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Research Report

Neural evidence reveals the rapid effects of reward history on selective attention

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ABSTRACT

Selective attention is often framed as being primarily driven by two factors: task-relevance and physical salience. However, factors like selection and reward history, which are neither currently task-relevant nor physically salient, can reliably and persistently influence visual selective attention. The current study investigated the nature of the persistent effects of irrelevant, physically non-salient, reward-associated features. These features affected one of the earliest reliable neural indicators of visual selective attention in humans, the P1 event-related potential, measured one week after the reward associations were learned. However, the effects of reward history were moderated by current task demands. The modulation of visually evoked activity supports the hypothesis that reward history influences the innate salience of reward associated features, such that even when no longer relevant, nor physically salient, these features have a rapid, persistent, and robust effect on early visual selective attention.

1. Introduction

Goal directed behavior requires the selection of task-relevant information. Efficient selection is subject to interference from competing task-irrelevant information, especially when physically salient (e.g., Corbetta et al., 2008; Desimone and Duncan, 1995; Petersen and Posner, 2012). Competition can also come from information that is neither task-relevant nor physically salient, including information previously selected or associated with reward (Anderson, 2013; Awh et al., 2012). Reward-associations can impair performance on a visual search task (Anderson et al., 2011) and can both impair and improve performance in the same task (Hickey et al., 2010). For instance, after a color-reward association is learned, the presence of that task-irrelevant color as a distracter in a subsequent task can increase reaction times (RT) to identify a target shape (Anderson et al., 2011). Thus, historically reward-associated information drives attention even though the information is not physically salient or task relevant.

The nature of reward history's influence on selective attention is unclear. According to several models, reward history is unlikely to impact selective attention at early stages of processing (e.g., Theeuwes, 1993; Lavie, 2005). Yet evidence from scalp-recorded ERPs indicates that the visual P1, one of the earliest neural responses generated in extrastriate visual cortex (Heinze et al., 1994) that is consistently influenced by selective spatial attention (Hopf and Mangun, 2000), is modulated during reward learning (Hickey et al., 2010). However,

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because this modulation of the P1 was observed in a task in which participants could still receive a reward (i.e., participants were still engaged in reward-learning), it is unclear whether this reward-learning effect is similarly responsible for the persistent effects of reward history on performance beyond reward learning when there is no prospect for explicit rewards. Furthermore, both the reward-associated and target-defining features used by Hickey et al. were physically salient singletons (color and shape respectively). Thus it is also unclear whether the P1 modulations that Hickey et al. observed would be replicated in a task using physically non-salient reward-associated and target-defining features. This issue is especially relevant given that early spatial selection processes, such as those indexed by the P1, are sensitive to physically salient stimuli (Luck and Hillyard, 1994).

The effect of reward history can be observed even when performance is no longer rewarded and the irrelevant reward-associated feature is neither task-relevant nor physically salient (Anderson et al., 2011). This persistent effect is observed months after reward learning (Anderson and Yantis, 2013). There is evidence of a neural correlate of the effect of reward history in extrastriate visual cortex (Anderson et al., 2014). However, the time-course of this effect is unknown. It is possible, that the preferential response of extrastriate visual cortex to previously reward-associated features is due to relatively slow re-entrant processes. In contrast, reward history may also rapidly affect selection, which would potentially indicate an effect of reward history on the innate salience of information.

A recent study failed to show any P1 effects of reward associated features that were neither physically salient or task relevant in a visual search task (Qi et al., 2013). Instead such features affected a later target selection related component, the N2pc. This suggests that the influence of reward history is early, but not as early as the P1 and thus may not influence non-reentrant attentional selection in the extrastriate cortex. However, it is possible that the task used by Qi et al. did not place sufficient demand on early spatial selectivity so as to observe P1 effects. Qi et al. used response-terminated displays, as opposed to brief, data-limited displays. A data-limited design, such as the one used in the current study, emphasizes early selection as performance ultimately depends on the information that is selected during the brief display. In contrast, a response-terminated display reduces the need for early spatial selection and increases the role for target selection processes such as reflected by the N2pc.

Furthermore, in the task used by Qi et al. there was only a single physically salient target and thus less demand for selectivity prior to encoding and an emphasis on single target selection. In contrast the task used in the current study contained three physically non-salient targets. In this case, early selection was essential to preventing encoding of non-target information as the number of targets to be encoded required greater working memory capacity. Thus, it could be that only when optimal performance relies heavily on early selection will irrelevant selection/reward history influence early visual selection and the P1. This may explain why Qi et al. did not observe P1 effects. In the current study brief, data-limited displays containing multiple, physically non-salient targets were used to emphasize the demands on early selection.

Here we investigate whether the persistent effects of reward history on performance are due to a rapid influence on early visual selection. We measured the effect of irrelevant reward history on performance and used the P1 ERP as a neural measure of early visual processing in a task where performance is no longer rewarded and the reward-associated feature is neither physically salient nor task-relevant. To examine the persistent effects of reward history we measured the behavioral and electrophysiological effects one week after the feature-reward associations were learned. If reward history influences P1 amplitude under these conditions this would represent strong evidence for the role of reward history in visual selective attention via persistent changes in the innate salience of reward-associated information.

2. Results

2.1. *Reward association training task*

2.1.1. *Response time*

A mixed-model ANOVA was used to examine RT on correct trials as a function of the within-subjects factor of reward size (high or low) and the between-subjects factor of reward group (whether red, $n=7$, or blue, $n=8$ was the high reward color). There was a significant main effect of reward size (F (1,13)=12.84, $p=.003$, $\eta^2=.49$, 95% CI [−20.49 to −5.08]), such that RTs were faster on high reward ($M=427$ ms, $SE=14$ ms) than low reward trials ($M=439$ ms, $SE=14$ ms). There was no significant main effect of or interactions with reward group (all p's>.250).

2.1.2. *Accuracy*

A similar mixed-model ANOVA was used to examine accuracy. The main effect of reward size was also significant for accuracy (F (1,13)=7.41, $p=.017$, $\eta^2=.36$, 95% CI [.01–.07]), such that accuracy was higher on high reward ($M=62.8\%$, $SE=2$) than low reward trials ($M=59.1\%$, $SE=2.2$). Although there was no significant main effect of reward group ($p>.250$), there was a significant interaction of reward size and reward group (F (1,13)=5.36, $p=.038$, $\eta^2=.29$), such that the effect of reward size on accuracy was significant for the group where blue was the high reward color (t (7)=10.59, $p=.014$) but not for the group where red was the high reward color ($p>.250$).

2.2. *Attention Task*

2.2.1. *Reward history*

Accuracy was significantly above chance in all experimental conditions and on neutral baseline trials (all p's<.001; see Table 1). Target accuracy on trials when a reward-associated color was present (probe target, other target, distracter, flanker) was compared to target accuracy on the neutral baseline trials, where no reward-associated color was present. Corrections for multiple comparisons were applied using false discovery rate (FDR) assuming dependence and p-values are adjusted for FDR (q).

When the irrelevant color previously associated with the high reward was present, accuracy was significantly higher

Table 1 – Mean proportion correct in the Attention Task.

	High reward	Low reward
Probed target	.82	.76
Other target	.69	.71
Distracter	.71	.71
Flanker	.71	.73
Neutral	.75	

Note: SEM=.02 for all conditions.

on probed target trials (i.e. a benefit; $t\ (14)=3.44$, $q=.017$, 95% CI [.03–.12]) and significantly worse on other target ($t\ (14)=3.62$, $q=.017$, 95% CI [−.09 to −.02]) and distracter trials (i.e. costs; $t\ (14)=2.94$, $q=.03$, 95% CI [−.07 to −.01]), but not significantly worse on flanker trials ($t\ (14)=2.52$, $q=.051$, 95% CI [−.07 to −.005]). When the irrelevant color previously associated with a low reward was present there were no significant differences in accuracy (all p's$>.097$). These results indicate that reward history, and not only selection history, influenced performance as there were significant effects for the high magnitude reward association but not for the low magnitude reward association.

2.2.2. *Task relevance X reward history*

We also investigated whether the costs associated with reward history decrease as task relevance decreases: other target>distracter>flanker. The cost of reward history was computed as a difference measure by subtracting accuracy on the neutral baseline trials from accuracy on the other target, distracter and flanker trials. Mean baseline subtracted accuracy is shown in Fig. 2. These data were analyzed in a mixed-model repeated-measures ANOVA as a function of the within-subjects factors of task relevance (other target, distracter, or flanker), size of irrelevant reward association (high or low) and the between-subjects factor of reward group. As hypothesized, the main effect of task relevance was significant ($F\ (2,28)=4.14\ p=.027$, $\eta^2=.23$) such that costs were largest for the other target condition, smaller for the distracter condition, and smallest for the flanker conditions (Fig. 2). No other main effects or interactions were significant (all p's$>.110$, η^2's$<.18$). Post-hoc paired comparisons revealed that the effect of reward history was significantly larger in the other target ($M_D=2$, $SEM_D=.8$; $p=.018$) condition than in the flanker condition, however no other comparisons were significant (p's$>.07$). This indicates that the effect of reward history was significantly larger when the reward-associated feature surrounded a target in a task-relevant location than in a task-irrelevant, flanker, location.

2.2.3. *P1 amplitude*

Mean P1 amplitude measured during the Attention Task was analyzed in a mixed-model ANOVA with task relevance (target, distracter, or flanker), size of reward association (high or low), and laterality (contra- or ipsi-lateral) as within-subject factors and reward group as a between-subjects factor. There was a significant main effect of laterality ($F\ (1,13)=77.89$, $p<.001$, $\eta^2=.86$, 95% CI [.41–.68]), where P1 amplitude was larger when measured at electrode sites contralateral to the reward-associated feature than when measured at ipsilateral sites (see Fig. 4). There were no other significant main effects. There was a significant interaction between electrode laterality and size of reward association ($F\ (1,13)=7.65$, $p=.016$, $\eta^2=.37$), where the difference between contralateral and ipsilateral electrodes sites was larger for high reward associated features ($M_D=.63$, 95% CI [.46–.80]) than low reward associated features ($M_D=.47$, 95% CI [.34–.59]). Finally, there was a significant three-way interaction between task relevance, size of reward association, and electrode laterality ($F\ (2,26)=8.99$, $p=.001$, $\eta^2=.41$), such that the interaction between reward association size and electrode laterality was significant for probed and other target trials (i.e. when a letter was presented inside reward associated colored circle; $F\ (1,13)=35.59$, $p<.001$, $\eta^2=.73$), but not for other trial types (i.e. when a number or flanker was presented inside reward associated colored circle; all p's$>.250$). The interaction was such that the P1 amplitude laterality effect (contra- vs. ipsilateral) was greater for features associated with the larger reward ($M_D=.69$, $SEM_D=.09$) than those with associated with the smaller reward ($M=.18$, $SEM_D=.06$). There were no other significant interactions nor any significant main effects of or interactions with reward group (all p's$>.06$).

2.2.4. *Post-hoc P1 amplitude analyses*

We observed that the P1 laterality effect was greater for high than low reward associated features in the target condition, this difference could be due to changes in the P1 amplitude at either contralateral, ipsilateral, or both electrode sites. In order to further investigate the two-way interaction of reward association size and electrode laterality in the target condition we performed two paired t-tests comparing high and low reward association size within each electrode laterality seperately. At contralateral electrodes there was no significant difference in P1 amplitude between high and low reward association conditions ($t\ (14)=1.99$, $p=.066$). However, at ipsilateral electrodes P1 amplitude was significantly lower in the high reward ($M=5.22$, $SEM=.72$) than in the low reward ($M=5.53$, $SEM=.73$) association conditions ($t\ (14)=2.57$, $p=.022$). Thus, the larger P1 amplitude laterality effect in the high as compared to the low reward association condition (target only) was primarily due to difference in P1 amplitude at electrode sites ipsilateral to the reward associated feature. The P1 at electrode sites contralateral to the reward associated feature did not differ according to reward association size.

2.2.5. *Correlations between P1 mean amplitude and behavior*

There was a significant positive correlation between the P1 laterality effect (contralateral P1–ipsilateral P1) in the target condition and the performance benefit observed in the probed target conditions ($r\ (15)=.69$, $p=.004$, 95% CI [.27–.89], Fig. 5), but not the cost observed for the other target condition ($r\ (15)=.28$, $p>.250$, 95% CI [−.27 to .69]). Individuals with larger P1 amplitude laterality effects to targets exhibited larger benefits to performance from reward-associated features, but not larger costs. No significant relationships between P1 amplitude laterality effects and performance costs in the distracter or flanker conditions were observed (all p's$>.176$).

2.2.6. P1 latency

P1 peak latency was measured as the time of the most positive peak between 75 and 200 ms after the onset of the stimulus array within each experimental condition (target, distracter, flanker X high vs. low). P1 latency was then submitted to a similar ANOVA as amplitude, however there were no significant main effects or interactions with P1 latency (all p's$>$.201).

3. Discussion

The results of this study provide both behavioral and neural evidence that reward history that is neither physically salient nor task-relevant persistently and rapidly influences selective attention at early stages of visual processing, even when there is no possibility for reward. Target performance on a task, which emphasized early perceptual selection processes using brief masked displays, was affected by the presence of a physically non-salient, irrelevant, previously reward-associated feature, resulting in both benefits and costs to performance relative to baseline. Even more compelling evidence was that one week after reward learning the P1 ERP was larger contra- than ipsilaterally to the reward-associated feature, indicating that the reward associated feature was spatially selected within ~100 ms of the presentation of stimuli. The size of the P1 amplitude spatial effect (contralateral>ipsilateral) was larger for features formerly associated with a high reward than those with a low reward, indicating that the reward association itself, and not simply the selection history of the feature, influenced early visual selection. However, this effect was only observed when the reward-associated feature directed attention towards a target inside task relevant space, indicating that task relevance modulates the effect of irrelevant reward associations on early visual processing as reflected by the P1. The results of the current study indicate that physically non-salient and task-irrelevant selection history, specifically features that were formerly targets, reliably influences early visual processing, but that reward history only influenced early visual selection when attention was directed towards a target. Furthermore, the fact that we observed P1 effects of both selection history and reward history (although limited) in a task that emphasized early selection while Qi et al. (2013) did not, suggests that the extent to which selection or reward history influences the earliest visual non-reentrant selection processes may be task dependent. The results of the current study strongly indicate that physical salience is not required to observe the effects of reward history on early visual selection because neither the reward-associated feature nor the target-defining feature were physically salient.

In the current study, the modulation of P1 amplitude was observed when the reward-associated feature directed attention to a distracter item and an item in a task-irrelevant location (flanker), but was not modulated by reward magnitude. This indicates that more likely selection history, i.e. that the reward associated features were previously target features in the training task, but not reward history are responsible for the P1 effects in the distracter and flanker conditions. However, when a former target feature directs attention to a target, i.e. a task relevant item, then reward history influenced the magnitude of the capture effect on early visual processing. In other words, while selection history generally effects subsequent selection processes, it is only when a formerly selected feature directs attention towards a task-relevant item (in this case a target letter) that reward history plays a role in early selective processes. This finding, that the influence of reward history on early visual selection is modulated by current task demands, is consistent with the findings that while target features on a task-irrelevant probe were associated with early (although later than the P1, ~>200 ms) enhancements in extrastriate cortex activity, reward related activity did not (Buschschulte et al., 2014).

On the surface, the present results stand in contrast to the previous finding that reward history (i.e., magnitude of former reward association) influenced whether the P1 was larger contralateral to a distracter with a reward-associated feature (Hickey et al., 2010). However, in that case it is important to note that both the reward associated feature and the task-relevant feature were singletons (color and shape respectively). In other words, the reward-associated feature, itself a singleton, was congruent with the target-defining feature in the singleton search. Thus, the reward-associated feature was itself not entirely task-irrelevant and this task-relevance may have contributed to the P1 effects. Furthermore, the reward-associated feature was also physically salient. This may indicate that reward history influences the P1 regardless of task relevance when the reward-associated feature is physically salient.

In the current study the effect of reward magnitude in the target condition was specifically observed at ipsilateral sites, such that the P1 at ipsilateral sites was significantly smaller when the feature directing attention towards a target was formerly associated with the larger magnitude of reward, resulting in a larger P1 amplitude spatial effect for high as compared to low magnitude reward-associated features. This suggests that when the feature is associated with a high magnitude of reward there is greater suppression of visual processing of information in location other than where the reward-associated feature appears. This suggests that reward history influences the selectivity of early visual processing by increasing suppression of non-reward related information, rather than enhancing the processing of the reward associated information. This is consistent, for example, with evidence that reward history alters the selectivity of tuning functions for reward-associated feature, increasing selectivity rather than amplitude (Serences and Saproo, 2010).

These results support recent models of attention in which task irrelevant information, including reward-associations, selection history, and context, while physically non-salient, can nonetheless represent a driving factor in visual selection (Anderson, 2013; Awh et al., 2012). However, reward history's effect was moderated by task relevance. Furthermore, the contrast of the current results with those previously observed (specifically Qi et al., 2013 and Hickey et al., 2010 respectively) suggest that the time course of reward history's influence on attention may be task dependent and whether task relevance moderates the effect of reward history on the P1 may depend on whether the reward-associated feature is also physically salient.

We also observed that the size of the P1 effect was correlated with the size of performance benefit conferred by the irrelevant, previously reward associated feature on probed target trials. This result indicates that the influence of irrelevant previously reward associated features on early selective attention explains a significant portion of the observed performance benefit across individuals. However, a similar relationship was not observed for performance costs. It is possible that additional post-perceptual processes may mitigate the costly effects of the influence of irrelevant previously reward associated features on early visual selective attention, which may also explain why the size of the performance benefits were larger than the costs. For example, subjects may be able to sometimes reject reward-associated distracters that initially capture attention, depending on factors such as the perceptual or cognitive load they experience on a given trial (Lavie and Cox, 1997; Kyllingsbæk et al., 2011; Lavie et al., 2004).

Extensive study of the limitations of information processing has focused on the need for selective attention in order to select relevant information from amongst irrelevant information, and defined relevance according to current tasks or goals ("top-down"), while physical salience ("bottom-up") has been the primary factor beyond relevance considered to influence selective attention (e.g. Desimone and Duncan, 1995; Kastner and Ungerleider, 2000; Itti and Koch, 2001; Serences and Yantis, 2007; Theeuwes, 2010). The results of the present experiment indicate that information that is neither relevant to current tasks or goals, nor physically salient, influences selective attention, even under conditions where the selection of task relevant information is critical for optimal performance, and the influence of salience is diminished.

4. Experimental procedure

4.1. *Participants*

Fifteen undergraduates volunteered for this study (Mean age = 19 years old; 10 females). Participants received 1 credit/hour (4 credits total) for participating. All procedures conformed to a protocol approved by the University of California Santa Barbara Human Subjects Committee.

4.2. *Reward association training task*

4.2.1. *Stimuli*

The stimuli were six differently colored rings (.63° diameter) presented on the top half of the arc of an imaginary circle (radius = 1.86° from the center of the screen to the center of each circle) and equidistant from each other (.95° center-to-center). The colors of the rings were red (RGB: 206,0,0), blue (0,0,250), orange (197,98,0), teal (0,118,118), brown (169,85,0), green (0,141,0), gold (118,118,0), violet (128,0,192), and gray (110,110,110). A white (255,255,255) line segment (.38° long, .05° thick) was presented centered inside each colored ring and the orientation of each segment was oblique (45°, left or right), horizontal, or vertical.

4.2.2. *Procedure*

Each trial began with a white fixation cross (.26° width/height) presented in the center of the display. The duration of the fixation cross varied randomly from 400 to 600 milliseconds (ms). The stimulus display followed the fixation cross and was presented for 600 ms. The stimulus display (Fig. 1) consisted one target ring and five distracter rings. The target ring was red on half of trials and blue on the other half of trials. The color of each distracter ring was drawn randomly without replacement on each trial from the remaining colors (orange, teal, brown, green, gold, violet, and gray). The location of the target ring was determined randomly without replacement from the six possible locations on each trial.

The line segment within the target ring was horizontal on half of trials and vertical on the other half of trials. The line segments within the distracter rings were tilted 45° either to the left or right. Participants were instructed to press 'z' on a keyboard if the line segment within the target ring was vertical and 'm' if it was horizontal. The participants were instructed to make this response "as quickly as possible while still being accurate". Once a response was made, a feedback display was then presented for 1500 ms. The feedback display indicated the amount of money won on that trial in the center of the screen with the total accumulated presented

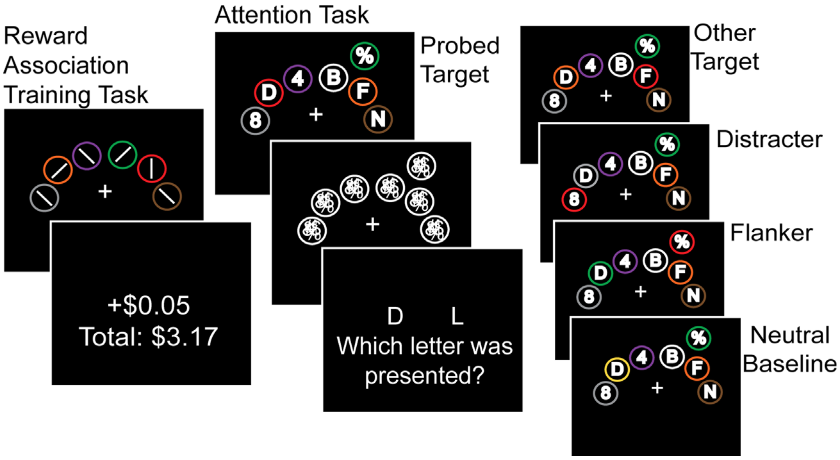

Fig. 1 – Examples of trials from Reward Training and Attention Tasks, where red is associated with a high reward. Examples of each of the task-relevance conditions, and the neutral baseline condition. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

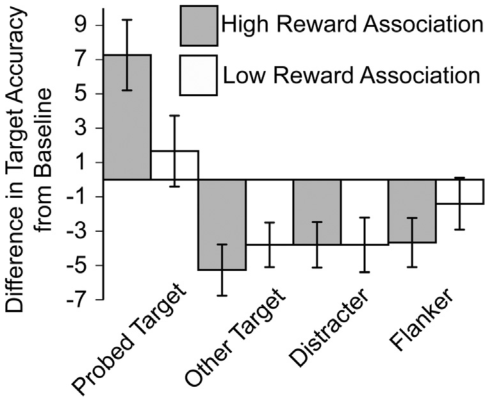

Fig. 2 – Behavioral results from the Attention Task, depicted as percent difference in target accuracy in each experimental condition from the neutral baseline condition.

below that. Participants could only receive a reward on correct trials although they were not informed of this. On high reward trials participants could win $.05, and 80% of high reward trials had the potential to be rewarded. On low reward trials participants could win $.01, and 20% of low reward trials had the potential to be rewarded. The target color (red or blue) associated with the high reward was counter-balanced across participants. Reward group refers to whether red or blue was the high reward-associated color for that participant. Participants were instructed that they had the chance to win money on each trial and that they would be paid the total amount they accrued over the course of the experiment.

The Training Task began with 20 practice trials which were not rewarded, followed by 10 blocks of 80 trials, consisting of 400 high reward trials and 400 low reward trials. High and low reward trials were mixed randomly and were distributed evenly within each block.

Percent accuracy and reaction times on correct trials (RT) were measured relative to the onset of the stimulus display for high and low reward trials separately.

4.3. *Attention Task*

4.3.1. *Stimuli*

The six colored rings used in the Training Task were also used in the Attention Task. An additional flanker ring was presented above the task array to the left on half of trials and to the right on the other half of trials. Because the flanker creates an unbalanced display, the congruency of the location of the flanker and the location of the reward-associated feature were fully crossed. For half of trials the flanker appeared in the same hemifield as the reward-associated feature, and for the other half it appeared in the opposite hemifield. Importantly, none of the P1 analyses reported here differed when flanker location (same or opposite hemifield) was included as a factor, nor were there any main effects or interactions with the factor of flanker location (all p's > .09). The flanker appeared 2.87° center-to-center from the fixation cross and 1.02° center-to-center from the nearest task array ring. In the six circles presented equidistant from fixation, three contained letters (.26° width, .31° height) drawn randomly on each trial (excluding B, C, D, G, I, O, Q, S, and Z due to their similarities with certain numbers). The remaining three contained numbers (.26° width, .31° height) drawn randomly on each trial from among numbers 1–9. A letter, number or symbol (%, #, &, or @) was presented in the flanker ring. Masks were all those symbols presented in white (255,255,255) on top of each other, creating a pattern mask inside each of the rings.

4.3.2. *Procedure*

Each trial began with a white fixation cross presented in the center of the display. The fixation was displayed until the participant pressed the spacebar to show the stimulus display. The participant was instructed to wait until they were fixated on the fixation cross before initiating the stimulus display and to maintain fixation on the fixation cross whenever it was displayed. The stimulus display followed the fixation cross and was presented for 232 ms, each stimulus was then masked for 250 ms, and then the response display was presented until response. The response display consisted of two letters: the probed target and a lure letter. The probed target was one of the letters presented in the task array, the lure was a letter not presented in the stimulus display. Participants were instructed to indicate which of those letters was presented in the task array. They were instructed to try and be as accurate as possible and to make their “best guess” if they were unsure. Each trial was separated by a 500 ms inter-trial interval. An example of the stimulus display is shown in Fig. 1.

Participants were instructed to pay attention to the letters (targets/task-relevant) and ignore the numbers (distracters/task-irrelevant). They were also told that the color of the rings was irrelevant to the task and to be ignored, as was the flanker.

The Attention Task began with 5 practice trials, followed by 18 blocks of 102 trials: 1728 reward-associated trials, 108 neutral trials. Reward-associated trials were trials where one of the rings was blue or red. Half of reward-associated trials were high association trials, where the high reward color was present, the other half were low association trials. Neutral trials were trials where neither reward-associated color was present. Note that there were no rewards in the Attention Task. The reward-association refers to the learned association from the Training Task, but is irrelevant to the Attention Task.

4.3.3. *Design*

Four conditions in the Attention Task determined which kind of object, distinguished by task-relevance, was presented inside of the reward-associated colored ring (see Fig. 1): probed target, other target, distracter, or flanker. On probed target and other target trials a task-relevant object (a letter) was presented in a task-relevant location (in the task array) inside the reward-associated (red or blue) ring. On distracter trials one of the task-irrelevant objects (a number) was presented in a task-relevant location inside the reward-associated ring. On flanker trials a task-relevant (letter), irrelevant (number), or neutral (symbol) object was presented in a task-irrelevant location (outside of the task array) inside the reward-associated ring. The factorial combination of object type and reward association size (high or low) yielded eight conditions. There were 100 trials of each experimental condition, 10 trials/block, inter-mixed randomly within each block.

4.4. *Procedure*

Participants completed the Reward Association Training and the Attention Task in two separate sessions, exactly one week apart. Before completing the experiment participants were not informed prior to training that they could win money as part of the experiment.

4.5. *Apparatus*

Both the Training and Attention Tasks were run using custom scripts using Matlab R2013a installed on a Mac Mini running OSX, and presented on CRT monitors (36 cm × 27 cm) with a resolution of 1280 × 1024 and a refresh rate of 60 Hz. All stimuli were viewed from a distance of 110 cm and presented on a black (RGB: 0,0,0) background.

4.6. *EEG/ERP acquisition and analysis*

EEG activity was recorded inside an 8' × 10' electromagnetic field shielded chamber (ETS-Lindgren, Cedar Park, TX). Data were sampled at 512 Hz using 64 Ag/AgCl sintered BioSemi active electrodes placed according the International 10/20 System on the scalp and referenced offline to left and right mastoid electrodes. EEG data were acquired using BioSemi's ActiView software and analyzed using custom Matlab scripts. The continuous EEG data were segmented into epochs from 100 ms before the onset of the stimulus display (in the Attention Task)

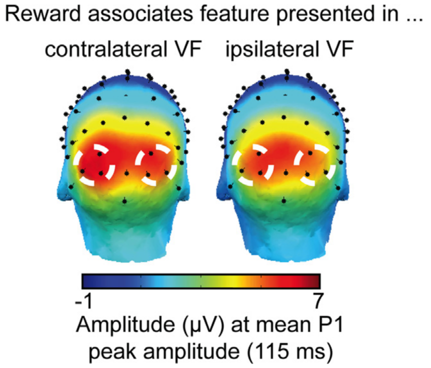

Fig. 4 – Topography at mean P1 peak latency from occipital view. Electrodes included in P1 amplitude measurements are represented inside the white dashed circles.

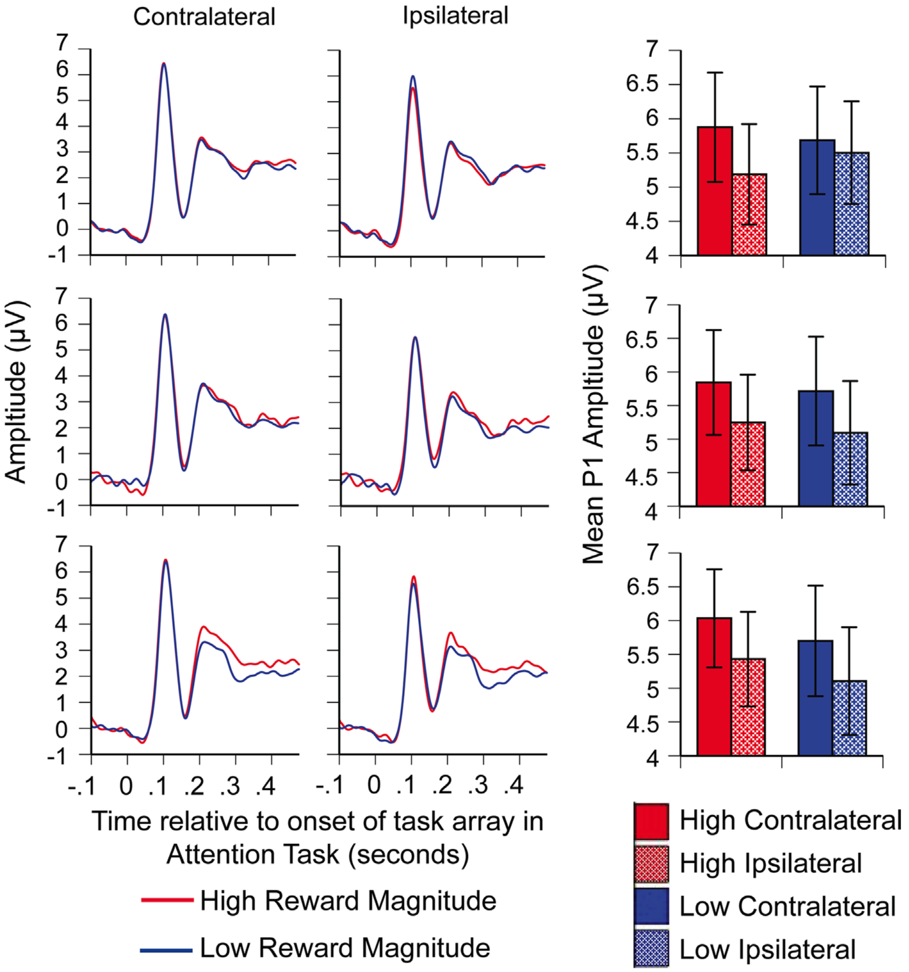

Fig. 3 – P1 waveforms and mean P1 amplitudes for each condition (target/distracter/flanker X high/low) and electrode laterality (contralateral vs. ipsilateral). Note that positive potentials are plotted up.

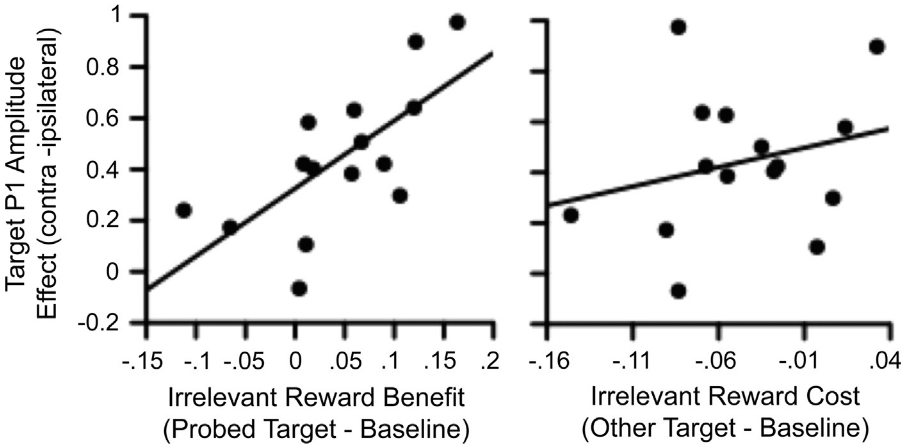

Fig. 5 – Scatterplots of correlation between P1 laterality effect and performance benefits and costs of reward history in the probed target and other target conditions respectively.

to 475 ms after. Epochs were baseline corrected to the 100 ms pre-stimulus baseline. The data were then filtered using the default EEGLAB v.13 filter (pop_eegfiltnew), a zero-phase, sinc FIR filter using a Hamming window (firfilt; Widmann, 2006), with a high-pass of .1 Hz a low-pass of 30 Hz (i.e., bandpass) and the default filter order (i.e., 2 Hz transition bandwidth). Blinks and other eye-movement related artifacts were removed using a recursive least squares regression (Gomez-Herrero et al., 2006). Epochs containing one or more saccades (acquired using an EyeLink eye tracker) during the stimulus display or amplitudes exceeding ±75 μV after artifact correction were excluded from further analysis. Remaining epochs were then visually inspected and any containing artifacts were then rejected.

P1 latency was defined as the largest positive peak between 75 and 200 ms after the onset of the stimulus displays at parieto-occipital sites PO3/P04, PO7/PO8, and O1/O2 (see Fig. 3). P1 peak latency was defined for each participant using their averaged waveform, collapsed across all experimental conditions. Mean P1 peak latency was 115 ms post-stimulus (*SEM*=4 ms). Data were baseline corrected to the pre-stimulus period prior to calculating P1 amplitude. P1 amplitude was then calculated as a function of reward-associated object type (target, distracter, or flanker) and size of reward-association (high or low), resulting in six conditions (including both correct and incorrect trials). For each of these conditions, for each participant, P1 amplitude was calculated at the mean amplitude within a 50 ms window centered at the individual's P1 peak latency. Laterality refers to whether the scalp sites were contra- or ipsi-lateral to the visual field where the reward-associated feature was presented. The average number of epochs included in all experimental conditions was greater than 50 after artifact rejection for all participants (high/low target *M*=204/204, *SEM*=4/4; high/low distracter *M*=102/101, *SEM*=2/2; high/low flanker *M*=102/102, *SEM*=2/2). As the target condition collapses across probed and other target condition there were twice as many available epochs, however none of the P1 results reported in the current study changed when only half of all target trials were included in the average.

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