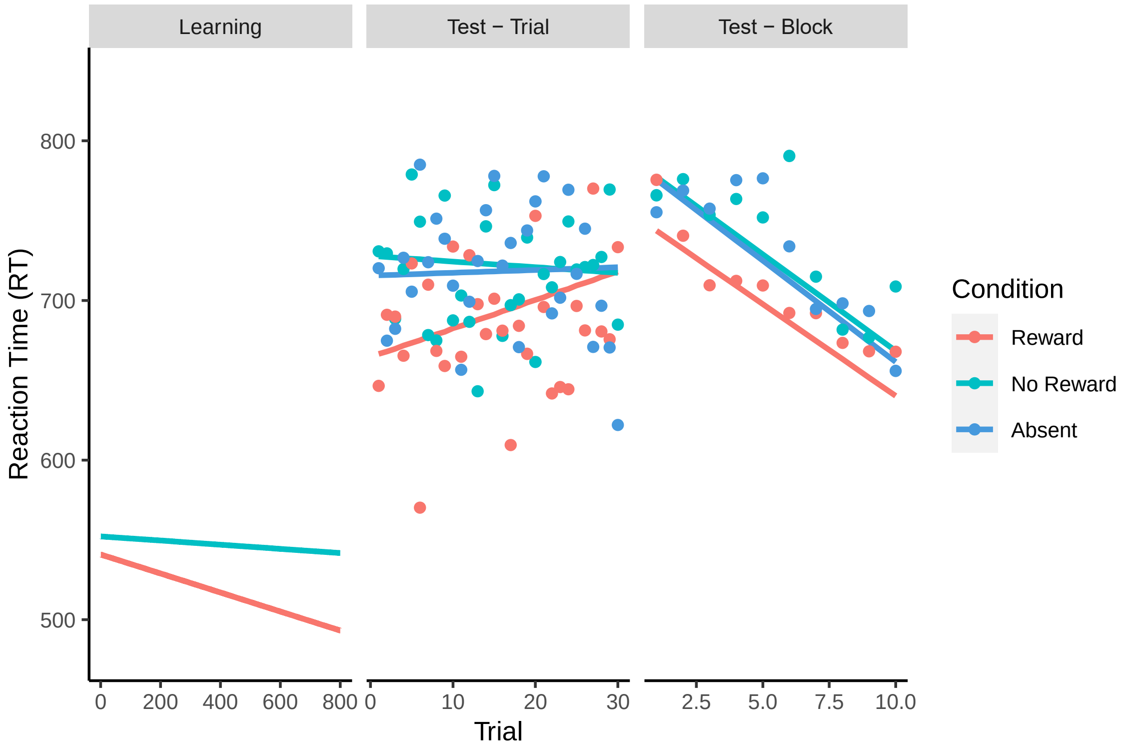

Figure 4. Reaction time plotted as a function of block and condition during the learning and test phase.

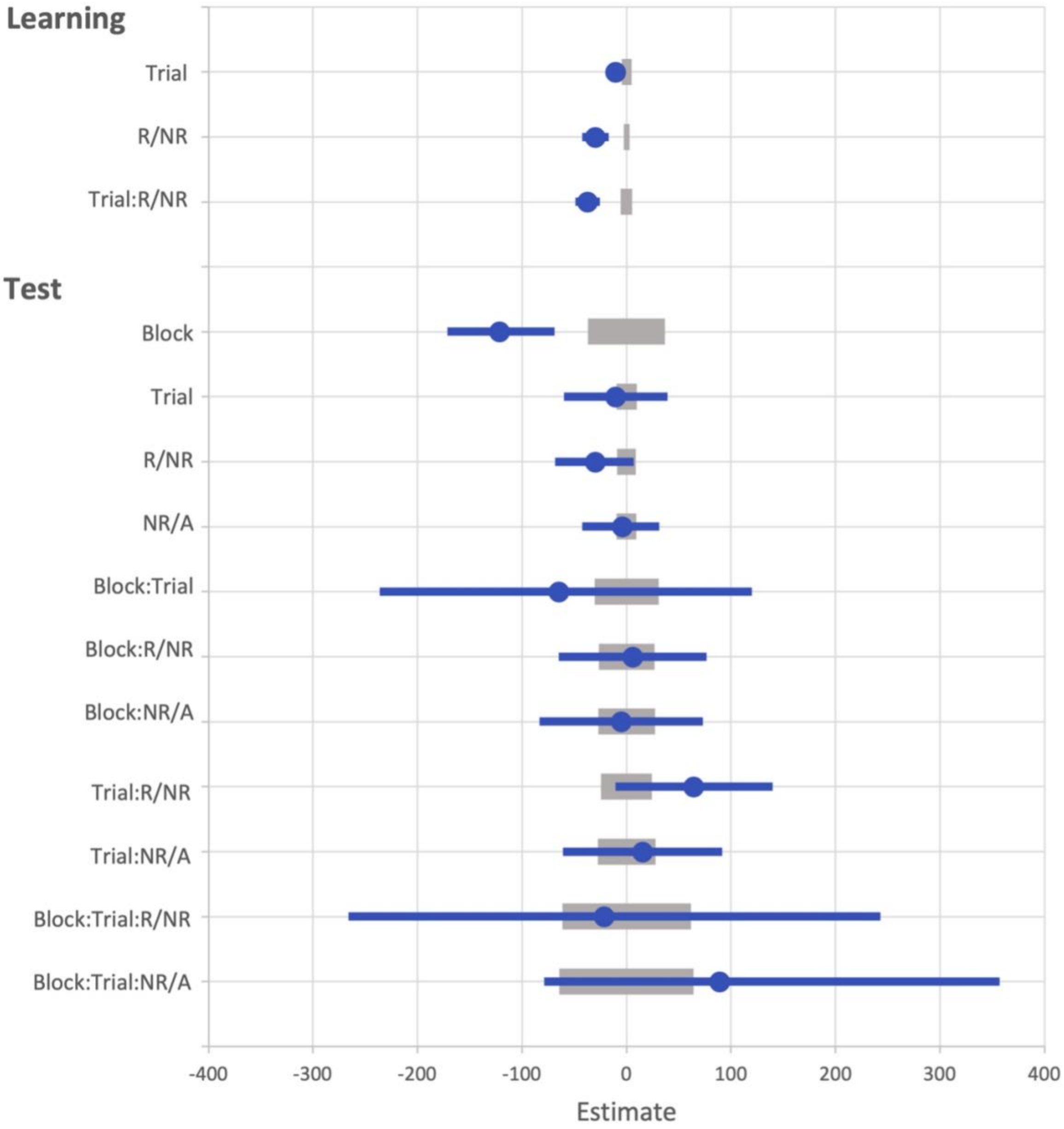

Figure 5. Mean point estimates and support intervals for each of the fixed effects from the generalized linear mixed effects model (GLMM) for RTs in Experiment 1. Grey boxes denote the null region (region of practical equivalence, *RPE*). R = Reward, NR = No-Reward.

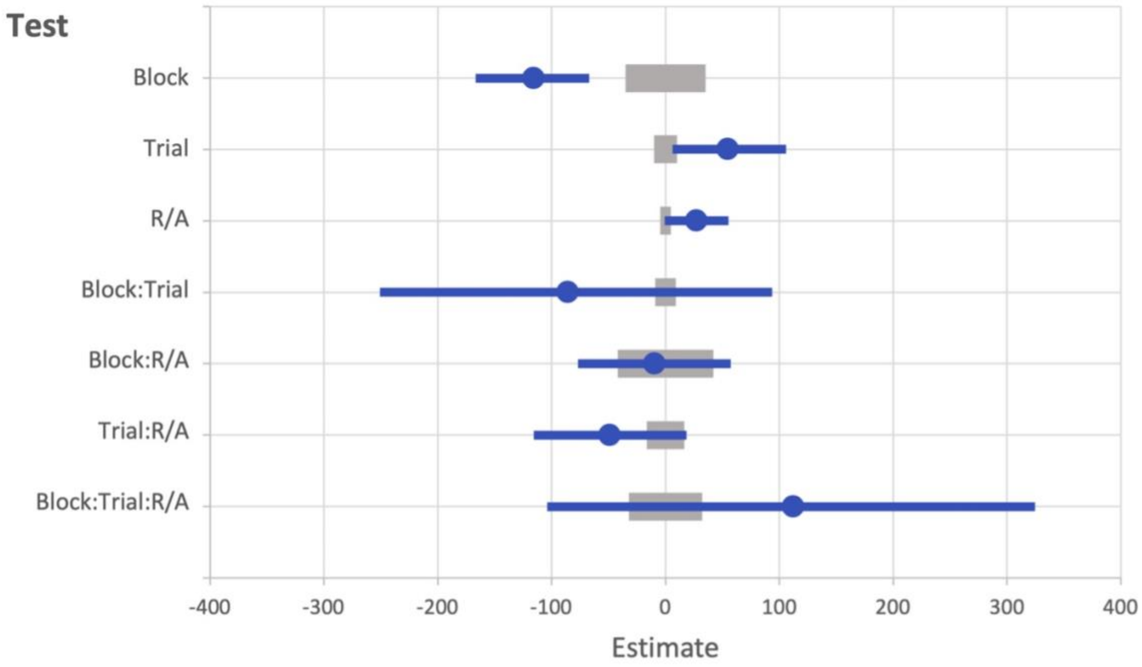

Figure 6. Mean point estimates and support intervals for each of the fixed effects for reward versus absent RTs in the test phase of Experiment 1. R = Reward, A = Absent.

Discussion

During the learning phase of Experiment 1, there was evidence that participants learned the reward association in the visual search task, as accuracy improved, and RTs reduced to rewarded targets relative to non-rewarded targets over time. During the test phase participants were found to have greater detection accuracy to targets presented in the rewarded compared to non-rewarded feature color. There was no evidence of an effect of selection history as there were no differences between non-rewarded and novel-colored targets. There were also no interactions between reward condition and trial or block suggesting that the effect did not diminish throughout the test phase. There were no effects of reward condition on RTs to targets. These results suggest that when learning occurs in one task, these learned reward associations do generalize to other tasks affecting attentional priority consistent with previous reports (Anderson et al., 2012). The previously reward-associated feature remained prioritized and improved detection performance while sustaining attention.

Experiment 2

The purpose of Experiment 2 was to investigate whether attentional priority for previously selected and rewarded stimuli translates to a real-world environment. The typical value-driven attention paradigm was adapted to be conducted using physical objects while eye movements were examined. It was expected that during learning participants would have a greater number of first fixations and overall fixations to rewarded targets compared to non-rewarded targets. In the test phase, it was expected that the rewarded and non-rewarded features presented as distractors would continue to be prioritized such that there would be a greater number of first fixations and total fixations to previously rewarded distractors than to non-rewarded and other distractors.

Method

Participants

Thirty-one healthy participants (18 Female, M_{age} = 19.26, SD_{age} = 1.50) were recruited from the Psychological and Brain Sciences paid research participation pool at the University of California, Santa Barbara. Seven participants were excluded from the final analyses due to poor tracking accuracy of the eye-tracker resulting in a final sample of 24 participants (14 Female, M_{age} = 19.21, SD_{age} = 1.67). Participants were paid $5 during the visual search task.

Stimuli and Apparatus

The real-world objects used in the task were cups. The cups could be either red, pink, dark blue, light blue, dark green, light green, dark orange, or light orange. Participants were seated behind a smart glass screen that was able to obscure the view of the search display from participants prior to the start of a trial. Participants wore a mobile eye-tracking headset (Pupil Lab; Kassner et al., 2014). One camera recorded the left. The data were recorded to a laptop using the Pupil Lab application (Kassner et al., 2014). The eye-tracker was manually calibrated to each of the 6 cups in the visual display, participants were instructed to look at each cup in turn.

Visual Search Task

The typical VDAC paradigm was modified to be carried out using physical objects. Different colored cups were used for the stimuli in this task. On each trial, there were six different colored cups that were placed equidistant from each other around an imaginary circle. Each cup had a white line attached to it, this line was straight for target stimuli (either horizontal or vertical) and diagonal for non-target stimuli (see Figure 7). There was always one target and five non-target stimuli for each trial. Each search display was created using MATLAB to randomize each of the colors, line orientation, and reward conditions.

Learning

During the learning phase targets were always red and blue cups. One color resulted in a 25¢ reward and the other with no reward. For the reward condition, a quarter was placed under the rewarded color cup. When participants picked up the cup, they were told to retrieve the reward if there was one and were informed that they would keep the money that they accrued throughout the task.

Test

During the test phase, the target colors red and blue became distractors at test. The target colors for the test phase were either the dark orange or dark green cup. On every trial either the rewarded or non-rewarded cup was presented as a distractor, there was only one presented per trial.

Procedure

Participants were seated behind opaque smart glass that obscured the view of the visual search display. For each trial, the visual search display containing the cups would be modified and placed behind the smart glass in preparation for the next trial. At the beginning of the trial participants would hear a tone and the smart glass would turn translucent indicating the start of a trial. Once a trial began, participants searched for the cup with either the horizontal or vertical line and were instructed to pick the cup up as quickly and accurately as they could. Participants first completed the learning phase where they received rewards. Then in the same session, participants completed the test phase and were informed that they would no longer be rewarded during the task.

Design and Analysis

There were 20 trials in each of the two phases. Each phase had 10 rewarded and 10 non-rewarded trials. Several metrics were examined in this Experiment. The first was reaction time which was measured as the difference between the start of the trial and successfully touching the target cup. In the learning phase, RT was examined as a function of whether the target cup was rewarded or not. During the test phase, RT was examined as a function of whether the distractor was previously rewarded or non-rewarded, this type of distractor is referred to as a *critical* distractor. Number of fixations were the total number of fixations that a participant made within a trial, which was also examined as a function of reward condition in the learning and test phase. The first fixation time was the difference in time from the onset of the trial and when the participant fixated on a cup in the display. First fixation time was examined as a function of whether the trial was rewarded or not and by the type of first fixation (target, distractor for learning; target critical distractor, other distractor at test). First fixations were examined as the percent of first fixations to each target type during learning (target, distractor) and test (target, critical distractor, other distractor). This was calculated by dividing the total number of fixations for each category and dividing by the total number of first fixations across the entire experiment for each participant. To control for the greater number of distractor stimuli relative to target stimuli the percent of first fixations for the distractor condition was divided by 5 in the learning phase (total number of distractor stimuli). For test, the percent of distractor fixations was divided by 4 (because there were four other distractors – not including the critical distractor that was measured seperatley). This method was also applied to the percent of total fixations. The total number of fixations was calculated as the percent of all fixations to each target type during learning (target, distractor) and test (target, critical distractor, other distractor). This was calculated by dividing the total number of fixations for each category by the total number of fixations across for that trial. The trials were averaged over for every participant.

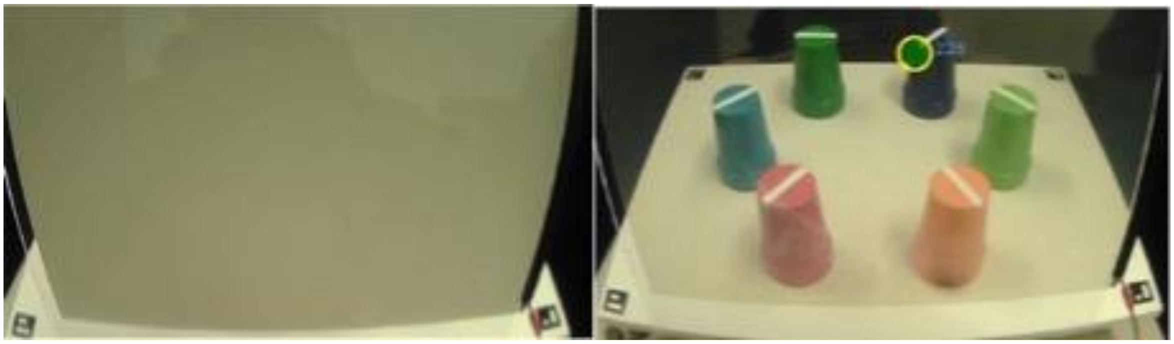

Figure 7. demonstration of trial during the test phase. Stimulus display is behind opaque smart glass which turns translucent at the beginning of each trial. Participants then respond to the orange/green cup and there is a previously rewarded or non-rewarded distractor present.

Results

Visual Search: Learning

Reaction Time

A Bayesian paired samples t-test was used to assess RTs between rewarded and non-rewarded trials during the learning phase. There was no difference in RTs between rewarded

(*M* = 2.66s) and non-rewarded trials (*M* = 2.66s), there was strong evidence in support of the null (*BF* = 0.22; see Figure 8a)

Mean Number of Fixations

A Bayesian paired samples t-test was used to assess whether mean number of fixations per trial differed as a function of reward condition. There was no difference found between rewarded trials (*M* = 5.73) and non-rewarded trials (*M* = 5.61), there was strong evidence in support of the null (*BF* = 0.22; see Figure 9a).

First Fixation Time

The time of the first fixation was assessed as a function of reward condition (rewarded, non-rewarded) and first fixation type (target, distractor) using a Bayesian repeated measures ANOVA (See Figure 10a). The data were 7.26 times more likely under the model that included only the main effect of fixation type than under the null model. The first fixation time was slower to targets (*M* = 337.50) than to non-targets (*M* = 294), there was very strong evidence for the alternative hypothesis (*BF* = 20.13).

First Fixations

To assess whether the percentage of first fixations to targets and distractors differed between reward conditions we conducted a Bayesian repeated measures ANOVA with the factors reward condition (rewarded, non-rewarded) and fixation type (target, distractor; see Figure 11a). The most probable model was the model containing only a main effect of target type (target vs. distractor), the data were 23.40 times more likely under this model compared to under the null. Post-hoc tests revealed that participants had a greater percentage of first fixations to targets (*M* = 23.38%) than distractors (*M* = 15.32%), there was very strong evidence for the alternative hypothesis (*BF* = 38.94).

Total Fixations

To assess whether the percentage of total fixations to targets and distractors differed between reward conditions a Bayesian repeated measures ANOVA with the factors reward condition (rewarded, non-rewarded) and fixation type (target, distractor; see Figure 12a). The most probable model was the model containing only a main effect of target type (target vs. distractor), the data were more than 1000 times more likely under this model compared to under the null. Post-hoc tests revealed that participants had a greater percentage of fixations to targets (M = 37.96%) than distractors (M = 12.41%), there was decisive evidence for the alternative hypothesis (BF > 1000).

Visual Search: Test

Reaction Time

A Bayesian paired samples t-test was used to assess RTs between rewarded and non-rewarded trials during the test phase. There was no difference in RTs when there was a rewarded (M = 2.52s) compared to non-rewarded distractor (M = 2.54s), there was strong evidence in support of the null (BF = 0.24; see Figure 8b)

Mean Number of Fixations

A paired samples t-test was used to assess whether mean number of fixations per trial differed as a function of reward condition (see Figure 9b). There was no difference found between rewarded trials (M = 5.09) and non-rewarded trials (M = 5.14), there was strong evidence in support of the null (BF = 0.23).

First Fixation Time

The time of the first fixation was assessed as a function of reward condition (rewarded, non-rewarded) and first fixation type (target, critical distractor, other distractor) using a Bayesian repeated measures ANOVA (See Figure 10b). The null model was the most probable suggesting that there were no differences in first fixation time between these conditions.

First Fixations

To assess whether the percentage first fixations to targets and distractors differed between reward conditions a Bayesian repeated measures ANOVA with the factors reward condition (rewarded, non-rewarded) and fixations type (target, critical distractor, other distractor) was conducted (see Figure 11b). The most probable model was the model containing only a main effect of target type, the data were 2.62 times more likely under this model compared to under the null. Post-hoc tests revealed that participants had a greater percentage of first fixations to targets (*M* = 21.72%) than to other distractors (*M* = 15.08%), there was substantial evidence for the alternative hypothesis (*BF* = 5.05). Participants also made a greater percentage of first fixations to the critical distractor (*M* = 17.74%) than to other distractors (*M* = 15.08%), there was anecdotal evidence for the alternative hypothesis (*BF* = 1.80). There was no difference between target first fixations (*M* = 21.72%) and first fixations to the critical distractor (*M* = 17.74%), there was anecdotal evidence in support of the null (*BF* = 0.41). These findings suggest that participants had a greater amount of first fixations to the previously selected target from the learning phase compared to other distractors in the search display, however, this effect was not modulated by reward condition suggesting only a selection-driven effect.

Total Fixations

To assess whether the percentage of total fixations to targets and distractors differed between reward conditions a Bayesian repeated measures ANOVA with the factors reward condition (rewarded, non-rewarded) and fixations type (target, critical distractor, other distractor) was conducted (see Figure 12b). The most probable model was the model containing only a main effect of target type, the data were more than 1000 times more likely under this model compared to under the null. Post-hoc tests revealed that participants made a greater percentage of fixations to targets (*M* = 37.82%) than to other distractors (*M* = 12.03%), there was decisive evidence for the alternative hypothesis (*BF* > 1000). Participants also made a greater percentage of fixations to the critical distractor (*M* = 17.74%) than to other distractors (*M* = 14.06%), there was decisive evidence for the alternative hypothesis (*BF* > 1000). There was also a greater number of fixations to targets (*M* = 37.82%) than the critical distractor (*M* = 14.06), there was decisive evidence in support of the null (*BF* > 1000). These findings suggest that participants made a greater number of total fixations to the previously selected target from the learning phase compared to other distractors in the search display. This effect was also not modulated by reward condition suggesting only a selection driven effect was present.

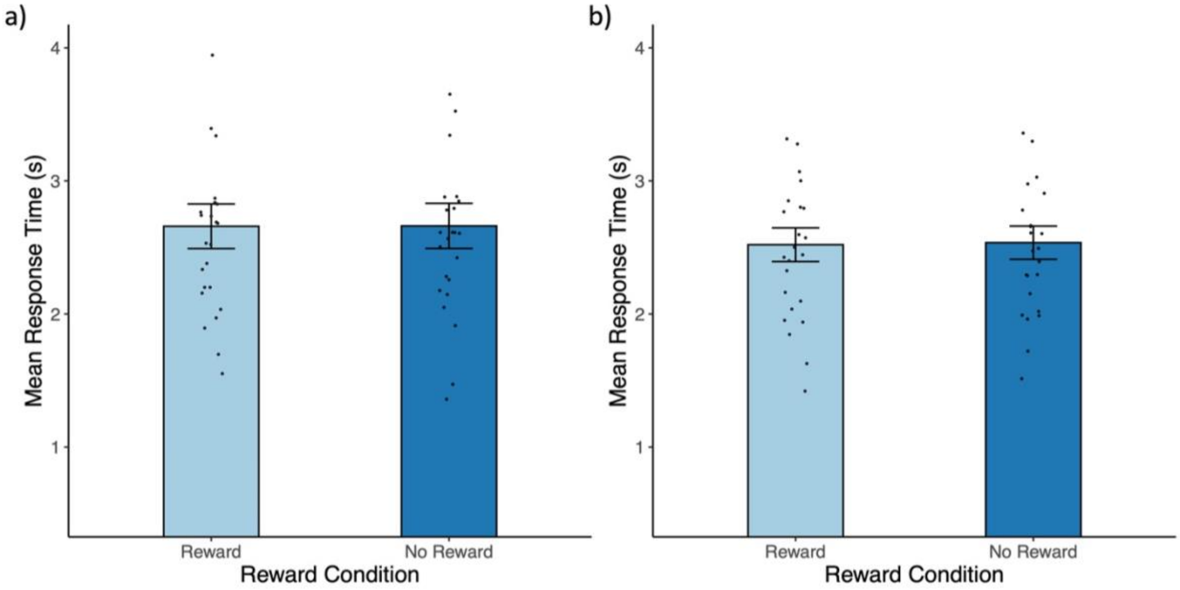

Figure 8. reaction time as a function of reward condition (rewarded, non-rewarded) a) during the learning phase and b) during the test phase.

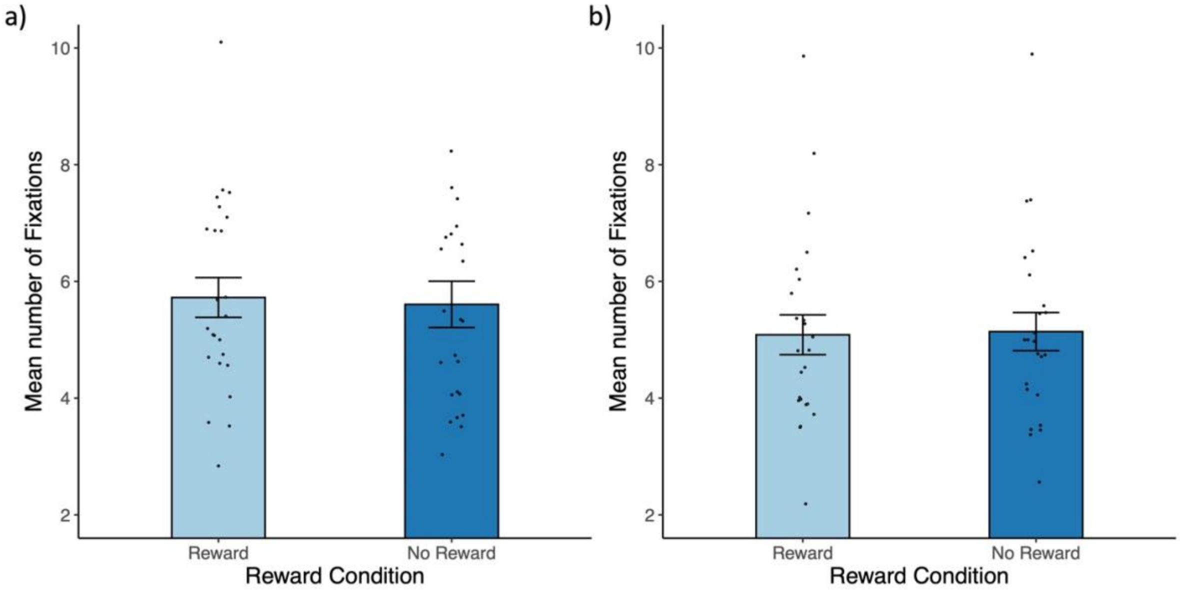

Figure 9. mean number of fixations per trial as a function of reward condition (rewarded, non-rewarded) a) during the learning phase and b) during the test phase.

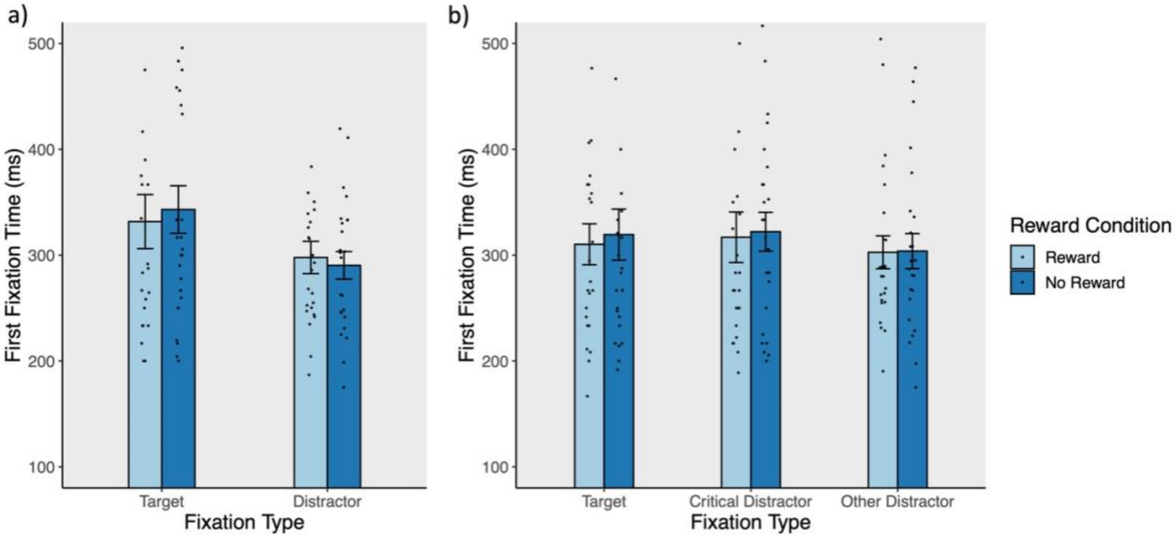

Figure 10. a) first fixation time as a function of first fixation type (target, distractor) and reward condition (rewarded, non-rewarded) during the learning phase and b) first fixation time as a function of first fixation type (target, critical distractor, other distractor) and reward condition (rewarded, non-rewarded) during the test phase.

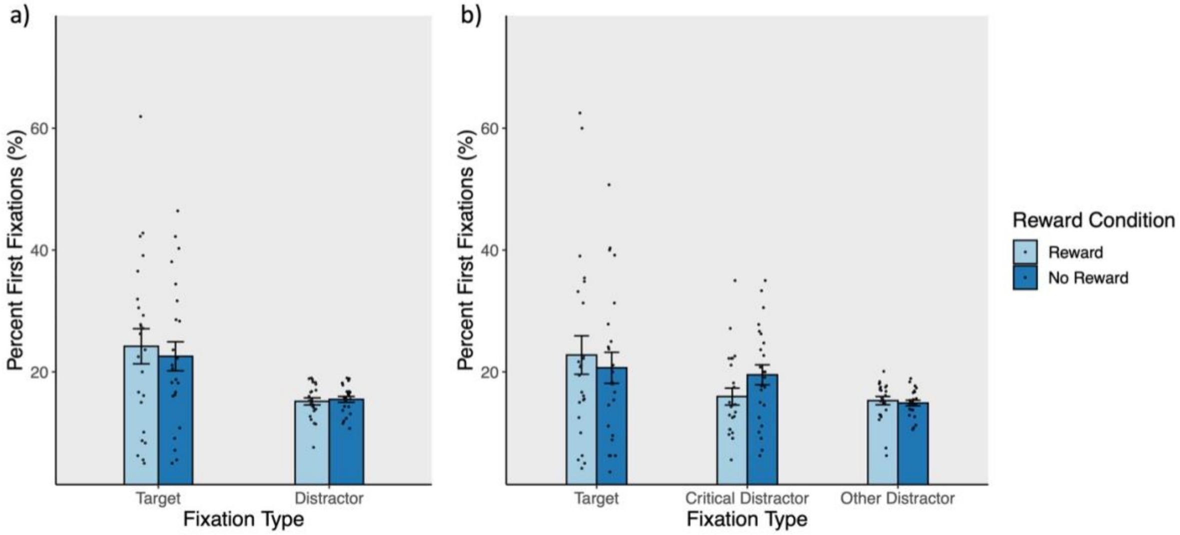

Figure 11. a) percent first fixations as a function of first fixation type (target, distractor) and reward condition (rewarded, non-rewarded) during the learning phase and b) percent first fixations as a function of first fixation type (target, critical distractor, other distractor) and reward condition (rewarded, non-rewarded) during the test phase.

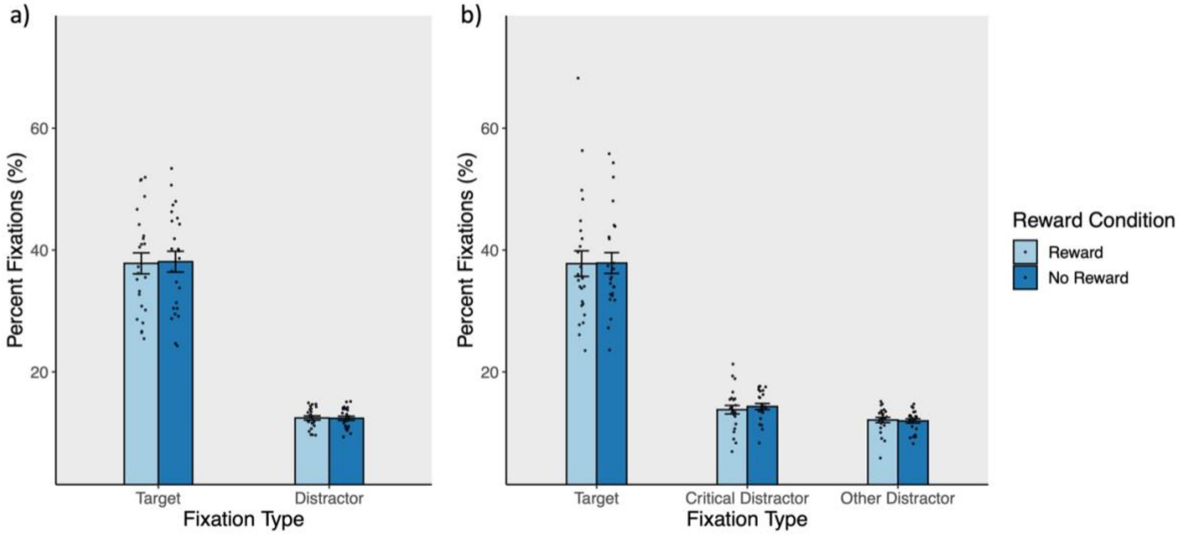

Figure 12. a) percent total fixations as a function of fixation type (target, distractor) and reward condition (rewarded, non-rewarded) during the learning phase and b) percent total fixations as a function of fixation type (target, critical distractor, other distractor) and reward condition (rewarded, non-rewarded) during the test phase.

Discussion

During the learning phase of Experiment 2, there was no evidence of any reward or selection history driven effects on the experimental measures. Although, it is not unusual that VDAC effects are reported at test, when a reward effect has not been observed during learning (e.g., Anderson et al., 2011b). During the test phase, there was no evidence of an effect of reward history across any of the metrics. Although there was an impact of selection history in two of the measures: percentage of first fixations and total fixations. Results showed that participants made a greater amount of first fixations to the critical distractor (previous target colors at learning) compared to the other distractors in the search display. A similar finding was found in total fixations, where participants also made a greater number of fixations to the previously selected distractor relative to the other distractors.

Previous studies have demonstrated that eye-movements are biased toward reward-associated stimuli (Anderson & Yantis, 2012b). The results of the current study are not consistent with this finding. This could possibly be due to VDAC not generalizing to a real world environment when interacting with objects in our environment. Although, this task is still highly controlled, and it would be expected that the computer-based task would translate into this similar real world task. Despite not finding an effect of reward history, an effect of selection history was found suggesting that prioritization of previously selected features can impact performance in a real-world task. There are several limitations of the current study that may have prevented the observation of an effect of VDAC. First, there were only 20 learning trials which may have not been a sufficient number to elicit reward effects, especially since the total amount of reward that could be accrued was only a small amount ($5). VDAC effects have been reported with as few as 240 learning trials (Anderson et al., 2011b), a considerable amount more than in the current experiment. It’s also possible that the extended time taken in between each trial for set-up to prepare the visual search display could reduce reinforcement, as typical VDAC studies participants receive a reward every few seconds whereas in the current study, participants would have received a reward approximately once every minute. Further research is required to investigate whether features associated with the reward in our environment can bias attention outside of a laboratory setting.

General Discussion

It has previously been shown that features associated with reward can involuntarily capture attention in laboratory tasks (Anderson et al., 2011b, 2016; Anderson & Yantis, 2012, 2013). However, it currently remains unclear whether such associations can impact attentional priority is able to generalize both beyond the specific task in which associations were learned and into the real world. In Experiment 1, findings showed that participants learned the reward associations during the visual search task as there was greater accuracy and reduced RTs to rewarded compared to non-rewarded targets. The test phase was a different task, a sustained attention task, where participants responded to long-duration stimuli in an RSVP stream. Targets were presented in the previously reward-associated, non-reward associated, or a novel color. Results showed that participants continued to show a bias for the reward-associated feature such that there was improved detection performance for rewarded relative to non-rewarded or novel-colored targets. This study demonstrates that reward history can generalize to a different task even when the requirements of the task and the attentional set differ. These results contradict research that suggests that a specific set of stimulus associations can only bias attention when in the specific context in which they were learned (Anderson, 2015). Furthermore, the results of Experiment 1 show that when reward is associated with a feature where selection of that feature is required to successfully complete the task, these features can benefit performance even in a task where spatial selection is not a requirement of the task. The reward-associated feature may have acted as a cue for participants, enhancing sustained attention on those trials where a reward-associated feature was present.

In Experiment 2, findings indicated that selection history but not reward history had an impact on the prioritization of attention, as evident by an increase in fixations toward previously selected targets from the learning phase. These findings are consistent with research that has found that actions influence subsequent perception, such that people are faster to find objects that they have previously acted upon even when the features of that object are irrelevant to the current definition of the target (Abrams et al., 2015). These results suggest that while there is an impact of selection history, VDAC failed to generalize to a task using objects in the real world. These results contrast with previous reports of both the effect of VDAC on oculomotor capture and more generally the effects of reward on biasing eye movements (Anderson & Yantis, 2012b; Bucker et al., 2015b; Failing et al., 2015; Hickey & van Zoest, 2012; Liao & Anderson, 2020b; Theeuwes & Belopolsky, 2012). However, as previously discussed the small number of learning trials in this Experiment could have resulted in the rewarded feature not being sufficiently reinforced to observe reward related effects. Further research is needed to explore this possibility.

Chapter V: Conclusions

In this Chapter two, the implications of typical VDAC design features on the observance of VDAC and its persistence was tested. During the test phase, task-relevance of the reward-associated distractor, the physical salience of the target, and the inclusion of absent trials were manipulated. There was an effect of reward when the reward-associated feature remained task-relevant during the test phase. However, when the reward-associated feature was task-irrelevant evidence for VDAC was only reliably found in Experiment 5, which was a replication of the typical VDAC paradigm where the target is defined as a salient shape singleton and there is the inclusion of absent trials (Anderson et al., 2011b;

Anderson & Yantis, 2013). The use of a salient and orthogonal target feature may increase the likelihood of capture because of the type of search strategy employed i.e., singleton detection mode (Bacon & Egeth, 1994; Connor et al., 2004; Lamy et al., 2006). The inclusion of absent trials may also enhance the effects of the reward-associated distractor as less frequent distractors are more difficult to ignore (Geyer et al., 2008; Müller et al., 2009). VDAC was also not found to persist throughout the test phase and was very much subject to extinction in contrast to many previous reports of its persistence (Anderson et al., 2011a, 2011b; Anderson & Yantis, 2013; Della Libera & Chelazzi, 2009; Stankevich & Geng, 2014). These findings suggest that observing VDAC depends heavily on the task that is employed and that when VDAC is observed there is not an enduring change in prioritization of the reward-associated feature.

In Chapter three, the extent to which features associated with reward can affect sustained attention was explored. In Experiments 1 and 2 it was found that previously reward-associated features improved sustained attention performance throughout the task when the reward-associated feature remained relevant to the task. In Experiment 2 absent trials were included, but no purely selection history effect was observed suggesting that the effects on sustained attention may be unique to reward history. In Experiment 3, there was no evidence of either VDAC or SDAC when the previous feature was presented on a distractor. Therefore, the reward-associated feature did not impair sustained attention when no longer task-relevant. However, a subset of participants continued to respond to distractor stimuli as if they were targets, suggesting that the reward-associated feature remained prioritized in attention.

In Chapter four, the generalizability of VDAC beyond the typical paradigm was examined. In Experiment 1, it was found that reward-associations learned in a typical VDAC visual search task improved performance in a sustained attention task when the reward-associated feature was presented on a target suggesting that VDAC can generalize across tasks (Anderson et al., 2012; but see Anderson, 2015). In Experiment 2, an effect of selection but not reward history was found when search was in a naturalistic environment interacting with real-world objects. Acting upon the objects could have resulted in an enhanced selection history effect even with a very small number of trials(Abrams et al., 2015).

VDAC has been shown to have a broad range of impacts on attention. However, it has been demonstrated here that the observance of VDAC depends heavily on the task at hand. It has also been shown that reward related biases can generalize to other domains of attention such as sustained attention by improving performance when the reward-associated feature was task-relevant. Finally, the effects of reward history were able to generalize between two very different tasks with different demands on attention. The studies reported here provide further insight into factors that determine the prioritization of attention. The studies reported here add to the growing body of literature that previously selected and rewarded features can impact attention even though they are not physically salient or related to current goals, providing further support that the top-down bottom-up dichotomy fails to adequately explain all factors that determine priority of attention (Awh et al., 2012).

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