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BRIEF REPORT

Reward supports flexible orienting of attention to category information and influences subsequent memory

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Abstract
Preparatory control of attention facilitates the efficient processing and encoding of an expected stimulus. However, this can occur at the expense of increasing the processing cost of unexpected stimuli. Preparatory control can be influenced by motivational factors, such as the expectation of a reward. Interestingly, expectation of a high reward can increase target processing, as well as reduce the cost associated with reorienting. Using a semantic cueing paradigm, we examined the interaction of reward expectation and cue-validity on semantic judgment performance and subsequent memory. Preparatory attention was assessed with pupillometry. Valid category cueing was associated with better semantic judgment performance and better subsequent memory compared to invalidly cued items. Higher reward also resulted in a larger pre-target pupil diameter, which could be indicative of increased preparatory task engagement or arousal. Critically, higher reward also reduced reorienting cost in both semantic judgment and subsequent memory performance. Our findings suggest that reward expectation can facilitate the effective control of preparatory attention for semantic information, and can support optimal goal-directed behavior based on changing task demands.

Keywords Reward · Category-cueing · Preparatory attention · Reorienting · Memory · Pupillometry

Introduction

The selective allocation of limited cognitive processing resources is necessary for effective goal-directed behavior and the learning of new environmental information. This allocation of cognitive resources can be strongly influenced by reward such that priority is given to information relevant for obtaining the reward (Chiew & Braver, 2011). Attentional orienting, the allocation of processing resources on task-relevant information in anticipation of its occurrence (Henderson, 1991; Posner, 1980; Posner, Snyder, & Davidson, 1980), is illustrated by the case of a thirsty hiker being more attuned to the sound of flowing water relative to the sound of rustling leaves, a bias that might increase with greater thirst.

Earlier work on attentional orienting has primarily focused on attention to basic perceptual features (e.g., Spatial: Posner, 1980; Object: Duncan, 1984). However, orienting can also be directed at non-perceptual features, such as the time of target appearance (Coull, Frith, Büchel, & Nobre, 2000; Coull & Nobre, 2008; Nobre, 2001), or semantic information (Cristescu, Devlin, & Nobre, 2006; Cristescu & Nobre, 2008; O'Craven, Downing, & Kanwisher, 1999; Yi, Kelley, Marois, & Chun, 2006). Orienting attention to task-relevant information can influence information processing, affecting both immediate behavioral performance and subsequent memory. An informative (valid) cue can enhance target detection performance, while an invalid cue results in longer response latencies (Posner, 1980), poorer detection accuracy (Engelmann & Pessoa, 2007), and poorer subsequent memory (Turk-Browne, Golomb, & Chun, 2013; Uncapher, Hutchinson, & Wagner, 2011). While facilitating the detection of an expected target, orienting can also come at the cost of de-emphasizing an unexpected stimulus, such as the appearance of a bear in the case of the lost hiker.

The ability to engage proactive control to maintain task-relevant information (Chiew & Braver, 2013) and the ability to suppress distracting information (Padmala & Pessoa, 2014) may

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be enhanced by the expectation of monetary rewards. Enhanced reactive control (Boehler, Schevernels, Hopf, Stoppel, & Krebs, 2014; Engelmann & Pessoa, 2007; Massar, Sasmita, Lim, & Chee, 2018) and greater attentional flexibility (Shen & Chun, 2011) are two potential additional benefits of anticipating reward. The reorienting of attention involves the disengagement and updating of original goal representations, and is essential for resolving cue-target incongruence. While reward has been shown to enhance target detection (Engelmann, Damaraju, Padmala, & Pessoa, 2009; Engelmann & Pessoa, 2007), reward-driven improvement was most prominent with invalid cues (Bucker & Theeuwes, 2014; Engelmann & Pessoa, 2007). Although reward-related behavioral improvement with valid cueing is consistent with the expectation of increased attentional control, behavioral facilitation with invalid cueing indicates that reward can also improve attentional flexibility and reduce the cost of reorientation.

In the current study we studied how reward modulates responses to invalid cues that convey semantic information by having participants make semantic judgments on pictures after receiving category and reward cues that denoted relevant image type and reward magnitude. One possible result of anticipating high reward is that this would increase engagement of preparatory attention for the cued information resulting in increased reorienting cost of an invalid cue. Alternatively, if reward works to support the flexible alteration of goal representations, reorienting cost would be reduced with expectation of high reward. This would functionally resemble the promotion of attentional flexibility. To continuously assess the engagement of attention, we monitored pupil diameter and predicted that high reward would be associated with larger pupil diameter in the preparatory period and would positively correlate with task performance.

Beyond examining immediate performance in the semantic judgment task, subsequent memory performance was also tested to ascertain the downstream consequences of attentional reorienting. Invalid spatial cueing can disrupt encoding and impair subsequent memory of target items (Turk-Browne et al., 2013; Uncapher et al., 2011). We expected invalid semantic cueing to also result in poorer subsequent memory, even when target images are correctly evaluated during semantic judgment. If reward increases the utilization of cue information, greater impairment would be expected following invalid cues when a high reward is anticipated. Alternatively, if reward can reduce the impact of cue-invalidity, it might collaterally benefit incidental encoding of cue-incongruent pictures.

Materials and methods

Participants

Thirty-two healthy young adults were recruited for the study. Prior experiments on semantic cueing have shown a large effect size in the range of ηp^2 = 0.49 to 0.58 (Cristescu et al., 2006). Power analysis showed that a sample size of eight would be sufficient in detecting an effect of this magnitude (α = .05, power = .80). As the effect size of the interaction is unknown, we decided on a sample size of 32, similar to prior work examining the effects of reward on spatial reorienting (Bucker & Theeuwes, 2014). Two participants were excluded from further analyses due to noncompliance with the experimental protocol, leaving a sample of 30 participants (18 females) aged 19–30 years (M = 22.5, SD = 2.3). All participants were fluent in English, had normal or corrected-to-normal vision, and reported no history of psychiatric or neurological disorders. All research procedures were approved by the Institutional Review Board of the National University of Singapore, and all participants provided informed consent.

Procedure

The experiment was presented on a 21-in. LCD display using the Psychophysics toolbox for MATLAB (Brainard, 1997; Pelli, 1997) on a Mac desktop. Participants were seated in front of a computer with their heads positioned on a chinrest with a viewing distance of approximately 600 mm. A semantic judgment task was administered while an eye-tracker recorded pupil responses (Tobii X60; Tobii AB, Danderyn, Sweden). After a brief delay following the semantic judgment task (~15 mins), a surprise recognition task was administered, and participants indicated whether images presented were previously seen during the semantic judgment task.

Materials

We selected a total of 360 images consisting of 180 scene images (90 indoor scenes and 90 outdoor scenes) and 180 face images (90 male faces and 90 female faces). The images were split into three sets of 120 images with an equal number of scene and face images. Two sets were used as target images in the semantic judgment task while the third set served as foils for the recognition task. All images were in gray-scale with the image sets counterbalanced across participants.

Experimental tasks

Semantic judgment task In this task participants were required to make semantic judgments regarding images depicting scenes or faces. Each trial started with the presentation of a semantic category cue (the word "face" or "scene") for 600 ms, indicating whether the upcoming trial is more likely to be a face or a scene image (Fig. 1). On 80% of trials the category cue was valid, such that it was predictive of the target image category, while the remaining 20% of trials had invalid category cues that did not predict the target image

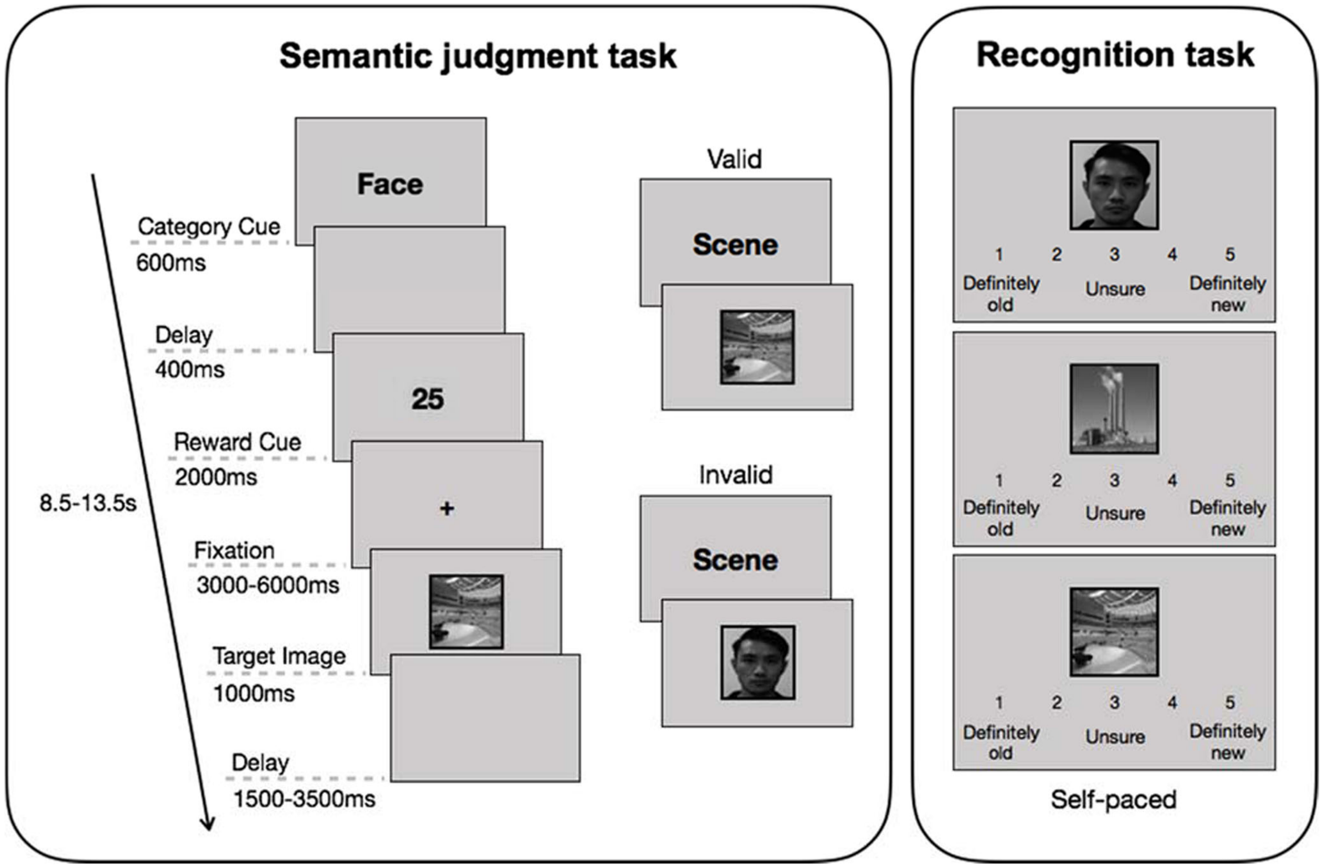

Fig. 1 Task schematics. In the semantic judgment task, participants were presented with a category cue, followed by a reward cue. Participants indicated whether the target image shown was Indoor/Outdoor (for Scenes), or Male/Female (for Faces). Category cues are predictive of the target image category on 80% of the trials (valid), and are not predictive on 20% of the trials (invalid). During recognition, participants indicated on a 5-point scale how confident they were that the image presented was a previously seen image

category. A reward cue was then shown for 2 s indicating the amount of reward that can be earned for that trial (1 cent for Low and 25 cents for High). There were an equal number of low and high-reward trials in the task. This was followed by a fixation cross for 3–6 s ($M = 4$ s) before an image of either a face or a scene was presented for 1 s. Participants were instructed to indicate whether the image depicted a male or female face, or an indoor or outdoor scene. Participants responded by pressing one of two keys with their index or middle finger according to the response mapping shown at the start of the experiment (counterbalanced across participants). Participants were instructed to respond as quickly and accurately as possible and that the reward shown at the start of each trial is earned if their response is both accurate and fast. In total, participants completed four blocks consisting of 60 trials each. At the end of each block, performance feedback was shown (Accuracy, Response Time (RT), and Bonus earned), and participants were allowed to take self-timed breaks before proceeding with the next block. Participants were not informed that their memory for the items would be tested. On average, participants earned a bonus of SGD$16.20 for the semantic judgment task.

To familiarize participants with the task structure, 32 practice trials were given using scene and face images that were not included in the main experiment. Feedback, including RT and response accuracy, was shown after each trial for the first 16 practice trials, after which feedback was omitted. To proceed with the actual experiment, participants had to obtain an accuracy of at least 75% (five out of eight) for each image category. The median RT for the last 16 trials (eight cue-valid trials from each image category) was used to define the RT threshold for obtaining the reward (separate thresholds for the different image categories).

Recognition task A surprise recognition task was administered following a brief interval (~15 mins) after the semantic judgement task. Participants were shown a total of 360 images, 240 of which were previously seen during the semantic judgement task (Old), and 120 of which were category-matched novel foils (New). Participants rated the images on a scale of 1–5 (1: definitely new, 3: unsure, 5: definitely old) to indicate how confident they were of having seen that image during the semantic judgment task. The recognition was self-paced and participants were informed that their memory performance would not affect the bonus that they had previously earned.

Data analysis

Behavioral data To examine performance on the semantic judgment task, response time (RT) was analyzed. All RTs were log-transformed prior to analysis. For all reported analyses, only trials that were correctly responded to during the semantic judgment task were included. Statistical analysis was performed using linear and logistic mixed-effects modeling fitted with the lme4 package (Bates, Mächler, Bolker, & Walker, 2015) in R (R Core Team, 2016). A mixed-effect modeling approach was chosen due to the unequal number of trials in each condition (i.e., Cue-valid vs. Cue-invalid), and this approach confers greater flexibility in being able to account for trial-level variations (Baayen, Davidson, & Bates, 2008). For the models, reward and cue-validity was dummy coded (0 for no-reward and 1 for reward; 0 for valid and 1 for invalid). To examine the effects of Reward, Cue-validity, and their interaction, we fitted models with Reward, Cue-validity, and Reward*Cue-validity as fixed effects and Subject was included as a random effect. Image category and Delay interval were included as regressors of no interest. For formal model comparisons, we used a likelihood ratio test ("lmtest" package) comparing a model with the factor of interest, and one without the factor of interest (including all other variables of no interest, e.g., Image category and Delay interval). Follow-up comparisons on the estimated marginal means were performed using Tukey's HSD implemented with the "emmeans" package. Confidence intervals were estimated using confint.merM (from the lme4 package), and *p*-values were computed using the "lmertest" package.

A similar analytic approach with logistic mixed-effect model was used to examine recognition performance. Subsequent memory for each of the old items was binarized to Remembered and Forgotten. Old items receiving a rating of 4 and 5 were labelled as Remembered, while items receiving a rating of 1 and 2 were classified as forgotten. Items rated as "Unsure" (Rating: 3) were excluded from subsequent analyses.

To ensure that our results were not due to modeling the data using a mixed-effect model, we repeated our analyses for both the semantic judgment task and the memory task using a repeated measures ANOVA approach on the condition averages. Semantic judgment task performance was quantified using the mean log-transformed RT, and recognition performance was measured using a non-parametric signal detection measure A', where 0.5 represents chance performance (Stanislaw & Todorov, 1999). Based on our hypothesis that reward would modulate the change in processing cost, additional planned comparisons were performed using a paired *t*-test, comparing the processing cost ($RT_{invalid}$ - RT_{valid} & A'_{valid} – $A'_{invalid}$) associated with the different reward levels. A threshold of $p < .05$ was used to define statistically significant comparisons.

Pupillometry preprocessing and analysis Pupil size was recorded during the semantic judgment task at a sampling rate of 60 Hz. Missing data due to blinks and eye-closures were corrected for offline by linear interpolation. The resulting time series was subsequently low-pass filtered with a 10-Hz cut-off. An algorithm was then used that: (1) removed trials with more than 30 interpolated samples within the 60-sample pre-target window; (2) removed trials with more than 18 contiguous interpolated samples; and (3) accepted trials with two or fewer interpolated samples. Trials that were not automatically removed or accepted according to these criteria were then subjected to manual inspection. Across participants, an average of 28.8 (*SD* = 32.9) trials were removed from further analysis. Single trial data were baseline corrected by subtracting the average pupil diameter during the 500 ms before the task cue appearance. Pre-target pupil diameter was defined as the average during the 1-s window preceding stimulus onset. Pupil data were not acquired for two subjects due to a failed connection between the eye-tracker and stimulus computer, leaving a final sample size of 28 participants for pupil analysis.

Results

RT-cost of invalid semantic cueing was modulated by reward

A linear mixed model with Cue-validity and Reward as predictors of RT revealed the expected significant effect of Cue-validity on RT, with invalid cues resulting in longer RTs than valid cues (β = 0.025, SE = 0.002, 95% CI = [0.019, 0.030], $p < .001$). There was also a significant interaction of Reward and Cue-validity (β = -0.008, SE = 0.004, 95% CI = [- 0.015, -0.0001], $p = .047$; Fig. 2A), and this was driven by a reduction in RT with high reward in the cue-invalid condition (β = 0.008, SE = 0.003, 95% CI = [0.001, 0.014], $p = .022$), but not the cue-valid condition (β = 0.0003, SE = 0.001, 95% CI = [-0.003, 0.004], $p = .87$). Results were consistent when using repeated measures ANOVA on the average log-transformed RT across conditions (Supplementary Analysis), and the planned comparison showed that the RT-cost ($RT_{invalid}$ – RT_{valid}) associated with invalid cueing was lower in the high-reward condition (Fig. 2C; Paired *t*-test: $t(29) = 2.29$, $p = .03$, mean difference = .008, 95% CI = [.001, .015], $d = 0.42$). Performance for each of the conditions is shown in Fig. 2B and Supplementary Table S1A and S1B.

Pre-target pupil diameter predicted subsequent semantic decision on congruent trials

Reward expectation modulated pre-target pupil diameter, with it being larger in high-reward trials (β = 0.016, SE = 0.016,

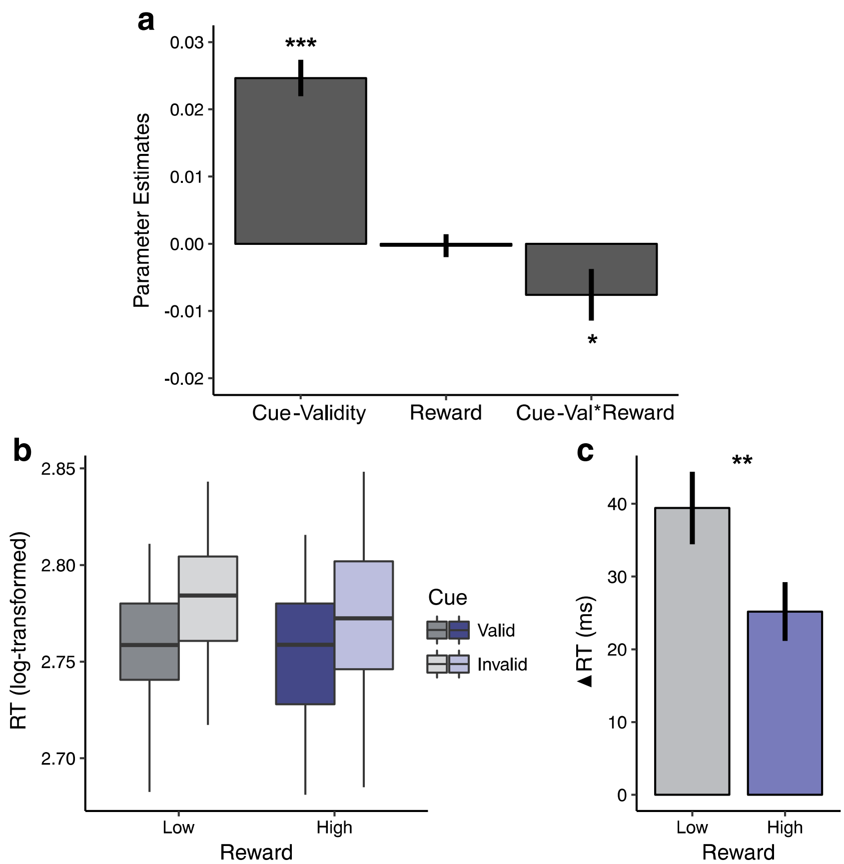

Fig. 2 Reward modulation of response-time (RT) cost associated with invalid category cueing. (**A**) Parameter estimates from the model showed a significant Cue-validity by Reward interaction. Error bar represents the standard error. (**B**) Box and whiskers plot of the log-transformed RT across the different conditions. The upper and lower hinges of each box correspond to the first and third quartiles, while the whiskers correspond to the largest and smallest values within 1.5 times of the interquartile range. (**C**) Comparison of RT cost associated with invalid category cueing across reward conditions. Invalid-category cueing was associated with longer RTs during semantic judgment, but this difference was reduced with high reward. Error bar represents the SEM. * $p < .05$, ** $p < .01$, *** $p < .001$

95% CI = [0.002, 0.029], p = .025; Fig. 3A). The Cue- and Target-locked pupil diameter is shown in Figs. 3B and 3C for illustration.

To examine if pupil diameter was predictive of subsequent performance, we added Pre-target pupil diameter as a predictor of behavior (RT) in the model. Pupil diameter was a significant predictor of RT on the semantic judgment task (β = -0.011, SE = 0.004, 95% CI = [-0.018, -0.004], p = .003), suggesting that preparatory engagement enhances subsequent target processing. The inclusion of an interaction term for Pupil diameter and reward did not result in a better model fit (χ^2 = 1.56, p = .21), indicating that the association between pupil diameter and RT was present in both reward conditions. Similarly, the inclusion of an interaction term for Pupil diameter and Cue-validity did not result in a better model fit (χ^2 = 0.03, p = .86), indicating that the association between pupil diameter and RT was present regardless of cue-validity. Together, these findings suggest that Pre-target pupil diameter indexes preparatory engagement or arousal, which facilitates subsequent task performance.

Recognition memory was poorer for invalidly cued items

A logistic mixed-effects model was used to examine subsequent recognition performance (Memory performance for each item was converted into a binary measure – Remembered/Forgotten). Cue-validity was a significant predictor of subsequent memory (β = -0.233, SE = 0.093, 95% CI = [-0.414, -0.051], p = .012; Fig. 4A). Recognition was poorer for invalidly cued items compared to the validly cued items (β = 0.266, SE = 0.131, 95% CI = [0.01, 0.522], p = .042). The interaction term for Cue-validity and Reward was not a significant predictor of subsequent recognition performance (β = 0.199, SE = 0.131, 95% CI = [-0.057, 0.455], p = .12). The inclusion of pre-target pupil diameter as a predictor did not result in a better model fit (χ^2 = 0.013, p = .90), suggesting that pupil diameter was not associated with subsequent recognition performance.

As the above analysis does not consider responses to foils (New items), additional analyses were conducted on a non-parametric signal detection measure (A'). Memory

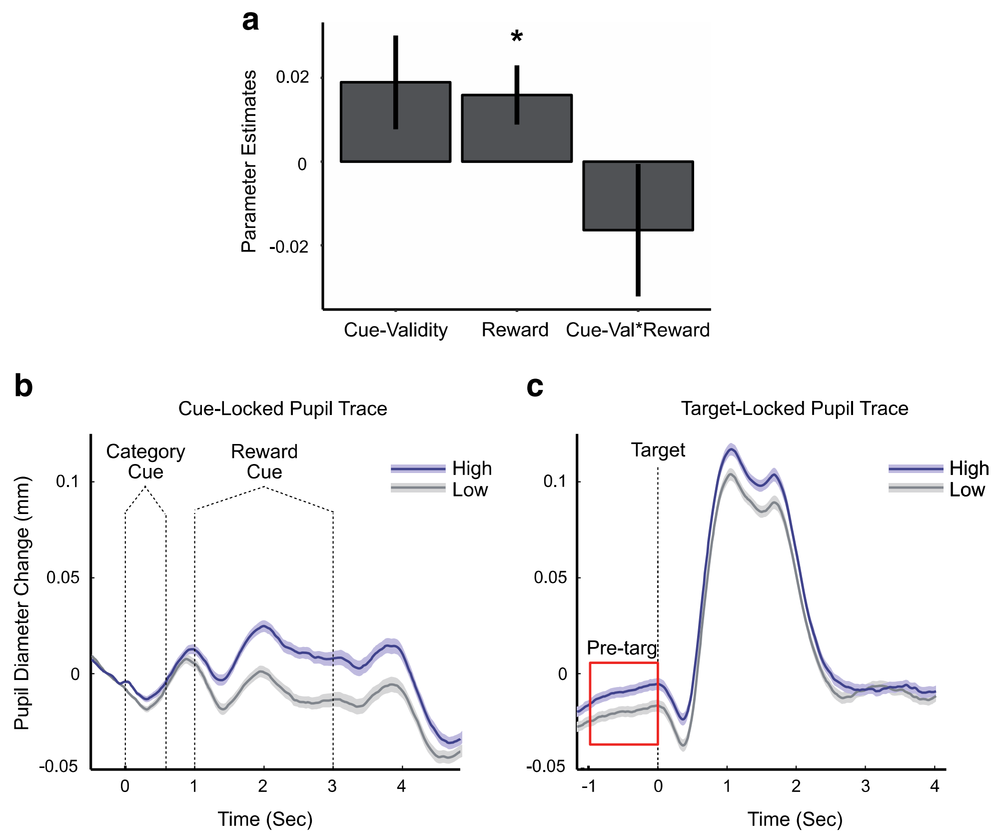

Fig. 3 Reward expectation and pupil diameter. (**A**) Parameter estimates from the model showed a significant effect of Reward where Pre-target pupil diameter was larger for high reward than for low reward. (**B**) Cue-locked and (**C**) Target-locked pupil trace. Pupil diameter was larger following the high-reward cue, and remained so across the preparatory period (pre-target). Error bar represents the SEM. * $p < .05$

performance was significantly greater than chance on all conditions (High reward-Valid: $t(29) = 12.73$, $p < .001$, mean = .66, 95% CI = [.64 .69], $d = 2.36$; Low reward-Valid: $t(29) = 16.46$, $p < .001$, mean = .67, 95% CI = [.65 .69], $d = 3.06$; High reward-Invalid: $t(29) = 9.28$, $p < .001$, mean = .65, 95% CI = [.61 .68], $d = 1.72$; Low reward-Invalid: $t(29) = 5.95$, $p < .001$, mean = .62, 95% CI = [.58 .66], $d = 1.10$). Consistent with results from the mixed model, we observed a significant main effect of Cue-validity ($F(1,29) = 6.1$, $p = .019$, $\eta_p^2 = 0.17$), with no significant main effect ($F(1,29) = 0.48$, $p = .49$, $\eta_p^2 = 0.01$) or interaction ($F(1,29) = 2.19$, $p = .15$, $\eta_p^2 = 0.07$) of Reward. Planned comparison of the Memory-cost ($A'_{valid} - A'_{invalid}$) showed that invalid cueing was associated with poorer memory in the low-reward condition ($t(29) = 2.76$, $p = .01$, mean difference = 0.05, 95% CI = [.01, .09], $d = 0.58$), but not in the high-reward condition ($t(29) = 0.89$, $p = .40$, mean difference = 0.01, 95% CI = [-02, .05], $d = 0.17$) (Fig. 4C). A direct test of the memory-cost associated with invalid cueing (between the two reward conditions) did not reach statistical significance ($t(29) = 1.48$, $p = .15$, mean difference = 0.03, 95% CI = [-.01, .08], $d = 0.28$). Memory performance for each of the conditions is shown in Fig. 4B and Fig. S1.

Discussion

We tested two predictions on how reward could modulate attentional orienting by semantic cueing. Our findings indicate that anticipating a higher reward can increase preparatory engagement, evidenced by the larger pupil diameter, but higher reward can also reduce the reorienting cost to invalid semantic cues. This suggests that reward can promote attentional flexibility in order to benefit the processing of cue-incongruent information.

Semantic cueing supports preparatory control of attention

The presentation of informative cues can enhance task performance by supporting the preparatory engagement of control processes and the allocation of limited attentional resources (Kastner, De Weerd, Desimone, & Ungerleider, 1998; Kastner, Pinsk, De Weerd, Desimone, & Ungerleider, 1999; Posner, 1980). This orienting of attention biases the selection of information, facilitating the processing of stimulus that is consistent with expectations (Soon, Namburi, & Chee, 2013; Stokes, Thompson, Nobre, & Duncan, 2009). In category-based attention, this facilitation is thought to occur through

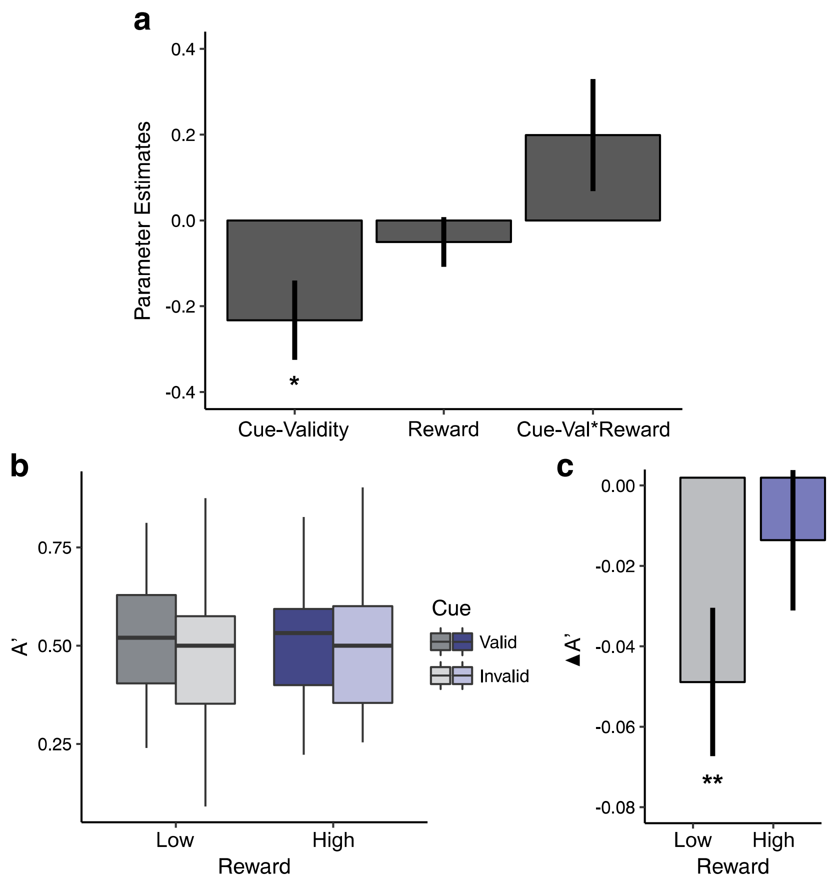

Fig. 4 Memory-cost associated with invalid category cueing. (**A**) Parameter estimates from the model showed a significant effect of Cue-validity where memory was better for items following valid- than invalid-category cues. Error bar represents the standard error. (**B**) Box and whiskers plot of memory performance (A'). Upper and lower hinges correspond to the first and third quartiles, and the whiskers correspond to the largest and smallest values within 1.5 times of the interquartile range. (**C**) Comparison of memory-cost associated with invalid category cueing across reward conditions. Invalid-category cue was associated with poorer subsequent memory in the low-reward but not in the high-reward condition. Direct comparison between the two reward conditions did not reach statistical significance. Error bar represents the SEM. * $p < .05$; ** $p < .01$

the preparatory activation of a categorical template, allowing for efficient processing of stimulus congruent with the activated template (Desimone & Duncan, 1995; Peelen & Kastner, 2014). Target-detection paradigms indicate that category-cueing can support faster detection of objects from the relevant category (Cristescu et al., 2006; Cristescu & Nobre, 2008), and can even raise suppressed objects to perceptual awareness (Lupyan & Ward, 2013). Here, we were able to probe immediate stimulus processing by evaluating semantic judgment and downstream benefits on memory encoding by evaluating subsequent memory.

Preparatory orienting to semantic information influences subsequent memory

Attention during encoding can influence subsequent memory, and prior work using spatial cueing has shown that a stimulus appearing in a validly cued location is better remembered than one appearing in an invalidly cued location (Turk-Browne et al., 2013; Uncapher et al., 2011). However, in these studies, impaired memory performance could have arisen from the brevity of target exposure duration, resulting in failure to sufficiently process or perceive the target. Here, we used target images that were presented foveally for an extended period to ensure that even when cueing was invalid, a target stimulus could be sufficiently processed to allow accurate category judgment. Our findings indicate that engagement of preparatory attention can facilitate and enhance the encoding of an expected stimulus, contributing to better subsequent memory.

Reward motivation enhances attentional preparation and improves flexibility

The extent of preparatory engagement can be modulated by the value of potential outcomes, with higher valuation leading to greater preparatory control (Chiew & Braver, 2013; Massar, Lim, Sasmita, & Chee, 2016; Sawaki, Luck, & Raymond, 2015). Higher reward was associated with faster responses on the invalid-cue trials, signifying a reduction in reorientation cost. While it might be expected that a greater utilization of cue information would result in greater reorienting cost, the converse was observed, suggesting that reward can also facilitate the flexible reorientation of attention to unexpected information. Prior work using spatial cueing has demonstrated similar reorientation benefits (Bucker & Theeuwes, 2014; Engelmann & Pessoa, 2007), and task-switching paradigms have also shown reduced switching costs (Savine, Beck, Edwards, Chiew, & Braver, 2010; Shen & Chun, 2011). Our results extend these findings to the semantic domain, adding support to the notion that reward can increase attentional flexibility.

High-reward trials were also characterized by larger pupil diameter. Larger pupil diameter has been associated with increased arousal (Bradley, Miccoli, Escrig, & Lang, 2008; Sturgeon, Cooper, & Howell, 1989), greater effort allocation (Kahneman & Beatty, 1966), and increased cognitive control (van der Wel & van Steenbergen, 2018). While our observation of larger pupil diameter on high-reward trials is consistent with the notion of enhanced preparatory control, it is likely that pupil diameter reflects a combination of both functional top-down control and an increase in non-specific arousal. The fact that pre-target pupil diameter was predictive of trial-by-trial semantic judgment performance, however, does provide partial support for the account that larger pupil diameter is related to increased preparatory attention.

While reward also appeared to reduce the impact of reorienting on memory, the reduction was relatively modest compared to its effect on task performance. Given the absence of a significant interaction, we interpret this finding with caution, and only in light of the robust observation of reduced RT-cost during semantic judgment. A possible explanation might be lowered specificity of reward-related enhancement with respect to task demands. As reward outcome was dependent on semantic judgment performance, category information processing may have been emphasized over detailed exemplar information. Alternatively, the demand for a speeded response on high-reward trials could have resulted in less elaborative processing, particularly when the semantic cue was invalid. Further studies varying task-demand would be needed to better address this possibility.

In addition, while we expected that memory may also be enhanced for items in the high-reward condition, we did not observe a clear effect of reward on subsequent memory performance. Existing theoretical framework posits that reward-related memory benefits occur through the dopaminergic modulation of memory consolidation processes (Chiew, Stanek, & Adcock, 2016; Lisman, Grace, & Duzel, 2011; Shohamy & Adcock, 2010). Consistent with this account, reward-related memory benefits are most commonly observed in studies using delayed testing (e.g., 24 h) (Adcock, Thangavel, Whitfield-Gabrieli, Knutson, & Gabrieli, 2006; Murty, Tompary, Adcock, & Davachi, 2017; Wittmann et al., 2005). While immediate memory benefits have also been observed (Gruber, Ritchey, Wang, Doss, & Ranganath, 2016; Gruber, Watrous, Ekstrom, Ranganath, & Otten, 2013; Murty & Adcock, 2014), studies explicitly comparing across delay intervals have often observed memory benefits for delayed testing but not for immediate testing, suggesting that reward enhancement of memory may be more strongly dependent on consolidation processes (Murayama & Kitagami, 2014; Patil, Murty, Dunsmoor, Phelps, & Davachi, 2017; Stanek, Dickerson, Chiew, Clement, & Adcock, 2018; Wittmann et al., 2005).

Conclusion

The current findings demonstrate that preparatory attention for category information can enhance the processing of stimulus from the expected category, supporting faster semantic judgment and also better subsequent memory. The expectation of higher reward is associated with enhanced attentional flexibility and reduced reorienting cost.

Materials for this experiment are available upon request. Data and program code used for the analysis are available at: https://osf.io/wfgcy/

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