Journal of Experimental Psychology: Learning, Memory, and Cognition

Winners and Losers: Reward and Punishment Produce Biases in Temporal Selection

Mike E. Le Pelley, Poppy Watson, Daniel Pearson, Ravini S. Abeywickrama, and Steven B. Most

Online First Publication, July 9, 2018. http://dx.doi.org/10.1037/xlm0000612

American Psychological Association

Journal of Experimental Psychology: Learning, Memory, and Cognition

0278-7393/18/$12.00 http://dx.doi.org/10.1037/xlm0000612

Winners and Losers: Reward and Punishment Produce Biases in Temporal Selection

Mike E. Le Pelley, Poppy Watson, and Daniel Pearson
University of New South Wales Sydney

Ravini S. Abeywickrama
University of New South Wales Sydney and University of Melbourne

Steven B. Most
University of New South Wales Sydney

Studies of visual search demonstrate that the 'learned value' of stimuli (the extent to which they signal valued events, such as rewards and punishments) influences whether they will be prioritized by spatial attention. Recent work suggests that learned value also modulates attentional prioritization even when all stimuli are presented in the same location, suggesting an influence on temporal selection wherein value-related stimuli become more capable of disrupting central mechanisms of perceptual awareness. However, it remains unclear whether temporal selection is influenced specifically by learning about the relationship of stimuli with reward, or with punishment, or both. This question motivated the current experiments. Participants saw a stream of pictures in a central location, and had to identify the orientation of a rotated target picture. In Experiment 1, response accuracy was reduced if the target was preceded by a 'valued' distractor picture that signaled that a correct response to the target would be rewarded, relative to a distractor picture that did not signal reward. In Experiment 2, accuracy was reduced if the valued distractor picture signaled that an incorrect response would be punished, relative to a distractor that did not signal punishment. Experiment 3 replicated these findings, and demonstrated that the influence of rewards/punishments persisted into an extinction phase in which valued distractors were entirely task-irrelevant. These findings suggest that it is the motivational significance of the outcome, rather than its valence, that is the crucial determinant of the influence of learned value on temporal selection.

Keywords: learning, nonspatial attention, punishment, reward, temporal selection

Attention refers to the set of cognitive mechanisms that act to prioritize certain stimuli for further processing or action. It is well-established that the extent to which a stimulus commands attention is influenced by its physical properties: a stimulus that is physically distinct from its surroundings (in terms of its color, brightness, sudden onset, loudness, etc.) will be more likely to capture a person's attention—regardless of their current goals or intentions—than one that is not (Corbetta & Shulman, 2002; Theeuwes, 1994; Yantis, 2000; but see also Folk, Remington, & Johnston, 1992). However, a substantial (and growing) body of research shows that this is not the whole story—attentional prioritization of stimuli is also influenced by our prior experience with those stimuli, their relation to other events in the world, and the consequences of selecting them (for reviews, see Anderson, 2016; Awh, Belopolsky, & Theeuwes, 2012; Le Pelley, Mitchell, Beesley, George, & Wills, 2016).

In particular, recent work has demonstrated that attention is influenced by the learned value of stimuli—our prior learning about the relationship between stimuli and motivationally significant (or 'valued') events: rewards and punishments. Most of the research in this area has examined spatial attention (selection of stimuli that occur in a distinct location, typically studied using visual search procedures). This research has shown that stimuli that have previously been paired with valued events are more likely to capture spatial attention. This increase in spatial capture has been observed both when the valued events are rewards (typically monetary gains, e.g., Albertella et al., 2017; Anderson, Laurent, & Yantis, 2011; Failing, Nissens, Pearson, Le Pelley, & Theeuwes, 2015; Hickey, Chelazzi, & Theeuwes, 2010; Le Pelley, Pearson, Griffiths, & Beesley, 2015; Pearson, Donkin, Tran, Most, & Le Pelley, 2015; Pearson et al., 2016; Wentura, Müller, & Rothermund, 2014) and when they are punishments—either loss of money (Wang, Yu, & Zhou, 2013; Wentura et al., 2014) or electric shock (Nissens, Failing, & Theeuwes, 2017; Schmidt, Belopolsky, & Theeuwes, 2015; Wang et al., 2013). In particular,

Mike E. Le Pelley, Poppy Watson, and Daniel Pearson, School of Psychology, University of New South Wales Sydney; Ravini S. Abeywickrama, School of Psychology, University of New South Wales Sydney, and School of Psychological Sciences, University of Melbourne; Steven B. Most, School of Psychology, University of New South Wales Sydney.

This research was supported by Australian Research Council Grant DP170101715. Daniel Pearson was supported by an Australian Government Research Training Program Scholarship.

Correspondence concerning this article should be addressed to Mike E. Le Pelley, School of Psychology, University of New South Wales Sydney, Sydney NSW 2052, Australia. E-mail: m.lepelley@unsw.edu.au

studies using eye-tracking have shown that learned value influences the likelihood that attention is rapidly summoned to the location of the value-related stimulus (Failing et al., 2015; Nissens et al., 2017; Pearson et al., 2016).

However, spatial attention is only one aspect of attentional selection. We can also prioritize detection of some events over others even when they occur in a shared location; for example, a quality control worker monitoring a production line knows in advance *where* faulty goods will appear, but not *when*. The problem here is one of temporal selection. Notably, recent studies show that value-related stimuli are also prioritized in temporal selection. These studies demonstrate that value-related stimuli can interfere with people's conscious perception of a subsequent target, even when the target was the focus of spatial attention (e.g., Failing & Theeuwes, 2015; Le Pelley, Seabrooke, Kennedy, Pearson, & Most, 2017; Raymond & O'Brien, 2009; Smith, Most, Newsome, & Zald, 2006).

Here we consider in some detail the procedure used by Le Pelley et al. (2017), which forms the basis of the current study. On each trial, a rapid serial visual presentation (RSVP) of pictures of buildings or landscapes appeared in the center of the screen (see Figure 1). Participants' task was to detect a target picture that was rotated to the left or right (all other pictures were presented upright). Shortly before this target picture, a *distractor* picture could appear—either a picture of a bird or a car. For half of participants, birds constituted the *valued* category and cars were the *neutral* category; for the other half of participants this assignment was reversed. On trials featuring a valued distractor, a correct response to the target earned a reward and an incorrect response earned punishment (gain or loss of points, respectively; points were converted to a monetary bonus at the end of the experiment). On trials featuring a neutral distractor, correct or incorrect responses to the target were inconsequential in that they did not result in gain or loss of any points. Thus the distractor category signaled the availability of a valued outcome, but critically the distractor was never the target that participants were required to identify and respond to in order to achieve that outcome.[1] The key finding was that participants performed more poorly on trials featuring a valued distractor than on trials featuring a neutral distractor. In other words, accuracy of target identification was lower on trials which influenced participants' final monetary payment than on trials that 'didn't matter,' that is, trials on which the response could have no effect on payment. This counterproductive effect of the distractor was most pronounced when it appeared shortly before the target (100–200 ms), and dissipated at longer distractor–target separations (400–1000 ms).

The implication is that the valued distractor was more likely to command attention and hence (temporarily) reduce perceptual processing of subsequent information. That is, a stimulus signaling the potential for reward or loss produced a greater impairment in conscious perception of the subsequent target than did a stimulus that had never been paired with reward or loss. This effect could not be attributed to shifts of spatial attention, because all stimuli (distractors and targets) were presented centrally, at the focus of participants' spatial attention.

The finding of an impairment in target detection following a valued distractor bears some similarity to the attentional blink (Raymond, Shapiro, & Arnell, 1992). In a typical attentional blink procedure, two targets (T1 and T2) occur close together in an RSVP stream: identification of the second target (T2) is impaired as a result of the requirement to identify the first target (T1). Although the details of the underlying mechanism are still debated, it is generally agreed that the attentional blink arises because attentional selection of T1 commands ongoing processing resources that interfere with processing of T2, and moreover that this interference occurs at a relatively late stage, after initial sensory processing (Dux & Marois, 2009; Shapiro, Raymond, & Arnell, 1997). The key difference between the standard attentional blink procedure and the RSVP procedure described above is that, in Le Pelley et al.'s (2017) task, the stimulus that caused interference with target identification was not itself a (T1) target that participants were required to report. Thus while the attentional blink shows that attentional selection of a T1 target can disrupt subsequent mechanisms of perceptual awareness, Le Pelley et al.'s findings suggest that a stimulus rendered salient by virtue of its association with valued events can likewise interfere with ongoing processing even though it is not a target and its selection is not required by the task.

In Le Pelley et al.'s (2017) study, valued distractors signaled both that correct responses to the target would be rewarded, and incorrect responses would be punished. Under these conditions we cannot be sure whether the influence of learned value on temporal selection reflects an effect of learning about the stimulus's relationship with reward, with punishment, or both. This issue has both theoretical and practical implications. From a theoretical perspective, it is important to establish whether effects of learned value on attention are driven by the motivational significance of the predicted outcome (rewards and punishments are both motivationally significant, in that they will drive behavior), or by the valence of that outcome (whether it is affectively positive [appetitive] or negative [aversive]). Findings from the animal neuroscience literature suggest distinct populations of dopaminergic neurons that encode motivational significance versus valence (Bromberg-Martin, Matsumoto, & Hikosaka, 2010), with motivational significance being processed via dorsal prefrontal cortex, and valence processed via ventromedial prefrontal cortex (for supporting evidence from studies of neuroimaging in humans, see Bartra, McGuire, & Kable, 2013). We noted earlier that previous studies of visual search have shown that capture of spatial attention is influenced by both rewards (e.g., Anderson et al., 2011; Failing et al., 2015; Pearson et al., 2016; Wentura et al., 2014) and punishments (e.g., Nissens et al., 2017; Schmidt et al., 2015; Wang et al., 2013; Wentura et al., 2014). These findings demonstrate that reward- and punishment-related stimuli can promote rapid orienting of spatial attention, that is, that orienting is a function of motivational significance rather than valence. The question remains open, however, as to whether this similarity between effects of reward and punishment extends beyond initial orienting—that

[1] We use the label 'distractor' for these stimuli because participants were not required to identify them to perform the task, and because the findings suggest that selecting the distractor typically impaired performance of the task. Nevertheless the distractors did provide information on whether making a correct/incorrect response to the target would produce reward/punishment or not. Hence they were not entirely task-irrelevant (unlike in some previous studies of learned value in visual search; e.g., Anderson et al., 2011). We return to the issue of the information value of the distractors in Experiment 3.

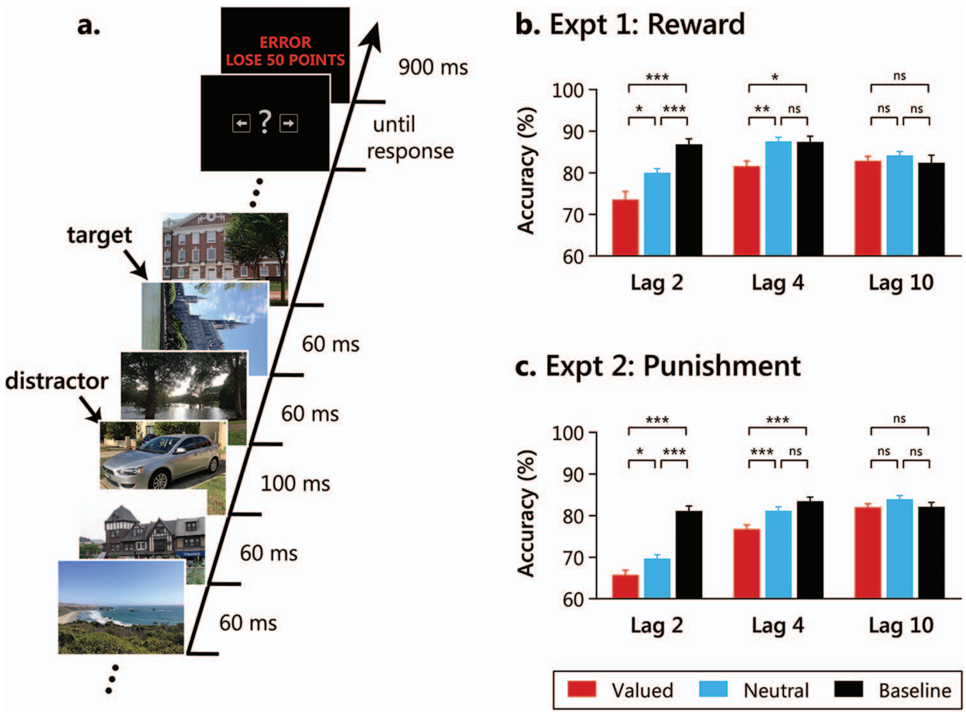

Figure 1. (a) Schematic of a trial from the Rapid Serial Visual Presentation (RSVP) task—actual RSVP streams comprised 18 pictures. Participants responded to the orientation of a rotated target picture. This could be preceded by a critical distractor picture of a bird or car: one of these categories (*valued* distractors) signaled that correct responses to the target would be rewarded by gain of points (Experiment 1), or that incorrect responses to the target would be punished by loss of points (Experiment 2); the other distractor category (*neutral* distractors) signaled that responses would not be rewarded or punished. On *baseline* trials, no bird/car distractor was presented and responses were not rewarded or punished. (b) Accuracy of responses to the target in Experiment 1. *Lag* refers to the difference in serial position of the critical distractor and target in the RSVP stream (or between the filler item that substituted for the distractor and the target on baseline trials). (c) Accuracy of responses to the target in Experiment 2. Error bars show within-subjects standard error of the mean (Cousineau, 2005). ns: $p \geq .10$, $^{*}p < .05$, $^{**}\ p < .01$, $^{***}\ p < .001$. See the online article for the color version of this figure.

is, whether reward and punishment also exert a similar influence on competition in ongoing cognitive processes. Answering this question requires studying the separate effects of reward and punishment on temporal selection, as implicated in studies of the attentional blink and related phenomena. One possibility is that the effect of the attentional prioritization produced by motivational significance (rather than valence) is not limited to spatial capture, but also biases competition for subsequent perceptual processing. On this account, reward- and punishment- stimuli are not only more likely than neutral stimuli to produce rapid orienting of attention, they also ‘hold’ cognitive processing resources for longer. An alternative possibility is that, while initial orienting is a function of motivational salience, subsequent attentional processing might instead be determined by valence. For example, it has previously been argued that while both reward- and punishment-related stimuli might attract rapid initial orienting, punishment-related stimuli might then be subject to suppression/avoidance while attention to reward-related stimuli is maintained (Hogarth, Dickinson, & Duka, 2010; Weierich, Treat, & Hollingworth, 2008).

From an applied perspective, the question of motivational salience versus valence is important because attentional biases toward appetitive and aversive stimuli are implicated in different types of mental disorder. For example, drugs of abuse produce potent neural reward signals (Hyman, 2005; Robinson & Berridge, 2001), and addiction is often associated with an attentional bias toward drug-related stimuli (see Wiers & Stacy, 2006). In contrast, emotional disorders such as anxiety and depression have been linked with biased attention to negative (aversive) emotional information (e.g., MacLeod, Mathews, & Tata, 1986). Understanding whether reward-driven and aversive-driven associations influence attention similarly would provide valuable insight into the nature and possible rectification of such maladaptive attentional biases.

A small number of existing studies have considered the separate influences of rewards and punishments on temporal selection (Failing & Theeuwes, 2015; Raymond & O’Brien, 2009; Smith et al., 2006). For example, Failing and Theeuwes (2015) initially trained participants on a task in which they were required to select one of two pictures from different semantic categories: choosing a picture from a particular category (e.g., mountains) typically yielded a large reward, while the other category (e.g., forests) yielded small reward. Participants learned these relationships, becoming more likely to choose pictures from the high-reward category. Critically, when the pictures were used as distractors in a subsequent RSVP task, pictures from the high-reward category produced a greater impairment in target identification than those from the low-reward category. This finding could be taken to suggest that learning about (specifically) reward relationships influences temporal selection. An important caveat, however, is that the difference in reward history of the different categories during the RSVP test phase of Failing and Theeuwes's (2015) study was confounded with a difference in their *selection history*: pictures from the high-reward category were selected more frequently on choice trials during the preceding training phase, and it may be this greater selection history (as opposed to a difference in learned value) that drives greater capture by these pictures in the test phase (cf. Kyllingsbaek, Schneider, & Bundesen, 2001: see Awh et al., 2012; Le Pelley et al., 2016: a similar explanation can be applied to the study by Raymond & O'Brien, 2009).

The study by Smith et al. (2006) examined the influence of learning about aversive (rather than rewarding) events on temporal selection. Participants experienced an initial training phase in which a single picture was presented on each trial. Pictures belonging to one category were consistently paired with delivery of an aversive loud noise; pictures from another category were never paired with the noise. When these pictures were subsequently used as distractors in an RSVP task, target identification was worse when it was preceded by a picture from the noise-paired category. In this case, the finding is consistent with the idea that learning about (specifically) aversive relationships influences temporal selection. However, a caveat is also necessary here. Rather than reflecting a change in the attention-grabbing properties of the noise-paired picture, the increased distraction may reflect participants' expectation of the noise itself. That is, perhaps the noise-paired stimulus did not command attention, but instead elicited some sort of strategic, preparatory response to protect against the aversive noise (which continued to be delivered occasionally during the RSVP test phase), resulting in disengagement from the RSVP task.

In summary, these existing studies are consistent with a role of both reward (Failing & Theeuwes, 2015; Raymond & O'Brien, 2009) and punishment (Smith et al., 2006) in driving temporal selection, but in both cases the interpretation is somewhat equivocal. Notably, the procedure used by Le Pelley et al. (2017) to study effects of learned value on nonspatial attention guards against the alternative explanations that apply to these prior studies. Explanation in terms of selection history does not apply to this procedure because participants are never required to select the critical value-related stimuli—these are only ever presented as distractors. Furthermore, selecting value-related stimuli in this procedure does not allow participants to gain reward or avoid punishment, and hence preparatory responses elicited by the distractors are unlikely. As such this procedure provides a purer measure of the influence of value (rather than prior selection) on attentional priority (rather than response preparation) in temporal selection.

The current experiments therefore adapted the procedure used by Le Pelley et al. (2017) to investigate whether counterproductive temporal selection of distractors is influenced specifically by learning about their relationship with reward (Experiment 1), or with punishment (Experiment 2). To investigate the possibility of a reward-driven attentional bias, Experiment 1 featured 'reward distractors' which signaled that a correct response to the target would be rewarded, but an incorrect response was never punished. To investigate the possibility of a punishment-driven bias, Experiment 2 featured 'punishment distractors' which signaled that an incorrect response to the target would be punished, but a correct response was never rewarded.

Experiments 1 and 2

Method

Participants. Thirty UNSW Sydney students (mean age = 19.1 years, 13 females) participated in Experiment 1 for course credit; 50 UNSW Sydney students participated in Experiment 2 (mean age = 25.1 years, 34 females) for payment of \$11.50 AUD.[2] Participants also received an additional monetary bonus dependent on their performance (see 'Design and Procedure' section). All research reported in this article was approved by the Human Research Ethics Advisory Panel (Psychology) of UNSW Sydney.

Apparatus and stimuli. Participants were tested individually and viewed stimuli on a 23-in. monitor (1920 × 1080 resolution, 100 Hz refresh) at a distance of ~60 cm (head position was not fixed). Auditory stimuli were played over headphones, and all responses were made using the keyboard. Stimulus presentation was controlled by MATLAB using Psychophysics Toolbox extensions (Kleiner, Brainard, & Pelli, 2007).

Visual stimuli were color photographs presented centrally on a black background; pictures subtended 8.1° × 6.1° visual angle. Target pictures were drawn from a pool of 244 pictures of buildings and landscapes, half of which had been rotated 90° to the left and the other half 90° to the right (while maintaining the same dimensions as the nonrotated pictures). Critical distractors (see 'Design and Procedure') were 10 pictures of birds and 10 pictures of cars. Filler items were drawn from a pool of 251 upright building/landscape pictures.

Design and procedure. For half of participants in each experiment, pictures of birds were the distractors that signaled the availability of valued outcomes (rewards in Experiment 1; punishments in Experiment 2) and cars were the neutral distractors. For the other half of participants, this assignment was reversed.

Participants were informed that they would see a stream of pictures presented rapidly on the screen, that one of these pictures would be rotated to the left or right, and that their task was to identify the direction in which this target picture was rotated. Subsequent instructions differed between experiments. Participants in Experiment 1 were told that they could earn points for making correct responses: that if the stream included a picture of a bird/car (whichever was the reward-related distractor category for that participant) they would win 50 points for making a correct response to the target, but on all other trials they would not win any points for a correct response. Participants in Experiment 2 were

[2] Experiment 2 was, in fact, run prior to Experiment 1. The larger sample of Experiment 2 was a consequence of a somewhat overenthusiastic research assistant collecting the data. Notably, restricting analysis of Experiment 2 to the first 30 participants tested (thus equating the sample sizes of the two experiments) leaves the pattern of significant and nonsignificant findings unchanged.

told that they would begin the experiment with 5,000 points, and could lose points for making errors: that if the stream included a picture of a bird/car (whichever was the punishment-related category for that participant) they would lose 50 points for making an incorrect response to the target, but on all other trials they would not lose any points for making an error. Participants in both experiments were then told that the bird/car would never be the target stimulus, and that they would therefore do better at the task (and earn more money) if they were to ignore the bird/car and instead focus on identifying the target as accurately as possible on each trial. Finally, all participants were told that the number of points that they had accumulated at the end of the experiment would determine their monetary bonus, and that most participants could earn between \$7 and \$12 AUD. No specific information on the conversion rate from points to money was provided.

The RSVP task comprised 6 blocks of 45 trials each. Each block contained 18 trials with a valued distractor, 18 trials with a neutral distractor, and 9 baseline trials. On baseline trials the RSVP stream did not contain a bird or a car; instead a building/landscape picture drawn from the same pool as the filler items was used in place of a critical distractor. Participants took a short break after each block, during which they were told their running total of points.

Figure 1 shows the general procedure of the RSVP task. Each trial began with presentation of a central fixation cross for 500 ms. A stream of 18 pictures was then presented. Each stream contained one rotated target picture. The distractor (or filler picture used in place of the distractor on baseline trials) was presented for 100 ms; all other items (including the target) were presented for 60 ms. In our previous work (Le Pelley et al., 2017) we used a presentation rate of 100 ms per item; by increasing the presentation rate of all nondistractor items (including the target), our aim was to make the current task harder while maintaining processing of the distractor. A difficult task is important to ensure a sufficient proportion of errors, such that participants in Experiment 2 would frequently experience punishment following errors on trials with a valued distractor. Importantly, because the uneven presentation rate (with longer distractor presentation) was the same across all three trial types (valued, neutral, baseline), this difference could not exert a systematic influence on our findings, which rely on comparisons across trial types.

Once all items in the stream had been presented, participants responded according to whether they thought the target picture was rotated left or right, using the left and right arrow keys respectively. Feedback was then provided for 900 ms, depending on the type of distractor that had preceded the target and the accuracy of the participant's response (see below). The next trial then began after an intertrial interval of 500 ms.

In Experiment 1, on trials featuring a valued distractor, a correct response to the orientation of the target yielded reward feedback: the message 'CORRECT: WIN 50 POINTS!!' appeared centrally in green, 42-point text, accompanied by a rising-pitch, 'victory' sound. A correct response on neutral and baseline trials produced the feedback 'correct' in white, 40-point text, with no gain of points. An incorrect response on any trial produced the feedback 'incorrect' in white, 40-point text, with no loss of points.

In Experiment 2, on trials featuring a valued distractor, an incorrect response to the target yielded punishment feedback: the message 'ERROR: LOSE 50 POINTS' appeared centrally in red, 42-point text, accompanied by a buzzer sound. An incorrect response on neutral and baseline trials produced the feedback 'incorrect' in white, 40-point text, with no loss of points. A correct response on any trial produced the feedback 'correct' in white, 40-point text, with no gain of points.

The distractor (or additional filler item on baseline trials) appeared randomly as the third, fourth, fifth, or sixth item in the stream. We systematically varied the delay between distractor and target (referred to as *lag*) to investigate the temporal characteristics of attentional bias toward the value-related distractor. The target appeared either as the second item (lag 2), the fourth item (lag 4), or the tenth item (lag 10) after the distractor; thus either 120 ms, 240 ms, or 600 ms separated the onset of the distractor and target. The shortest lag (120 ms) provides an index of the early impact of the distractor; at the longest lag (600 ms), the target occurs outside what would typically be considered the temporal window of distraction by a salient stimulus in RSVP tasks (Folk, Leber, & Egeth, 2008; Raymond et al., 1992). The intermediate lag (240 ms) provides a proxy measure of rate of recovery from distraction by a salient stimulus. One-third of trials for each distractor type (valued, neutral and baseline) in every block were at each of the different lags. Even though baseline trials did not feature a critical distractor, controlling lag on these trials in the same way as for valued and neutral trials is important because it controls for the serial position of the target in the RSVP stream; the target will tend to occur later on long-lag trials than short-lag trials.

Nondistractor and nontarget items in the RSVP stream on each trial were drawn randomly, and without replacement, from the pool of filler items. The target item was drawn randomly from the pool of target pictures, such that target rotation (left or right) was random on each trial.

On completing the RSVP task, participants were paid according to their points total. Because of a programming error, the conversion rate between points and money differed between experiments such that participants in Experiment 1 tended to receive a higher payoff (M = \$9.56 AUD, SEM = \$0.19) than those in Experiment 2 (M = \$7.48 AUD, SEM = \$0.11). Given that this difference occurred only after the experiment was complete (and participants received no prior information on the conversion rate), it cannot have influenced performance on the RSVP task.

Results

Data from all experiments are available via the Open Science Framework at https://osf.io/yd7st/.

Experiment 1. Figure 1b shows accuracy of responses to the target in Experiment 1, averaged across all blocks; recall that in Experiment 1 the valued distractor signaled that a correct response would be rewarded. These data were analyzed using a 3 (distractor: valued, neutral, and baseline) × 3 (lag: lag 2, lag 4 and lag 10) analysis of variance (ANOVA). This revealed significant main effects of distractor, $F(2, 58) = 11.7$, $p < .001$, $\eta_p^2 = .29$, and lag, $F(2, 58) = 11.6$, $p < .001$, $\eta_p^2 = .29$, and a significant interaction, $F(4, 116) = 6.89$, $p < .001$, $\eta_p^2 = .19$.

We were particularly interested in the difference in accuracy on valued versus neutral trials: both featured a critical distractor (bird or car), with the only difference being that one category of distractor signaled availability of reward while the other did not. We therefore analyzed the data from these trials using a 2 (distractor: valued vs. neutral) × 3 (lag) ANOVA. This revealed a significant main effect of distractor, $F(1, 29) = 14.9$, $p = .001$, $\eta_p^2 = .34$, with lower accuracy on valued trials than neutral trials. There was also a main effect of lag, $F(2, 58) = 23.0$, $p < .001$, $\eta_p^2 = .44$. Finally, the Distractor × Lag interaction approached significance, $F(2, 58) = 2.47$, $p = .093$, $\eta_p^2 = .08$, with Figure 1b showing that the pattern of lower accuracy on valued trials than neutral trials was somewhat smaller at lag 10 than at lag 2 or 4.

Pairwise *t* tests were used to analyze the effect of distractor at each lag, controlling for multiple comparisons via the Benjamini and Hochberg (1995) procedure with a false discovery rate of .05. At lag 2, accuracy for valued and neutral trials was lower than for baseline trials, smaller $t(29) = 4.77$, $p < .001$, $d_z = .87$, presumably because the distractor in both cases (bird or car) was categorically distinct from the other items in the stream (buildings or landscapes: see Kennedy & Most, 2015; Le Pelley et al., 2017). More importantly, accuracy was significantly lower for valued trials than neutral trials, $t(29) = 2.60$, $p = .014$, $d_z = .48$, suggesting an influence of learned value on accuracy, independent of the categorical distinctiveness of the distractor. At lag 4, accuracy was again significantly lower for valued trials than for neutral trials, $t(29) = 3.45$, $p = .002$, $d_z = .63$, and baseline trials, $t(29) = 2.52$, $p = .017$, $d_z = .46$. Accuracy on neutral trials did not differ significantly from baseline trials, $t < 1$. At lag 10, there were no significant differences, $t\text{s} \leq 1$.

Experiment 2. Figure 1c shows accuracy of responses to the target in Experiment 2; recall that in Experiment 2 the valued distractor signaled that an incorrect response would be punished. These data were analyzed using a 3 (distractor: valued, neutral, and baseline) × 3 (lag: lag 2, lag 4 and lag 10) ANOVA. This revealed significant main effects of distractor, $F(2, 98) = 45.2$, $p < .001$, $\eta_p^2 = .48$, and lag, $F(2, 98) = 64.8$, $p < .001$, $\eta_p^2 = .57$, and a significant interaction, $F(4, 196) = 15.5$, $p < .001$, $\eta_p^2 = .24$.

As for Experiment 1, we were particularly interested in the difference in accuracy on valued versus neutral trials: both featured a critical distractor, with the only difference being that one distractor category signaled the possibility of punishment while the other did not. Analyzing the data from these trials with a 2 (distractor: valued vs. neutral) × 3 (lag) ANOVA revealed a significant main effect of distractor, $F(1, 49) = 26.7$, $p < .001$, $\eta_p^2 = .35$, with lower accuracy on valued trials than neutral trials. There was also a main effect of lag, $F(2, 98) = 96.4$, $p < .001$, $\eta_p^2 = .66$, with accuracy tending to increase as lag increased. Finally, the distractor × lag interaction was not significant, $F(2, 98) < 1$. Thus, although the effect of learned value (difference between valued and neutral trials) was significant at the shorter lags but not at the longest lag, the size of this effect did not differ significantly as a function of lag.

Pairwise *t* tests were used to analyze the effect of distractor at each lag, controlling for multiple comparisons using the Benjamini-Hochberg procedure. At lag 2, accuracy was significantly lower for valued trials than neutral trials, $t(49) = 2.46$, $p = .017$, $d_z = .35$, and accuracy for valued and neutral trials was lower than for baseline trials, smaller $t(49) = 7.08$, $p < .001$, $d_z = 1.00$. At lag 4, accuracy was again significantly lower for valued trials than for neutral trials, $t(49) = 3.82$, $p < .001$, $d_z = .54$, and baseline trials, $t(49) = 4.35$, $p < .001$, $d_z = .62$. Accuracy on neutral trials did not differ significantly from baseline trials, $t(49) = 1.57$, $p = .12$, $d_z = .22$. At lag 10, there were no significant differences, largest $t = 1.81$, $p = .077$, $d_z = .26$.

Combined analysis of Experiments 1 and 2. In Experiment 1 valued distractors signaled the possibility of reward; participants started with nothing and earned points during the experiment. In Experiment 2 valued distractors signaled the possibility of punishment; participants started with 5,000 points and lost points during the experiment. Aside from this key difference, both experiments used the same procedure. We therefore ran a combined analysis of the two experiments to compare the influence of reward and punishment on attentional bias in the RSVP task. It should be noted, however, that Experiments 1 and 2 were run at different times and recruited from different samples (participants in Experiment 1 were first-year undergraduates participating for course credit; participants in Experiment 2 came from a range of years and courses and participated for payment). Thus differences in the design of the two experiments are confounded with the potential for systematic differences in the samples recruited. The results of this combined analysis (as for any between-experiments comparison) should be interpreted with this caveat in mind.

The data from the two experiments were first analyzed using a mixed 2 (experiment: Experiment 1 vs. Experiment 2) × 3 (distractor: valued, neutral, baseline) × 3 (lag: lag 2, lag 4, lag 10) ANOVA. We were particularly interested in effects of the experiment factor, which would suggest differences in the pattern of performance between Experiment 1 and Experiment 2. This ANOVA revealed a main effect of experiment, $F(1, 78) = 8.05$, $p = .006$, $\eta_p^2 = .09$, with higher overall accuracy in Experiment 1 than Experiment 2. There was also an Experiment × Lag interaction, $F(2, 156) = 12.2$, $p < .001$, $\eta_p^2 = .14$. No other interactions involving experiment were significant, largest $F(2, 156) = 1.28$, $p = .28$, $\eta_p^2 = .02$. That is, experiment did not interact with distractor, suggesting that relative performance on the valued, neutral and baseline trials did not significantly depend on whether the experiment involved rewards or punishments.

A follow-up analysis focused on the data from trials with valued and neutral distractors, because these were the critical trials that allowed us to assess the influence of learned value. A 2 (experiment: Experiment 1 vs. Experiment 2) × 2 (distractor: valued vs. neutral), × 3 (lag) ANOVA revealed that, as for the overall analysis, there was a main effect of experiment, $F(1, 78) = 9.26$, $p = .003$, $\eta_p^2 = .11$, with higher overall accuracy in Experiment 1. Again there was an experiment × lag interaction, $F(2, 156) = 11.9$, $p < .001$, $\eta_p^2 = .13$. And once again, no other interactions involving experiment were significant, $F\text{s} < 1$. Thus this more focused analysis suggested that the influence of learned value (the impairment in accuracy caused by a valued distractor relative to a neutral distractor) did not significantly depend on whether the valued distractor signaled the possibility of reward or punishment.

Discussion

In Experiment 1, the valued distractors signaled that a correct response to the target would be rewarded, but an incorrect response would not be punished. Hence in this experiment the valued distractors were reward signals. Under these conditions we found that valued distractors caused a greater impairment in target identification than neutral distractors which did not signal the availability of reward. The implication is that participants prioritized detection of reward-related distractors in this task, even though doing so was counterproductive since it meant they performed worse on the critical trials on which reward was available (and hence earned less money) than if they had ignored these distractors. These data show that knowledge of stimulus–reward 'signaling relationships' enhances nonspatial attention and consequently increases the likelihood and/or extent of temporal selection.

In Experiment 2, the valued distractors signaled that an incorrect response to the target would be punished, but a correct response would not be rewarded. Hence in this experiment the valued distractors were punishment signals. Under these conditions we again found that valued distractors caused an impairment in target identification relative to neutral distractors, suggesting that participants prioritized detection of punishment-related distractors. Once again this was counterproductive since it meant that participants experienced more punishments (and hence earned less money overall) than if they had ignored these distractors. The results of Experiment 2 show that knowledge of stimulus–punishment signaling relationships enhances nonspatial attention and thus temporal selection.

Taken together, these experiments show that learning about rewards *or* punishments can increase the extent to which stimuli command nonspatial attention. The pattern of behavior in both experiments was broadly similar, regardless of whether rewards or punishments were involved: a between-experiments comparison did not find any significant difference in the effect of learned value in the two experiments. In both cases, the effect was rapid and relatively short-lived, being present at lag 2 (distractor–target separation of 120 ms) and lag 4 (240 ms), but nonsignificant at lag 10 (600 ms). This timecourse is similar to that observed in studies of capture of nonspatial attention by physically salient stimuli (Folk et al., 2008). That said, the evidence for an influence of lag on the learned value effect in the current experiments was not especially strong: although analyses at each lag suggested a change over time, the corresponding interaction did not reach significance in either experiment. This is most likely because the range of lags tested (120 ms to 600 ms) was not particularly large; presumably the learned value effect would dissipate further at even longer lags (such as the 1000 ms used by Le Pelley et al., 2017). Indeed, at very long distractor–target lags we might even expect better performance on valued than neutral trials: perceptual processing of the distractor would be complete by the time the target appeared, but a more controlled, goal-directed influence of the distractor might exist, with participants having greater motivation to respond accurately on valued trials than neutral trials (cf. Ciesielski, Armstrong, Zald, & Olatunji, 2010). We do not pursue this possibility here, but it could be addressed in future studies with much longer distractor–target lags.

Experiment 3

We now turn to the question of the cognitive level at which the influence of learned value operates. As noted above, the influence of learned value on behavior observed in both experiments was counterproductive, because it meant that participants performed worse on trials that mattered (i.e., contributed to their final payoff) than trials that did not. The persistence of this effect despite its negative consequences might be taken to suggest that the influence of learned value observed in these experiments reflects a mechanism over which participants have little control. That is, learned value may be modulating exogenous capture of nonspatial attention (cf. Folk et al., 2008; Le Pelley et al., 2017). That said, the fact that attending to valued distractors was a demonstrably poor strategy in this task (and this was pointed out to participants at the outset) does not mean that participants did not adopt and persist in using this strategy. Although the valued stimuli were unrelated to the response (to the target) that was required on each trial, they did provide information on the consequences of that response: whether it could result in reward/punishment. As such, the value-related stimuli had informational value (see Gottlieb, Hayhoe, Hikosaka, & Rangel, 2014). This raises the possibility that participants may have attempted to use these stimuli strategically, to identify which trials were 'important' (even though, as noted above, this was clearly a poor strategy).

Experiment 3 investigated this possibility by testing whether the learned value effects driven by rewards and punishments were contingent upon the critical distractors having current informational value. This experiment included a final phase of the RSVP task in which participants were explicitly informed that no more rewards or punishments would be provided but that otherwise the task would carry on as before. If selection of value-related stimuli in the earlier, rewarded/punished phase reflected a strategic process of information-gathering, then it should be abolished in this final 'extinction' phase. This is because participants already knew that no reward was available on each trial, so the (previously) valued distractors no longer provided any information: that is, during extinction, the distractors were entirely task-irrelevant (cf. Anderson et al., 2011). If, in contrast, selection of the valued distractor were involuntary and based on its history of association with reward/loss, the selection of this distractor may persist even when participants were explicitly aware that rewards/punishments would no longer occur.

Method

Participants, apparatus, and stimuli. Experiments 1 and 2 found effect sizes for the critical 'valued versus neutral' difference of around d_z = .54-.63. We therefore aimed for a sample size of 40 in each of the reward and punishment conditions of Experiment 3, giving power of more than .90 to detect an effect with $d_z = .54$. Hence we recruited 80 UNSW Sydney students (mean age = 19.9 years, 45 females), who participated for course credit. Participants also received an additional monetary bonus dependent on their performance. Half of participants were randomly assigned to a reward condition, and the other half to a punishment condition. Within each of these between-subjects conditions, half of participants had birds as valued distractors and cars as neutral distractors; for the other half of participants, this assignment was reversed. Apparatus and stimuli were as for Experiments 1 and 2.

Design and procedure. The design of the reward condition was similar to that of Experiment 1; the punishment condition was similar to Experiment 2. All participants first completed 12 'training' blocks, in which they could win or lose points (depending on which condition they were assigned to). Experiment 3 used lag-2 and lag-4 trials only (i.e., unlike in Experiments 1 and 2, there were no lag-10 trials). Our previous experiments found an effect of distractor value at short distractor–target lags; removing lag-10 trials allowed us to increase the proportion of short-lag trials and hence sensitivity to detect effects of reward and punishment. Each trial-block contained 40 trials: 16 valued-distractor trials, 16 neutral-distractor trials, and 8 baseline trials. Half of the trials of each type (valued, neutral, baseline) in each block were at lag 2, and the other half were at lag 4. Since we no longer had lag-10 trials, we reduced the length of the RSVP stream on each trial to 14 items, with the distractor occurring in a randomly chosen position between 3 and 8 (inclusive).

Another change was with regard to the auditory feedback. In Experiments 1 and 2, only valued distractors were followed by auditory feedback, raising the possibility that the impairment caused by these distractors was a consequence of them being paired with an auditory outcome event rather than more specifically reflecting their pairing with gain/loss of points. To overcome this issue, in Experiment 3 auditory feedback was provided on all trials so that all distractors—not just the valued distractors—were paired with sounds. During the training phase, for participants in the reward condition correct responses on valued trials produced the same rising-pitch 'victory' sound as in Experiment 1, and for participants in the punishment condition incorrect responses on valued trials produced the same error buzz as in Experiment 2. In all other cases, a correct response produced a high beep (392 Hz), and an incorrect response produced a low beep (294 Hz). Text-based feedback during the training phase for the reward and punishment condition was as for Experiments 1 and 2, respectively.

Following the training phase, participants were informed that "From now on, you will never [win/lose—depending on condition] any points in this task, regardless of the pictures presented in the stream. Nevertheless, you should carry on responding to the rotated target as accurately as you can on each trial." They then completed two 'extinction' blocks. These blocks were structured in the same way as for training blocks, but no points were won or lost on any trial (feedback was just 'correct' or 'incorrect' written in white text, with a high or low beep as appropriate).

Participants received a monetary bonus at the end of the experiment based on their final points total. The exchange rate was scaled separately for reward and punishment groups to ensure that both received similar amounts (M = 6.97 AUD, SEM = 0.11 AUD for reward condition; M = 7.16 AUD, SEM = 0.12 AUD for punishment condition).

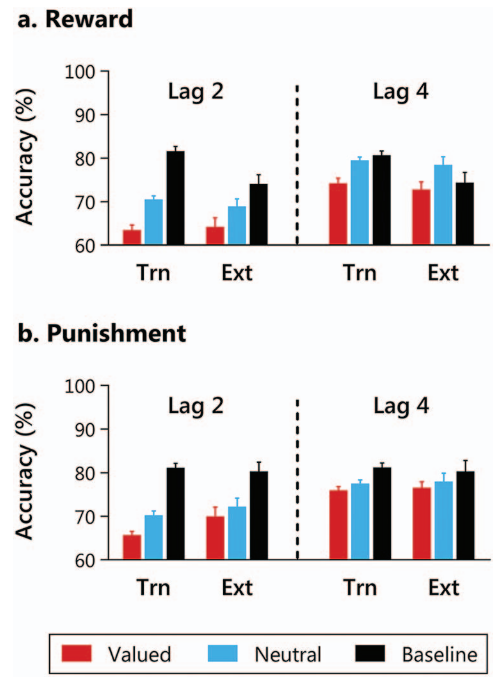

Figure 2. Accuracy of responses to the target in the (a) reward and (b) punishment conditions of Experiment 3, for the three different trial types (valued, neutral, and baseline: see text for details) during the training (Trn) and Extinction (Ext) phases. Lag refers to the difference in serial position of the critical distractor and target in the RSVP stream (or between the filler item that substituted for the distractor and the target on baseline trials). Error bars show within-subjects standard error of the mean (Cousineau, 2005). See the online article for the color version of this figure.

Results

Figure 2 shows accuracy of responses to the target, averaged across blocks of the training and extinction phases. As in Experiments 1 and 2, our main interest was in the effect of value-signaling distractors on performance, given by the difference in accuracy between valued and neutral distractor trials. We therefore analyzed data at each lag using a 2 (outcome condition: reward vs. punishment group) × 2 (distractor: valued vs. neutral) × 2 (phase: training vs. extinction) ANOVA. If an effect of distractor was observed, this was followed up by more focused tests within each outcome condition.

Lag 2. At lag 2, there was a significant main effect of distractor, $F(1, 78) = 16.5$, $p < .001$, $\eta_p^2 = .17$, with lower accuracy on valued trials than neutral trials. The Outcome Condition × Phase interaction approached significance, $F(1, 78) = 3.02$, $p = .086$, $\eta_p^2 = .04$, with Figure 2 showing that accuracy was similar during training and extinction for the reward condition, but increased slightly during extinction in the punishment condition. No other main effects or interactions approached significance, largest $F(1, 78) = 1.71$, $p = .20$, $\eta_p^2 = .02$.

For the reward condition, a 2 (distractor) × 2 (phase) ANOVA revealed a significant main effect of distractor, $F(1, 39) = 14.0$, $p = .001$, $\eta_p^2 = .26$. There was no significant main effect of phase, or interaction, Fs < 1. Separate analysis of each phase found that there was a significant effect of distractor during training, $t(39) = 5.54$, $p < .001$, $d_z = .88$, but the numerical trend during extinction did not reach significance, $t(39) = 1.62$, $p = .11$, $d_z = .26$.

For the punishment condition, a Distractor × Phase ANOVA revealed a significant main effect of distractor, $F(1, 39) = 4.21$, $p = .047$, $\eta_p^2 = .10$. There was also a main effect of phase, $F(1, 39) = 4.62$, $p = .038$, $\eta_p^2 = .11$, but no interaction, $F < 1$. Separate analysis of each phase found that there was a significant effect of distractor during training, $t(39) = 3.75$, $p = .001$, $d_z = .59$, but the numerical trend during extinction did not reach significance, $t < 1$.

To summarize, in both reward and punishment conditions there was a significant effect of distractor, with valued distractors impairing performance relative to neutral distractors, and this effect did not differ significantly in training and extinction phases. However, when considering the extinction phase alone, the effect of distractor was not significant. A finer-grained analysis suggested this may have been because extinction of distractor–value associations was very rapid. Figure 3 shows data from the extinction phase broken down by blocks of the extinction phase. For both reward and punishment conditions, at lag 2 there was a significant

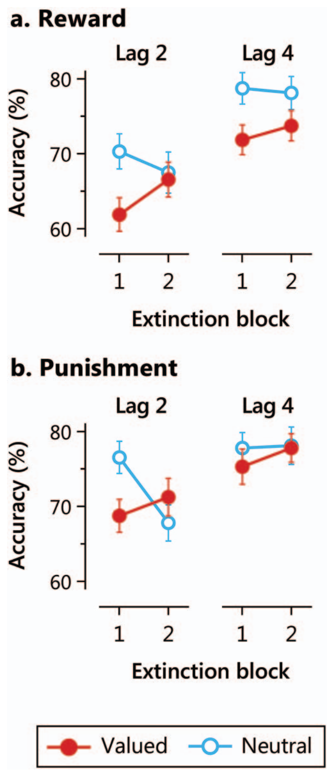

Figure 3. Accuracy of responses to the target in the two blocks of the extinction phase in Experiment 3, for (a) reward and (b) punishment conditions, for valued and neutral trial-types. Lag refers to the difference in serial position of the critical distractor and target in the RSVP stream. Error bars show within-subjects standard error of the mean (Cousineau, 2005). See the online article for the color version of this figure.

effect of value during the first extinction block: for reward, $t(39) = 2.45$, $p = .019$, $d_z = .39$; for punishment, $t(39) = 2.22$, $p = .032$, $d_z = .35$. In the second block, the effect of value was not significant for either condition, ts < 1.

Lag 4. At lag 4, the 2 (outcome condition) × 2 (distractor) ×2 (phase) ANOVA revealed a significant main effect of distractor, $F(1, 78) = 10.0$, $p = .002$, $\eta_p^2 = .11$, with lower accuracy on valued trials than neutral trials. The outcome condition × distractor interaction approached significance, $F(1, 78) = 3.28$, $p = .074$, $\eta_p^2 = .04$, with a trend toward a larger effect of distractor type in the reward condition than the punishment condition. No other main effects or interactions were significant, all Fs < 1.

For the reward condition, a 2 (distractor) × 2 (phase) ANOVA revealed a significant main effect of distractor, $F(1, 39) = 12.7$, $p = .001$, $\eta_p^2 = .25$. There was no significant main effect of phase, or interaction, Fs < 1. Separate analysis of each phase found that there was a significant effect of distractor during training, $t(39) = 5.43$, $p < .001$, $d_z = .86$, and during extinction, $t(39) = 2.13$, $p = .040$, $d_z = .34$. Finer-grained analysis of the reward condition showed that the effect of distractor during the first block of extinction (see Figure 3a) approached significance, $t(39) = 1.95$, $p = .058$, $d_z = .31$, whereas the effect in the second block did not, $t(39) = 1.18$, $p = .24$, $d_z = .19$.

For the punishment condition, a Distractor × Phase ANOVA found no significant main effects or interaction, Fs < 1.

Discussion

As in Experiments 1 and 2, during the training phase (in which rewards/punishments were delivered) valued distractors impaired target identification at short distractor–target lags, relative to neutral distractors. For the reward condition, the effect of value was significant at lag 2 and lag 4; for the punishment condition the effect was perhaps slightly shorter-lived, being significant at lag 2 but not lag 4.

For both reward and punishment conditions, we also observed some evidence that the effect of valued distractors persisted into the extinction phase, when no valued outcomes were delivered and hence the distractors were entirely task-irrelevant. In both cases, valued distractors continued to impair performance during the first block of extinction trials. As during training, this effect was longer-lived in the reward condition (present at lag 2 and lag 4) than in the punishment condition (lag 2 only). The influence of distractor type dissipated rapidly, being absent in the second extinction block—presumably because the associations between distractors and rewards/punishments extinguished rapidly when the valued outcomes were removed during the extinction phase; that is, these stimuli lost their status as signals of valued outcomes.

The finding that valued distractors continued to impair performance during the first extinction block, even when participants were aware that no valued outcomes would be delivered, suggests that the impact of reward and punishment on performance does not (entirely) reflect a strategic search for information. Instead reward- and punishment-related distractors were still prioritized for nonspatial attention even when they no longer carried information. This finding is consistent with the idea that the impairment caused by valued distractors can be a consequence of automatic (exogenous) capture of nonspatial attention as a result of prior experience of a distractor—reward or distractor—punishment relationship.

General Discussion

Three experiments investigated how prioritization of stimuli in a temporal selection task is influenced by knowledge about the relationship between those stimuli and motivationally significant events. We measured the extent to which distractor stimuli impaired identification of a subsequent target in an RSVP task, as a function of the information signaled by the distractors regarding the consequences of a correct or incorrect response. When valued distractors signaled that a correct response to the target would be rewarded, but an incorrect response would not be punished (Experiment 1 and reward condition of Experiment 3, training phase), these reward-signaling valued distractors impaired target identification relative to neutral distractors. The implication is that, under these ‘reward-only’ conditions, participants prioritized detection of reward-related distractors even though doing so was counterproductive because it meant they performed worse on the critical trials on which reward was available (and hence earned less money) than if they had ignored these distractors. When instead valued distractors signaled that an incorrect response to the target would be punished, but a correct response would not be rewarded (Experiment 2 and punishment condition of Experiment 3, training phase), these punishment-signaling valued distractors again impaired target identification relative to neutral distractors. Thus under these ‘punishment-only’ conditions, participants prioritized detection of punishment-related distractors; once again this was counterproductive since it meant that participants experienced more punishments (and hence earned less money) than if they had ignored these distractors.

Experiment 3 demonstrated that the impairment in target identification caused by reward- and punishment-related distractors persisted (for a short time at least) into an extinction phase in which participants were aware that they would no longer receive any rewards or punishments. Under these conditions, the distractors no longer carried any information regarding the trial outcome; hence the impairment caused by valued distractors during extinction could not be a consequence of participants strategically selecting these distractors on the basis of their informational value. Instead the implication is that learning about rewards and punishments can exert an automatic influence on attentional selection, increasing the likelihood that valued distractors will capture nonspatial attention. Thus it appears that, to some extent at least, participants could not help prioritizing the selection of valued distractors, even though they knew that doing so was detrimental to their performance. This tallies with subjective experience: many participants reported their frustration at being unable to avoid noticing the bird/car in the stream, and subsequently missing the target.

Taken together, these findings demonstrate that learning about rewards or punishments can increase the extent to which stimuli command nonspatial attention, thus enhancing temporal selection. The effect on performance was broadly similar, regardless of whether rewards or punishments were involved: a between-experiments comparison did not find any significant difference in the effect of learned value in Experiments 1 and 2, and a within-experiment comparison in Experiment 3 found no significant difference in the distractor effect between the reward and punishment conditions. In both cases, the impairment caused by valued distractors was observed at short distractor–target lags of around 120–240 ms. That said, Experiment 3 produced some hints that the effect of reward might be somewhat greater than that of punishment: the significant influence of reward extended to lag 4, whereas for punishment it was observed at lag 2 only. However, although it is tempting to draw conclusions on the relative strength of the impact of reward and punishment, this should be done with caution. First, although the reward and punishment manipulations were of the same magnitude (a gain of 50 points vs. a loss of 50 points), we cannot be sure that they were equivalently salient to participants. Second, participants did not receive equal exposure to the critical reward and punishment relationships. Mean response accuracy on trials with valued distractors was well above 50% for all conditions/lags (see Figures 1 and 2). Consequently, there were more distractor–reward pairings in the reward conditions than there were distractor–punishment pairings in the punishment conditions. Hence reward-related distractors may have been stronger signals of reward than punishment-related distractors were signals of punishment. Future studies could address this issue by making feedback noncontingent on responses, so that (e.g.) participants always lost points on a trial with a punishment-related distractor, irrespective of whether their response was correct or incorrect (see Bucker & Theeuwes, 2017, for a study taking this approach in the context of spatial capture)—though under these conditions, attending to the valued distractor will not result in lower earnings and so is less clearly counterproductive (and there is still the problem of how to equate the psychological salience of reward and punishment outcomes). Regardless, a head-to-head comparison of the strength of reward and punishments effects is beyond the scope of the current research: our aim here was to investigate whether reward and punishment individually produce qualitatively similar biases in temporal selection, and our results clearly show this to be the case.

We noted in the Introduction that previous studies of visual search have shown that rapid orienting of spatial attention is enhanced for both reward- and punishment-related stimuli, suggesting that orienting is a function of the motivational significance of the outcome, rather than its valence. The current findings demonstrate that this prioritization as a function of motivational significance extends beyond initial orienting to influence competition in ongoing cognitive processes relating to perceptual awareness. Without further data, the precise nature of this competition is as yet unclear, as multiple sources of attentional interference have been linked with perceptual failures during rapid serial visual processing (Wyble & Swan, 2015). One possibility is that such competition involves mechanisms implicated in the attentional blink (see Introduction), wherein stimuli established as signals of reward or punishment gain increased salience such that, when they are encountered in the RSVP stream, they automatically initiate an attentional episode and are admitted to higher stages of processing for episodic registration and consolidation in working memory (Chun & Potter, 1995; Dux & Marois, 2009). In this case, because these processes are attentionally demanding, capture of attention by the valued distractor means that fewer attentional resources are available for higher processing of a target that follows shortly afterward. As such a short-lag target is less likely to be encoded/registered/consolidated, and hence is less likely to become available to consciousness. Alternatively, learned value may increase the weight given to distractors as they compete to drive the response of receptive fields in the visual system (see Keysers & Perrett, 2002); this mechanism has been similarly proposed to underlie emotion-induced blindness, wherein emotional distractors impair perception of targets during RSVP (e.g., Kennedy, Pearson, Sutton, Beesley, & Most, 2018). Regardless of the precise nature of this competition, the data show arguably a more profound effect of learned value than observed in previous studies of visual search, in that distractors interfered with conscious perception of the target, that is, awareness of whether a target was presented, even when that target was at the focus of spatial attention.

Learned Value and Evaluative Conditioning

The aim of the current study was to investigate whether establishing stimuli as signals of reward or punishment increases the likelihood that they are prioritized for (temporal) attentional selection. Previous research has demonstrated that pairing stimuli with positive or negative outcomes can also increase the extent to which they are liked or disliked respectively, known as evaluative conditioning (for a review, see Hofmann, De Houwer, Perugini, Baeyens, & Crombez, 2010). One possibility is that the influence of learned value on attention observed in the current study was mediated by evaluative conditioning: pairing distractors with reward or punishment produced a change in liking of those distractors, and it was this change in liking that led to attentional prioritization (with greater selection of liked/disliked stimuli than neutral stimuli). The alternative is that the influence of learned value on attention is independent of any change in affect:

stimuli are prioritized to the extent that they signal the availability of rewards/punishments, regardless of any change in liking that this may produce. The current study does not allow us to decide between these alternatives; this issue could be addressed in future studies by including an independent assessment of participants' evaluations of the distractors at the end of the experiment. An 'implicit' measure (Fazio, Sanbonmatsu, Powell, & Kardes, 1986; Greenwald & Banaji, 1995) would be ideal for this purpose to distinguish genuine changes in liking from demand effects, though it has been argued that even these so-called implicit measures are not insulated from top-down influences (e.g., Klauer & Teige-Mocigemba, 2007).

Instruction Versus Incidental Learning

In the current experiments, participants were explicitly instructed at the outset with regard to the signaling relationships in the task; that is, that one of the distractor categories signaled the possibility of reward or punishment. This raises the question of whether such instruction is necessary for the observed effects of learned value to emerge, or whether a similar pattern would occur if participants were not preinformed but instead learned the signaling relationships incidentally, through trial-by-trial experience with the task. Le Pelley et al. (2017) investigated this issue in their procedure in which valued distractors signaled *both* rewards and punishments. They found that similar effects of learned value could emerge through incidental learning, but that this learning was generally quite weak—many participants showed little evidence of having learned the status of the valued distractor category. This was the driving force behind the use of explicit instruction in the current study: presumably, incidental learning would have been even weaker in the present experiments (in which valued distractors were paired with motivationally significant outcomes only following correct responses [Experiment 1] or only following errors [Experiment 2]) than in Le Pelley et al.'s prior study (in which valued distractors were paired with motivationally significant outcomes—either reward or punishment—on *every* trial). Nevertheless, future studies could verify that incidental learning would produce the same patterns of learned value effects as observed here, though this might require extensive training and large participant samples.

Conclusion

In summary, learning about the 'signaling' (Pavlovian) relationship between stimuli and either rewards or punishments appears to influence the extent to which those stimuli are prioritized in temporal selection. That is, our study indicates a critical role for motivational significance in modulating temporal selection. Previous evidence from the neuroscience literature tentatively suggests that this influence might be mediated by a dopaminergic 'motivational significance network' that involves ventromedial prefrontal cortex (Bartra et al., 2013; Bromberg-Martin et al., 2010). The general idea that our attentional system might be adapted so as to prioritize processing of reward- and punishment-signaling stimuli is intuitive: under normal circumstances, rapidly identifying such stimuli might allow an organism more time to prepare for (or possibly even avoid, in the case of punishments) important upcoming events. However, the current experiments demonstrate that these stimuli continue to be prioritized even when doing so is maladaptive, in the sense that it reduces participants' overall payoff in a task. These findings are therefore testament to the profound and sometimes counterintuitive role that rewards and punishments can play in shaping not just our behavior, but our conscious experience of the world.

References

Albertella, L., Copeland, J., Pearson, D., Watson, P., Wiers, R. W., & Le Pelley, M. E. (2017). Selective attention moderates the relationship between attentional capture by signals of nondrug reward and illicit drug use. *Drug and Alcohol Dependence, 175,* 99–105. http://dx.doi.org/10.1016/j.drugalcdep.2017.01.041

Anderson, B. A. (2016). The attention habit: How reward learning shapes attentional selection. *Annals of the New York Academy of Sciences, 1369,* 24–39. http://dx.doi.org/10.1111/nyas.12957

Anderson, B. A., Laurent, P. A., & Yantis, S. (2011). Learned value magnifies salience-based attentional capture. *PLoS ONE, 6,* e27926. http://dx.doi.org/10.1371/journal.pone.0027926

Awh, E., Belopolsky, A. V., & Theeuwes, J. (2012). Top-down versus bottom-up attentional control: A failed theoretical dichotomy. *Trends in Cognitive Sciences, 16,* 437–443. http://dx.doi.org/10.1016/j.tics.2012.06.010

Bartra, O., McGuire, J. T., & Kable, J. W. (2013). The valuation system: A coordinate-based meta-analysis of BOLD fMRI experiments examining neural correlates of subjective value. *NeuroImage, 76,* 412–427. http://dx.doi.org/10.1016/j.neuroimage.2013.02.063

Benjamini, Y., & Hochberg, Y. (1995). Controlling the false discovery rate: A practical and powerful approach to multiple testing. *Journal of the Royal Statistical Society Series B: Methodological, 57,* 289–300.

Bromberg-Martin, E. S., Matsumoto, M., & Hikosaka, O. (2010). Dopamine in motivational control: Rewarding, aversive, and alerting. *Neuron, 68,* 815–834. http://dx.doi.org/10.1016/j.neuron.2010.11.022

Bucker, B., & Theeuwes, J. (2017). Pavlovian reward learning underlies value driven attentional capture. *Attention, Perception, & Psychophysics, 79,* 415–428.

Chun, M. M., & Potter, M. C. (1995). A two-stage model for multiple target detection in rapid serial visual presentation. *Journal of Experimental Psychology: Human Perception and Performance, 21,* 109–127. http://dx.doi.org/10.1037/0096-1523.21.1.109

Ciesielski, B. G., Armstrong, T., Zald, D. H., & Olatunji, B. O. (2010). Emotion modulation of visual attention: Categorical and temporal characteristics. *PLoS ONE, 5,* e13860. http://dx.doi.org/10.1371/journal.pone.0013860

Corbetta, M., & Shulman, G. L. (2002). Control of goal-directed and stimulus-driven attention in the brain. *Nature Reviews Neuroscience, 3,* 201–215. http://dx.doi.org/10.1038/nrn755

Cousineau, D. (2005). Confidence intervals in within-subject designs: A simpler solution to Loftus and Masson's method. *Tutorial in Quantitative Methods for Psychology, 1,* 42–45.

Dux, P. E., & Marois, R. (2009). The attentional blink: A review of data and theory. *Attention, Perception, & Psychophysics, 71,* 1683–1700. http://dx.doi.org/10.3758/APP.71.8.1683

Failing, M., Nissens, T., Pearson, D., Le Pelley, M., & Theeuwes, J. (2015). Oculomotor capture by stimuli that signal the availability of reward. *Journal of Neurophysiology, 114,* 2316–2327. http://dx.doi.org/10.1152/jn.00441.2015

Failing, M. F., & Theeuwes, J. (2015). Nonspatial attentional capture by previously rewarded scene semantics. *Visual Cognition, 23,* 82–104. http://dx.doi.org/10.1080/13506285.2014.990546

Fazio, R. H., Sanbonmatsu, D. M., Powell, M. C., & Kardes, F. R. (1986). On the automatic activation of attitudes. *Journal of Personality and Social Psychology, 50,* 229–238. http://dx.doi.org/10.1037/0022-3514.50.2.229

Folk, C. L., Leber, A. B., & Egeth, H. E. (2008). Top-down control settings and the attentional blink: Evidence for nonspatial contingent capture. *Visual Cognition, 16,* 616–642. http://dx.doi.org/10.1080/13506280601134018

Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance, 18,* 1030–1044. http://dx.doi.org/10.1037/0096-1523.18.4.1030

Gottlieb, J., Hayhoe, M., Hikosaka, O., & Rangel, A. (2014). Attention, reward, and information seeking. *The Journal of Neuroscience, 34,* 15497–15504. http://dx.doi.org/10.1523/JNEUROSCI.3270-14.2014

Greenwald, A. G., & Banaji, M. R. (1995). Implicit social cognition: Attitudes, self-esteem, and stereotypes. *Psychological Review, 102,* 4–27. http://dx.doi.org/10.1037/0033-295X.102.1.4

Hickey, C., Chelazzi, L., & Theeuwes, J. (2010). Reward changes salience in human vision via the anterior cingulate. *The Journal of Neuroscience, 30,* 11096–11103. http://dx.doi.org/10.1523/JNEUROSCI.1026-10.2010

Hofmann, W., De Houwer, J., Perugini, M., Baeyens, F., & Crombez, G. (2010). Evaluative conditioning in humans: A meta-analysis. *Psychological Bulletin, 136,* 390–421. http://dx.doi.org/10.1037/a0018916

Hogarth, L., Dickinson, A., & Duka, T. (2010). Selective attention to conditioned stimuli in human discrimination learning: Untangling the effect of outcome prediction, value and uncertainty. In C. J. Mitchell & M. E. Le Pelley (Eds.), *Attention and associative learning: From brain to behaviour* (pp. 71–97). Oxford, UK: Oxford University Press.

Hyman, S. E. (2005). Addiction: A disease of learning and memory. *The American Journal of Psychiatry, 162,* 1414–1422. http://dx.doi.org/10.1176/appi.ajp.162.8.1414

Kennedy, B. L., & Most, S. B. (2015). Affective stimuli capture attention regardless of categorical distinctiveness: An emotion-induced blindness study. *Visual Cognition, 23,* 105–117. http://dx.doi.org/10.1080/13506285.2015.1024300

Kennedy, B. L., Pearson, D., Sutton, D. J., Beesley, T., & Most, S. B. (2018). Spatiotemporal competition and task-relevance shape the spatial distribution of emotional interference during rapid visual processing: Evidence from gaze-contingent eye-tracking. *Attention, Perception, & Psychophysics, 80,* 426–438. http://dx.doi.org/10.3758/s13414-017-1448-9

Keysers, C., & Perrett, D. I. (2002). Visual masking and RSVP reveal neural competition. *Trends in Cognitive Sciences, 6,* 120–125. http://dx.doi.org/10.1016/S1364-6613(00)01852-0

Klauer, K. C., & Teige-Mocigemba, S. (2007). Controllability and resource dependence in automatic evaluation. *Journal of Experimental Social Psychology, 43,* 648–655. http://dx.doi.org/10.1016/j.jesp.2006.06.003

Kleiner, M., Brainard, D. H., & Pelli, D. G. (2007). What's new in Psychtoolbox-3? [ECVP Abstract Suppl.]. *Perception, 36,* 1–16.

Kyllingsbaek, S., Schneider, W. X., & Bundesen, C. (2001). Automatic attraction of attention to former targets in visual displays of letters. *Perception & Psychophysics, 63,* 85–98. http://dx.doi.org/10.3758/BF03200505

Le Pelley, M. E., Mitchell, C. J., Beesley, T., George, D. N., & Wills, A. J. (2016). Attention and associative learning in humans: An integrative review. *Psychological Bulletin, 142,* 1111–1140. http://dx.doi.org/10.1037/bul0000064

Le Pelley, M. E., Pearson, D., Griffiths, O., & Beesley, T. (2015). When goals conflict with values: Counterproductive attentional and oculomotor capture by reward-related stimuli. *Journal of Experimental Psychology: General, 144,* 158–171. http://dx.doi.org/10.1037/xge0000037

Le Pelley, M. E., Seabrooke, T., Kennedy, B. L., Pearson, D., & Most, S. B. (2017). Miss it and miss out: Counterproductive nonspatial attentional capture by task-irrelevant, value-related stimuli. *Attention, Perception, & Psychophysics, 79,* 1628–1642. http://dx.doi.org/10.3758/s13414-017-1346-1

MacLeod, C., Mathews, A., & Tata, P. (1986). Attentional bias in emotional disorders. *Journal of Abnormal Psychology, 95,* 15–20. http://dx.doi.org/10.1037/0021-843X.95.1.15

Nissens, T., Failing, M., & Theeuwes, J. (2017). People look at the object they fear: Oculomotor capture by stimuli that signal threat. *Cognition and Emotion, 31,* 1707–1714. http://dx.doi.org/10.1080/02699931.2016.1248905

Pearson, D., Donkin, C., Tran, S. C., Most, S. B., & Le Pelley, M. E. (2015). Cognitive control and counterproductive oculomotor capture by reward-related stimuli. *Visual Cognition, 23,* 41–66. http://dx.doi.org/10.1080/13506285.2014.994252

Pearson, D., Osborn, R., Whitford, T. J., Failing, M., Theeuwes, J., & Le Pelley, M. E. (2016). Value-modulated oculomotor capture by task-irrelevant stimuli is a consequence of early competition on the saccade map. *Attention, Perception, & Psychophysics, 78,* 2226–2240. http://dx.doi.org/10.3758/s13414-016-1135-2

Raymond, J. E., & O'Brien, J. L. (2009). Selective visual attention and motivation: The consequences of value learning in an attentional blink task. *Psychological Science, 20,* 981–988. http://dx.doi.org/10.1111/j.1467-9280.2009.02391.x

Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1992). Temporary suppression of visual processing in an RSVP task: An attentional blink? *Journal of Experimental Psychology: Human Perception and Performance, 18,* 849–860. http://dx.doi.org/10.1037/0096-1523.18.3.849

Robinson, T. E., & Berridge, K. C. (2001). Incentive-sensitization and addiction. *Addiction, 96,* 103–114. http://dx.doi.org/10.1046/j.1360-0443.2001.9611038.x

Schmidt, L. J., Belopolsky, A. V., & Theeuwes, J. (2015). Attentional capture by signals of threat. *Cognition and Emotion, 29,* 687–694. http://dx.doi.org/10.1080/02699931.2014.924484

Shapiro, K. L., Raymond, J. E., & Arnell, K. M. (1997). The attentional blink. *Trends in Cognitive Sciences, 1,* 291–296. http://dx.doi.org/10.1016/S1364-6613(97)01094-2

Smith, S. D., Most, S. B., Newsome, L. A., & Zald, D. H. (2006). An emotion-induced attentional blink elicited by aversively conditioned stimuli. *Emotion, 6,* 523–527. http://dx.doi.org/10.1037/1528-3542.6.3.523

Theeuwes, J. (1994). Endogenous and exogenous control of visual selection. *Perception, 23,* 429–440. http://dx.doi.org/10.1068/p230429

Wang, L., Yu, H., & Zhou, X. (2013). Interaction between value and perceptual salience in value-driven attentional capture. *Journal of Vision, 13,* 1–13. http://dx.doi.org/10.1167/13.15.36

Weierich, M. R., Treat, T. A., & Hollingworth, A. (2008). Theories and measurement of visual attentional processing in anxiety. *Cognition and Emotion, 22,* 985–1018. http://dx.doi.org/10.1080/02699930701597601

Wentura, D., Müller, P., & Rothermund, K. (2014). Attentional capture by evaluative stimuli: Gain- and loss-connoting colors boost the additional-singleton effect. *Psychonomic Bulletin & Review, 21,* 701–707. http://dx.doi.org/10.3758/s13423-013-0531-z

Wiers, R. W., & Stacy, A. W. (2006). Implicit cognition and addiction. *Current Directions in Psychological Science, 15,* 292–296. http://dx.doi.org/10.1111/j.1467-8721.2006.00455.x

Wyble, B., & Swan, G. (2015). Mapping the spatiotemporal dynamics of interference between two visual targets. *Attention, Perception, & Psychophysics, 77,* 2331–2343. http://dx.doi.org/10.3758/s13414-015-0938-x

Yantis, S. (2000). Goal-directed and stimulus-driven determinants of attentional control. In S. Monsell & J. Driver (Eds.), *Attention and performance XVIII* (pp. 73–103). Cambridge, MA: MIT Press.

Received July 7, 2017
Revision received March 10, 2018
Accepted March 15, 2018 ■