The Role of Selective Attention in Value-Modulated Attentional Capture

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Abstract

Stimuli that reliably predict reward can increase their capacity to capture attention. This Value-Modulated Attentional Capture (VMAC) is typically viewed as independent of task goals or physical salience, arising from Pavlovian learning. However, recent evidence suggests that the awareness of the stimulus-reward contingency may be necessary during the acquisition of such attentional biases, although the underlying mechanism remains unclear. One possibility is that awareness mediates the learning process of VMAC by directing selective attention toward the reward-predictive feature. The present preregistered study tested whether reward-related attentional biases arise primarily from such selective attention, independently of awareness. Participants performed a visual search task in which one of two singleton distractors—one predicting high reward, the other low reward—appeared on a subset of trials. Selective attention to the reward-predictive feature (distractor color) was manipulated between groups: In some trials, one group reported the distractor's color, while the other group reported an irrelevant feature (its location). Otherwise, the stimulus–reward contingencies remained identical for both groups. VMAC, as measured by slower response times for the high-value compared to the low-value distractor, emerged only in the group that reported the color. Critically, the previous result cannot be explained by individual differences in awareness. These findings demonstrate a causal role of selective attention in the acquisition of reward-related attentional biases.

Keywords: attentional capture, learning, reward, selective attention, awareness

Public Significance Statement

Whether Pavlovian associations can guide attention without awareness of the specific statistical contingency remains an outstanding issue, critical for understanding not only how learning impacts attention in general, but also how such attentional biases operate in certain psychopathological conditions, such as addiction. Although most research shows the apparent automaticity of VMAC once learning is established, recent studies highlight that awareness of statistical contingencies is associated with the learning process of VMAC. In this study, we show that a manipulation of selective attention toward a feature associated with reward modulates its learning, independently of awareness. Our findings expand the boundary conditions under which a stimulus associated with reward can bias attention automatically, with broader implications for theories of learning and attentional control.

The Role of Selective Attention in Value-Modulated Attentional Capture

When individuals learn to associate a specific stimulus feature with reward, this stimulus often becomes a stronger distractor in visual search tasks (Anderson et al., 2021; Failing & Theeuwes, 2018). The weight of evidence suggests that the learning process underlying this phenomenon is Pavlovian in nature and thus depends on the history of stimulus-reward pairings (Le Pelley et al., 2016). One of the clearest demonstrations of this Pavlovian account is provided by Le Pelley et al. (2015), who used a modified version of the additional singleton task (Theeuwes, 1992, 1994). In their study, participants searched for a target defined by one feature (shape) while a uniquely colored distractor was occasionally presented. Critically, rewards were contingent on the distractor's color—one color predicted high reward, the other low reward. When the high-reward singleton appeared, participants showed increased response times (RTs) compared to trials with the low-reward singleton, an effect known as value-modulated attentional capture (VMAC).

Most of the evidence gathered so far suggests that once established, VMAC is automatic. For instance, in the study by Le Pelley et al. (2015), VMAC emerged even when the reward-predictive feature was task-irrelevant, and also when attending to it resulted in obtaining less reward. This attentional capture has also been documented using oculomotor measures (Pearson et al., 2016; Theeuwes & Belopolsky, 2012), where participants fixated more frequently on the high-value singleton even if it led to reward omission. However, the role of awareness in the learning process of VMAC is controversial. While some studies suggest that stimulus-reward associations can be learned without awareness (Anderson, 2015; Anderson & Yantis, 2013; Grégoire & Anderson, 2019; Theeuwes & Belopolsky, 2012), other studies have found the opposite (Failing & Theeuwes, 2017; Garre-Frutos, Lupiáñez, et al., 2025; Le Pelley et al., 2017;

Meyer et al., 2020). Consistent with the latter, instructing participants about the feature-reward contingency appears to be one of the strongest moderators of the VMAC effect across studies (Garre-Frutos, Lupiáñez, et al., 2025). Although these findings may appear contradictory, it is well-established that human Pavlovian learning is sensitive to the same manipulations (Lovibond et al., 2011; Lovibond & Shanks, 2002; Mertens et al., 2016; Mertens & Engelhard, 2020; Weidemann et al., 2016). Some theoretical models even propose that Pavlovian learning could be entirely propositional (Mitchell et al., 2009), making awareness a necessary condition for learning.

An alternative and potentially more parsimonious explanation focuses on the role of selective attention toward reward-associated features. Research from other experimental paradigms suggests that implicit learning often depends on spatial (Duncan et al., 2024; Golan et al., 2024; Jiang & Chun, 2001; Vadillo et al., 2020; Vadillo et al., 2024) or feature-based (Jiménez & Méndez, 1999) selective attention. In the paradigm used by Le Pelley et al. (2015), distractors in the additional singleton task capture attention (Theeuwes, 1992, 1994). However, participants are never explicitly required to selectively attend to the reward-predictive feature, i.e., color, as it is never directly task-relevant. Instructions regarding stimulus-reward contingencies might direct participants' attention specifically toward the reward-associated feature, potentially making selective attention both necessary and sufficient for learning. If selective attention is crucial, any manipulation compelling participants to attend to the reward-associated feature (color) rather than other features (e.g., location) should enhance VMAC, even if participants remain unaware of the exact contingencies.

The Present Study

The current preregistered study aimed to test the causal role of selective attention in the learning process underlying VMAC. We employed the general procedure from Garre-Frutos, Lupiáñez, et al. (2025), but rather than manipulating instructions, we introduced a concurrent task designed to force selective attention toward distinct distractor dimensions. Specifically, we manipulated between participants whether they had to report the color or the location of the singleton distractor (similar to Gao & Theeuwes, 2020). This design allowed us to specifically compare selective attention directed toward the irrelevant reward-associated feature (color) versus a completely irrelevant feature (location; independent of reward), without informing participants about the color-reward association (conceptually similar to Jiménez & Méndez, 1999).

As preregistered, we hypothesized a dissociation in VMAC based on the type of concurrent task (color vs. location). Specifically, we predicted that only the group reporting color would show a VMAC effect. Furthermore, we expected that this effect would remain independent of individual differences in awareness. In other words, we expected that the difference between groups would not be accounted for by between-group differences in awareness or individual differences in the relationship between awareness and VMAC.

Methods

Transparency and openness

This experiment complies with the TOP guidelines. All materials, data, and scripts are publicly available at https://osf.io/eczrn, and the methods and analyses were registered before data collection in December 2024 (https://osf.io/f3bm8). Data were analyzed using R, version

4.3.1 (R Core Team, 2023)[1]. We report how we determined our sample size, data exclusions, manipulations, and measures in the study.

Participants

We performed a simulation-based power analysis (fully reported at https://osf.io/f3bm8) for the critical Group (color vs. location) × Distractor (high- vs. low-value) interaction, based on a similar effect from the linear mixed model (LMM) in Garre-Frutos, Lupiáñez, et al. (2025) (effect size: $\beta = 0.018$), excluding trials from the first 48 trials where VMAC is typically not observed (Garre-Frutos et al., 2024; Garre-Frutos, Lupiáñez, et al., 2025). Power was estimated using R (version 4.3.1; R Core Team, 2023) and the *simr* package (Green & MacLeod, 2016). Simulations indicated that 70 participants per group would yield 84.2% power ($\alpha = .05$). To account for exclusions, we collected data from 80 participants per group. Following the pre-registered protocol, seven participants were excluded due to low accuracy (<70%), RTs deviating ±3 SDs from the group mean, or poor performance in the reporting task. The final sample included 153 participants ($n_{\text{color}} = 77$, $n_{\text{location}} = 76$; 117 self-identified as women; $M_{\text{age}} = 21.4$, $SD = 4.2$).

Design and procedure

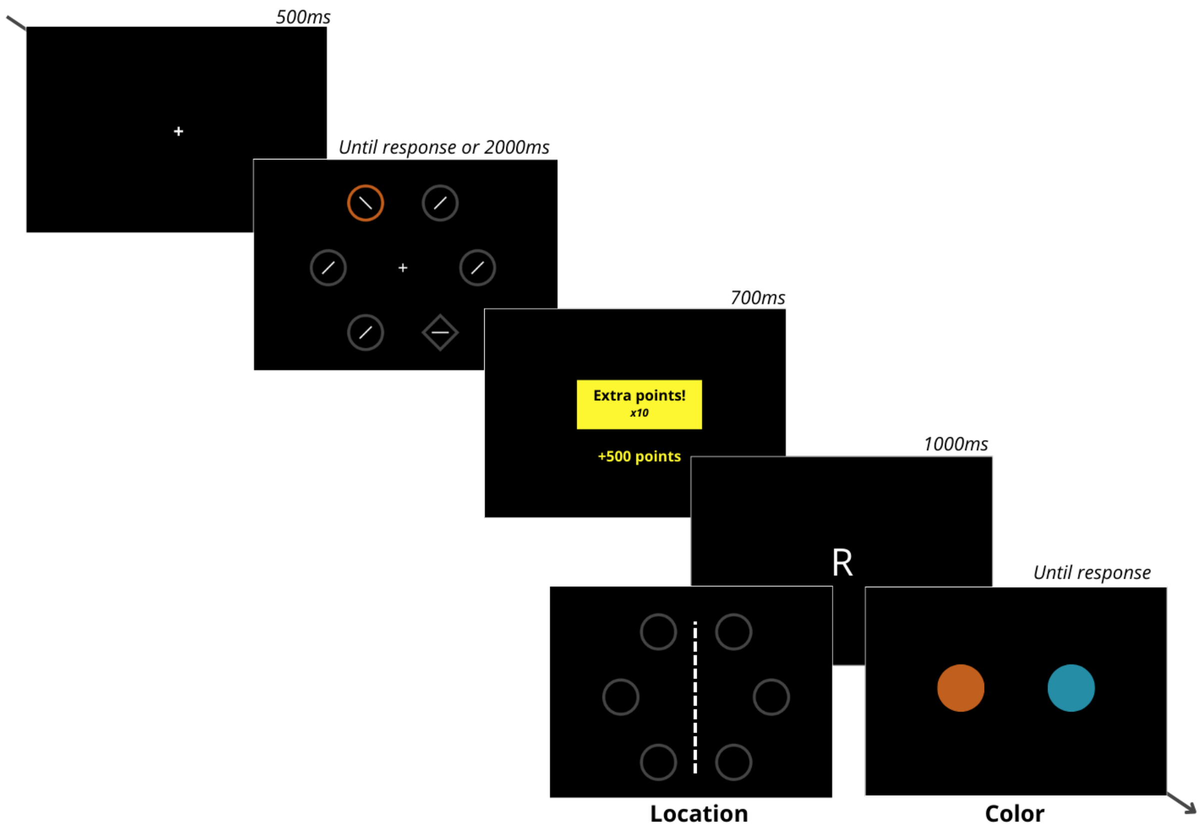
Participants completed an online version of the additional singleton task (Garre-Frutos et al., 2024), in which they searched for a diamond target among circle distractors. The target always contained a horizontally or vertically oriented line segment, while each circle contained a segment tilted by 45 degrees. On most trials, one of the circles appeared in a uniquely colored

[1] Packages: *lme4* (Bates et al., 2015), *betareg* (Cribari-Neto & Zeileis, 2010) and *tidyverse* (Wickham et al., 2019).

singleton distractor (orange/blue or pink/green), which could be either a high- or low-value color, counterbalanced. Participants were instructed to locate and report the orientation of the line segment within the diamond as quickly as possible by pressing the <b> key for horizontal or the <j> key for vertical.

Figure 1

Schematic representation of the task.



Note. Example of the sequence of events in the experimental task. Participants could earn points based on performance, and when a high-value singleton appeared in the display, points were multiplied by 10 (a bonus trial). In some trials, participants were presented with the letter ‘R’, which signaled that participants had to report the color or the location (as a function of the assigned group) of the distractor in the preceding trial. Feedback was provided in Spanish.

Participants received 0.1 points for every millisecond their RTs were below 1000 ms on low-value distractor trials on correct responses, and points were multiplied by 10 on high-value trials. Errors resulted in the loss of the same number of points earned on correct responses, and no points were awarded for RTs above 1000 ms. Critically, participants were not informed of the relationship between color and reward. The task consisted of six blocks of 48 trials (20 high- and low-value trials each, and 8 distractor-absent trials).

Participants were randomly assigned to one of two groups, each required to perform a brief secondary task that occurred pseudorandomly at the end of selected trials. One group reported the color of the singleton distractor from the previous trial, while the other reported its location, indicating whether it appeared on the left or right side of the display (Fig. 1). Participants were informed that the letter "R" would occasionally appear on the display after reward feedback, indicating that they had to report either the color or the location of the distractor, depending on their assigned group, using the <c> and <m> keys to indicate left or right. To integrate the reporting task with the visual search task, correct responses were worth 2000 points, while incorrect responses resulted in the loss of the same number of points. Feedback on these trials was provided only at the end of each block. Participants encountered two or four report trials per block, with at least one in each half.

At the end of the experiment, participants completed an awareness test to assess their knowledge of the color-reward contingencies using a Visual Analog Scale (VAS; Reips & Funke, 2008). First, they rated the extent to which they believed the distractor color influenced the likelihood of "bonus trials" (contingency belief), on a scale from 0 ("I don't believe color makes any difference") to 100 ("I believe color completely determines the likelihood of bonus trials"). They then estimated the relative proportion of bonus trials associated with each color (contingency awareness). To do this, they were presented with another VAS showing the high- and low-rated distractors with endpoints indicating the percentage of bonus trials estimated to be associated with each color. After providing these ratings, participants indicated their confidence in each answer using a confidence VAS ranging from 0 ("no confidence") to 100 ("very confident").

Results

Unless noted otherwise, all the analyses reported follow our preregistered analysis plan, including data selection criteria, significance thresholds, and directionality of hypotheses. Following preregistration, we excluded incorrect responses (5.53%), anticipations and timeouts (RTs < 150 or > 1800 ms; 0.57%), and all trials from the first block of the visual search task.

Report task

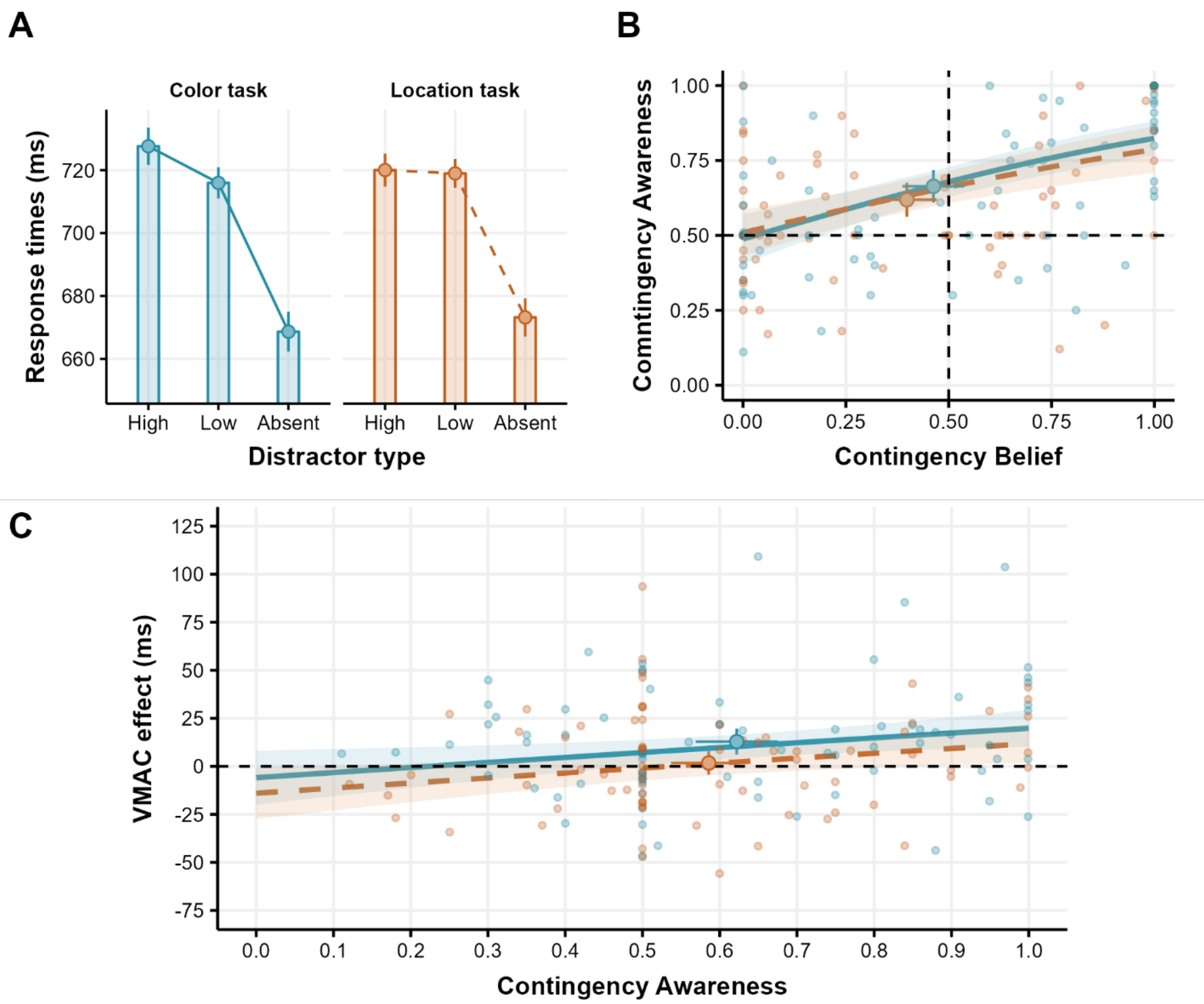
We fitted a generalized linear mixed model (GLMM) with binomial likelihood to analyze accuracy on the report task, including a group predictor. Accuracy was high ($M_{\text{Accuracy}} = 0.946,\ 95\%\,\text{CI}[0.933, 0.959]$) and did not differ significantly between groups ($p = 0.749$), suggesting that participants performed well on the secondary task.

Visual search task

We analyzed log-transformed RTs using LMMs that included two predictors of theoretical interest: value-modulated attentional capture (VMAC: high- vs. low-value distractor) and attentional capture (AC: low-value vs. absent distractor), along with a Group predictor (color vs. location report task). All contrasts were two-tailed except for the VMAC × Group interaction, for which, as preregistered and following our hypothesis, we used a one-tailed test in the direction of a larger VMAC effect in the color group.

Figure 2

Summary of results



Note. **A**) Mean RTs in the visual search task. Bars and dots show condition means; error bars indicate within-subject 95% CIs (Morey, 2008). **B**) Beta regression predictions for awareness results. Transparent dots are individual responses; lines and shaded areas show model predictions and 95% CIs, and solid dot points and error bars represent mean predicted responses at the group-level. **C**) RT analysis with contingency awareness as covariate. Transparent dots show individual VMAC scores; lines and shaded areas depict model predictions by task and awareness level. Solid, large dots and error bars show group means and 95% CIs. Note that both the selective attention manipulation and contingency awareness have independent effects on observed VMAC scores, showing that our results cannot be explained by individual differences in awareness.

RT analyses showed significant effects of both AC and VMAC ($\beta_{\text{VMAC}} = 0.008,\ t_{151} = 2.57,\ p = 0.011$; $\beta_{\text{AC}} = 0.062,\ t_{151} = 17.26,\ p < 0.001$), indicating that participants were slower in the presence of a high-value ($M_{\text{High}} = 734.0,\ 95\%\ \text{CI}[719.6, 748.7]$) compared to a low-value distractor ($M_{\text{Absent}} = 684.0,\ 95\%\ \text{CI}[670.9, 697.4]$), and faster when no distractor was present ($M_{\text{Low}} = 728.3,\ 95\%\ \text{CI}[713.7, 743.2]$). Critically, the Group predictor interacted significantly only with VMAC ($\beta_{\text{VMAC}\times\text{Group}} = 0.006,\ t_{151} = 1.98,\ p = 0.025$; Fig.2A), such that a significant VMAC effect was observed in the color group ($M_{\text{VMAC}} = 10.4,\ 95\%\ \text{CI}[3.9, 16.8]$) but not in the location group ($M_{\text{VMAC}} = 1.2,\ 95\%\ \text{CI}[-5.3, 7.6]$)[2]. No other effects reached significance (*ps* > 0.133).

We also analyzed accuracy with a GLMM, showing that accuracy was high ($M_{\text{Accuracy}} = 0.953,\ 95\%\ \text{CI}[0.948, 0.959]$) and none of the predictors reached significance (*ps* > 0.365).

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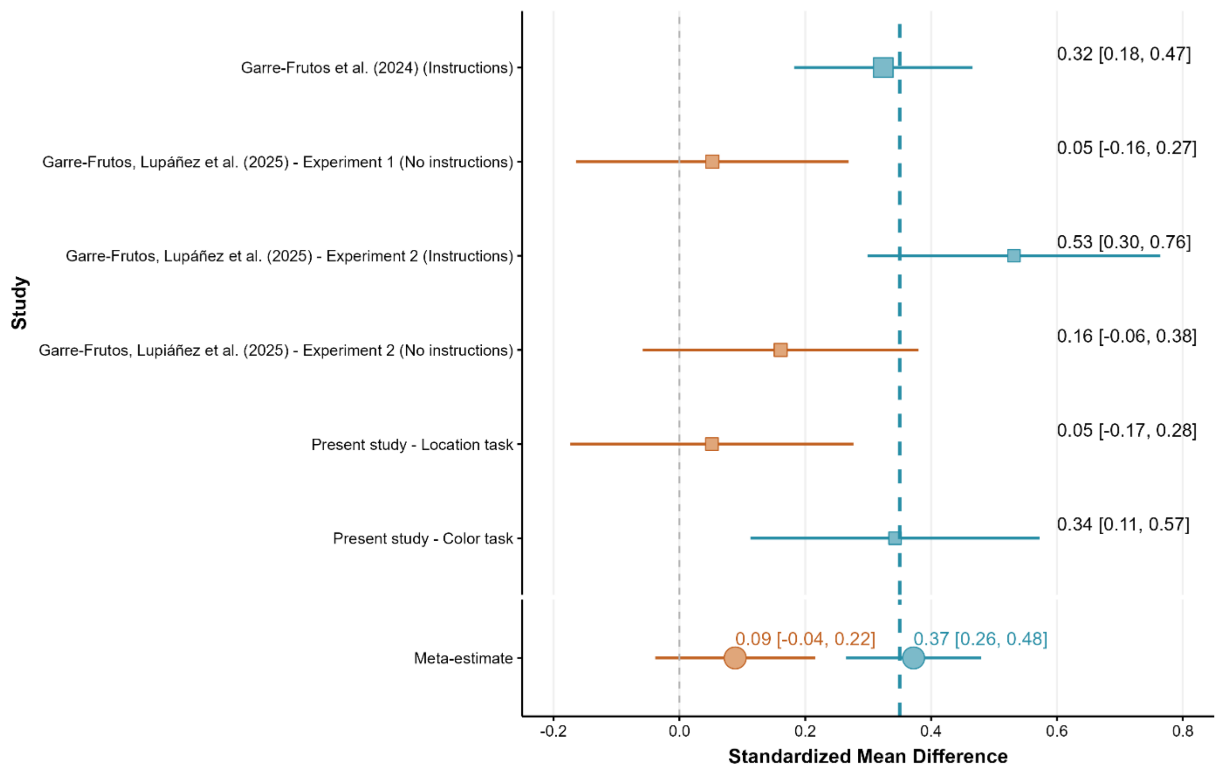
[2] As preregistered, we estimated the split-half reliability of the VMAC effect (Garre-Frutos et al., 2024), which was low ($r_{\text{sb}} = 0.28,\ 95\%\ \text{CI}[0.08, 0.44]$), suggesting that between-groups differences are possibly attenuated by measurement error (Karvelis & Diaconescu, 2025; Wiernik & Dahlke, 2020; but see Parsons, 2018).

Figure 3

Meta-analysis comparing the present results with prior literature



Note. To illustrate the conceptual similarities between manipulating instructions and selective attention, blue color indicates that participants received instructions about the feature-reward contingency or selectively attended to color (in the present study), while orange indicates that they did not receive instructions or selectively attended to location (in the present study). The blue dashed line indicates the meta-analytic estimate (Standardized Mean Difference) of the effect of reward-driven distraction in the broader literature (0.35; Rusz et al., 2020). Squares indicate standardized effect sizes for individual studies, with size indicating precision and error bars indicating CI. Results from the meta-analysis showed that the effect size observed in the present study for the color group is perfectly consistent with effect sizes observed in the literature and prior studies.

Note that the size of the VMAC effect in the color group is fully consistent with previous studies where participants were informed about the feature–reward contingency, whereas the (null) effect in the location group matches the typical findings of studies without such instructions. To confirm this consistency, we conducted a (non-registered) meta-analysis on the standardized VMAC effect size (see the Supplementary Material), comparing the present results with prior studies using the same design (Garre-Frutos et al., 2024; Garre-Frutos, Lupiáñez, et al., 2025), and with the meta-estimate from the broader literature (Rusz et al., 2020). As shown in Fig.3, effect sizes closely align with prior findings, with no significant heterogeneity within the two broad groups of studies, but significant differences between them. An additional meta-analysis (reported in the Supplementary Material) shows that the VMAC × Group interaction found in the present study is also comparable to the analogous interaction observed in Garre-Frutos, Lupiáñez, et al. (2025), showing that manipulating selective attention to the reward-predictive feature has the same effect as manipulating instructions.

Awareness

Following our preregistered plan, we analyzed awareness measures using beta regression (Smithson & Verkuilen, 2006). Neither measure differed significantly between groups (*ps* > 0.224). However, the two awareness measures were significantly correlated ($\beta = 0.551,\ z = 6.632,\ p < 0.001$; Fig. 2B) with no significant group differences in this correlation ($p = 0.444$). While contingency awareness was positively associated with confidence ($\beta = 0.579,\ z = 7.197,\ p < 0.001$; no group difference, $p = 0.409$), contingency belief was not (*ps* > 0.231).

As preregistered, we repeated the RT analysis, including contingency awareness and its interaction with VMAC as covariates. This analysis revealed a significant VMAC × awareness interaction ($\beta_{\text{VMAC×Awareness}} = 0.008,\ t_{151} = 2.58,\ p = 0.011$), indicating a positive association (Figure 2C). However, the VMAC × Group interaction remained significant ($\beta_{\text{VMAC} \times \text{Group}} = 0.006,\ t_{151} = 1.79,\ p = 0.038$), with a significant VMAC effect in the color group, even assuming no contingency awareness ($M_{\text{VMAC}} = 7.2,\ 95\%\ \text{CI}[0.5, 13.8]$), but not in the location group ($M_{\text{VMAC}} = -0.9,\ 95\%\ \text{CI}[-7.3, 5.5]$). Therefore, even though VMAC and awareness interact, the interaction with selective attention cannot be explained by individual differences in awareness.

To test the robustness of the prior pre-registered analysis, following a reviewer's suggestions, we perform additional non-preregistered analyses showing that there was no between-group differences in confidence rating for any awareness measure (*ps* > 0.311), and that our between-group manipulation remained significant even when controlling for Contingency Belief instead of Contingency Awareness, or even when both awareness measures were multiplied by their corresponding confidence rating (*ps* < 0.026). That is, results under specific pre-registered choices are in agreement with different plausible analytical choices.

Discussion

In this preregistered study, we investigated the role of selective attention in the learning process underlying VMAC. We manipulated between groups whether participants reported the color or the location of a distractor in a concurrent task, forcing selective attention to a specific dimension of the distractor. Our results indicate that only participants tasked with reporting color showed a significant VMAC effect. Critically, the groups did not differ on any *awareness measure*, and the modulation of VMAC by task demands remained significant even after controlling for individual differences in awareness. However, such individual differences were positively associated with VMAC, suggesting that both contingency awareness and selective attention independently modulated the VMAC effect.

Similar to visual statistical learning (Wang & Theeuwes, 2018), where learning needs spatial attention to the relevant high-probability location (Duncan et al., 2024; Golan et al., 2024), our results suggest that VMAC needs attention to the specific reward-predictive feature (Jiménez & Méndez, 1999). This might explain potential qualitative differences about the role of awareness and instructions in paradigms where the reward-predictive feature is task-relevant compared to when it is task-irrelevant. Specifically, when distractors are task-irrelevant during learning, awareness of the contingency would promote selective attention to the relevant distractor feature, while in conditions where this feature is task-relevant, the reward-predictive feature would be selectively attended due to task demands, which may explain why null findings regarding VMAC and awareness are particularly common when the reward-predictive feature is task-relevant. As suggested by classical theories of automaticity, such as the instance theory (Jamieson et al., 2012, 2022; Logan, 1988, 2002), the simplest explanation for this result is that selective attention determines what is learned (Logan et al., 1996, 1999; Logan & Etherton, 1994). However, it is also possible that the dual-task demands encouraged participants to actively maintain the reward-predictive feature in working memory, which may be a necessary condition for learning (Carter et al., 2003). Both interpretations converge in predicting that making the reward-predictive feature task-relevant is sufficient to produce VMAC.

Interestingly, we also found that VMAC significantly correlated with awareness, independent of the selective attention manipulation. Based on the previous account, learning should depend not only on selective attention to the reward-predictive feature but also on reward feedback. Thus, contingency awareness could reflect joint attention to both elements. Still, other mechanisms could explain the relationship between awareness and VMAC. For instance, propositional knowledge might trigger Pavlovian learning through a different mechanism (Dayan

& Berridge, 2014; Mitchell et al., 2009; Pauli et al., 2019), or knowledge of feature-reward associations might artificially amplify VMAC for reasons unrelated to Pavlovian learning, such as strategically directing attention to the high-value distractor (Doyle et al., 2025; Garre-Frutos, Ariza, et al., 2025; Gottlieb et al., 2014; Mahlberg et al., 2025). Understanding the specific mechanism linking VMAC to awareness is relevant for assessing both the validity and the practical impact of this bias in psychopathology conditions (Anderson et al., 2021).

In summary, our study shows that the relationship between attention and VMAC can be mediated by selective attention to the reward-predictive feature, independently of awareness. This finding underscores that VMAC requires selective attention to encode and represent the contingency between features and rewards.

Constraints of Generality

This study was conducted online using a specific experimental paradigm. The findings may not generalize to other paradigms or settings (Anderson et al., 2011).

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