# Prioritizing pleasure and pain: attentional capture by reward-related and punishment-related stimuli

Watson, P.; Pearson, D.; Wiers, R.W.; Le Pelley, M.E.

**DOI**
10.1016/j.cobeha.2018.12.002

**Publication date**
2019

**Document Version**
Final published version

**Published in**
Current Opinion in Behavioral Sciences

**License**
Article 25fa Dutch Copyright Act

Available online at www.sciencedirect.com

ScienceDirect

ELSEVIER

Current Opinion in Behavioral Sciences

# Prioritizing pleasure and pain: attentional capture by reward-related and punishment-related stimuli

Poppy Watson[1], Daniel Pearson[1], Reinout W Wiers[2] and Mike E Le Pelley[1]

Attention is shaped by our prior experiences with stimuli, and in particular by learning about their relationship with motivationally significant events: rewards and punishments. While it is typically adaptive to prioritize detection of signals of reward and punishment, recent evidence suggests that attentional prioritization of motivationally relevant information can be involuntary and inflexible, which can be counterproductive when circumstances change, and these signals are no longer the focus of a person's goals. We review this literature, which suggests that attentional capture is promoted by learning about both rewards and punishments, though further research is required to probe for differences in the temporal dynamics of these processes. We also highlight the clinical relevance of interactions between appetitive and aversive motivation and perceptual-cognitive processes.

**Addresses**
[1] School of Psychology, UNSW Sydney, Sydney, Australia
[2] ADAPT Lab, Department of Psychology, University of Amsterdam, The Netherlands

Corresponding author: Watson, Poppy (poppy.watson@unsw.edu.au)

**Current Opinion in Behavioral Sciences** 2019, **26**:107–113

This review comes from a themed issue on **Pain and aversive motivation**

Edited by **Ben Seymour** and **Joshua Johansen**

For a complete overview see the Issue and the Editorial

Available online 2nd January 2019

**https://doi.org/10.1016/j.cobeha.2018.12.002**



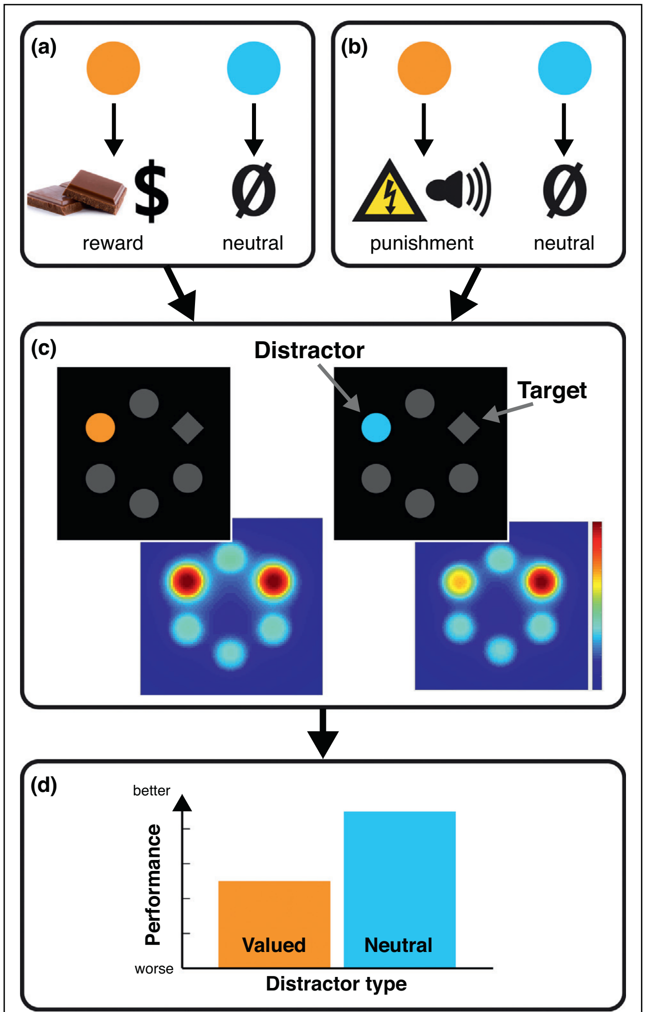
## Introduction

Attention refers to the set of cognitive processes that act to prioritize certain information in the environment. Traditional accounts [e.g. Refs. 1,2] distinguish between stimulus-driven attention (determined by physical features of stimuli) and goal-directed attention (driven by the goals of the observer). Recent research has extended this view by showing that attention is also powerfully affected by our prior experiences—often referred to as an effect of selection history—in a way that falls outside the stimulus-driven/goal-directed distinction [3–5]. For example, it has been shown that attention automatically prioritizes stimuli that have previously been selected as targets [6,7,8•] and is biased toward stimuli that have previously provided useful information about upcoming events, or the utility of different actions [9–13]. In this article, we review recent evidence on a further facet of selection history: namely that attention is shaped by prior experience of the relationship between stimuli and motivationally significant outcomes — rewards and punishments (see Figure 1). We begin by outlining the burgeoning literature on effects of reward-signaling stimuli on attention, before considering the somewhat smaller collection of studies examining effects of aversive stimuli. Some of the studies reviewed here used eye gaze data to provide a relatively direct measure attention whereas others used (arguably) less direct measures of attention such as reaction time and accuracy. Additionally, studies differ in the complexity of the visual displays used which can range from simplistic shapes and colors to more complex visual displays comprised of a variety of colors or naturalistic scenes. Regardless of the methods used, similar patterns of results have been observed.

## Attentional capture by reward-related stimuli

In many situations, it is adaptive to prioritize the detection of reward-related stimuli, since these are the stimuli that should motivate goal-directed behavior [14]. For example, if red berries have previously been experienced as tasty, a forager should prioritize detection of red items. However, it is not always useful or adaptive to prioritize stimuli that have previously been reward-associated, particularly when circumstances change. For example, imagine our forager moves to a new area in which red berries are bland and non-nutritious, but tasty yellow berries are abundant: it is no longer adaptive to prioritize red items. However, abundant recent evidence suggests that humans continue to prioritize detection of previously reward-related stimuli even when doing so is no longer adaptive [for reviews, see: Refs. 3–5]. Many studies have used visual search tasks to demonstrate that reward history influences the extent to which stimuli capture spatial attention and several different variants of this approach have been used. In one [15–18], during an initial training phase, participants receive high reward for responding to (say) a red target, and low reward for responding to a blue target. In a subsequent test phase (in which rewards are no longer available), participants are informed that they must now search for and respond to a target that is defined by its shape (e.g. a diamond among

**Figure 1**




Current Opinion in Behavioral Sciences

Schematic of value-modulated attentional capture. A *valued* stimulus (in this case an orange circle) is paired with either **(a)** reward (e.g. chocolate or money) or **(b)** punishment (e.g. electrical shock or loud noise), while a *neutral* stimulus is not paired with reward or punishment (or in some studies, is paired with smaller rewards/ punishments than the valued stimulus). In a subsequent task **(c)**, the previously experienced stimuli are presented as distractors. The example here is a visual search task, in which participants' aim to is locate a diamond (target) shape among circles as quickly as possible; one of the circles (the distractor) is rendered in either the valued (orange) or neutral (blue) color. Heat maps represent the salience of each location in the display on an attentional priority map [85,86]. Relative to the non-salient grey circles, saliency of the target diamond is enhanced as a result of top-down attentional set [87]. Both colored circles are physically salient by virtue of their status as color singletons [88], but critically the orange circle (valued distractor) is rendered particularly salient due to prior learning of its status as a signal of reward/punishment. This value signal is integrated early on into topographical saccade maps, competing with (or enhancing) other salience signals (e.g. selection history or physical salience) to prioritize attentional focus [35,85,89]. The increased salience of the valued distractor (relative to the neutral distractor) means that it is more likely to capture attention and hence impair participants' performance in the task **(d)**.

circles), and that color is now irrelevant. Response time to the target is often found to be slower when one of the non-target shapes in the search display (termed the *distractor*) is rendered in the color previously associated with high reward (red in this example) versus the color that was associated with low reward [15–18].[1] The implication is that the 'high-value' distractor is more likely to capture participants' attention and hence slow search for the target. Thus, the effect of differential reward for orienting attention toward high value versus low value colors during the training phase persists to influence orienting toward these colors in the test phase even when these colors are now task-irrelevant (so that attending to them is contrary to participants' current task goals). A variant of this approach condenses the training and test phases into a single trial each, and demonstrates that providing a large reward for responding to (say) a red target on trial N increases the likelihood that a red distractor will capture attention on trial N + 1 [21•,22–24].

The studies described in the previous paragraph effectively implement instrumental conditioning procedures: participants are rewarded for attending to particular colors during the training phase (or on trial N), and these colors continue to capture attention during the subsequent test phase (or on trial N + 1) when they are now task-irrelevant. As such, one interpretation of these studies is that they suggest that attention can become a conditioned 'habit' [25] just as other forms of more overt behavior can become habitual and hence no longer under the control of a person's current goals [26,27]. However, evidence for a true attentional habit requires a demonstration that attentional capture persists for a stimulus that has previously been paired with a rewarding outcome, *even though that outcome is no longer rewarding*: that is, despite devaluation of the outcome. We are aware of two studies that have investigated this issue. In one of these, Pool *et al.* [28] demonstrated reduced attentional capture by a stimulus that previously produced a chocolate reward after participants were fed chocolate to satiety, relative to a non-sated control group. This suggests that reward-related attentional capture *is* sensitive to shifts in motivational

[1] We note that a number of studies using this 'training phase — test phase' procedure have claimed to show evidence of an effect of reward on attention on the basis of a comparison (during the test phase) between performance on trials featuring a distractor in a color that was paired with high reward during the training phase, and trials without a distractor in either of the target colors from the training phase [e.g. Refs. 19,20]. This contrast is flawed, however, as the difference in reward history is confounded with a difference in whether the distractor has previously been selected as a target over hundreds of training trials, which—as noted earlier—itself has been shown to influence attentional capture [6,8•]. In contrast, the high-reward versus low-reward contrast is specific to the effect of reward, since (across participants) these cues differ only in their reward history. In this article we include only studies in which the critical comparison indicating an effect of reward or punishment is not confounded with differences in prior selection, or perceptual salience.

significance of outcomes (contrary to the idea of a truly habitual response). A second study [29•] used electroencephalography to show that low-latency neural markers of visual attention to reward-related stimuli were unaffected by outcome devaluation (consistent with a habitual component to attention), whereas slower components were sensitive to the current value of the outcome (consistent with a goal-directed process). Given these mixed findings, and a general paucity of existing evidence, further work is warranted to assess whether value-modulated attentional capture can reflect formation of true instrumental habits.

Other studies have demonstrated that attentional capture can also be modulated by Pavlovian conditioning, in which stimuli are established as signals of reward but are never the targets that participants must respond to in order to obtain that reward [30–33,34••]. In one such procedure using eye tracking [30–32,35], participants had to make a saccade to a single diamond among a set of circles on each trial. The color of one of the circles (the distractor) signaled the size of the monetary reward—high or low—that would be produced by making a rapid saccade to the diamond target. If participants looked at the reward-signaling distractor circle, however, the reward that would otherwise have been delivered on that trial was cancelled. Hence the critical distractors were Pavlovian signals of reward magnitude, but the instrumental action of looking at these distractors was never rewarded. Nevertheless, participants were more likely to look at distractors that signaled high rather than low reward, even though this was counterproductive as it meant they missed out on more of the high-value rewards. This influence of Pavlovian reward-signaling on attentional capture has been likened to *sign-tracking* in animals — a tendency to approach and engage with cues that signal reward and an animal model of vulnerability for drug addiction [36,37]. In line with this latter issue, one study using this procedure found that among individuals with relatively low levels of executive control (who should be particularly susceptible to capture by salient stimuli), the influence of reward on attentional capture was positively correlated with illicit drug use [38•]. See Box 1 for further discussion of clinical implications of research on attention and reward/punishment.

**Box 1 Clinical considerations.**

The effects of rewards and punishments on attention are interesting not only because of what they tell us about interactions between motivational and perceptual-cognitive processes, but also because of their potential clinical relevance. For example, many studies have shown that drug use and disorders are associated with abnormal attentional biases toward drug-related stimuli [see for reviews: 72,73]. It has been argued that such biases are learned: repeated pairing of certain stimuli with the reward consequences of taking a drug leads to these stimuli acquiring *incentive salience* [74,75], which increases the likelihood that they will attract attention and control behavior in their own right. On this view, we can see laboratory studies of attentional capture by reward-related cues as a model of processes relevant to the development and maintenance of addiction. Indeed, one study has shown that attentional capture by distractors related to *non*-drug (monetary) reward correlated with illicit drug use, in particular among participants scoring low on a task of executive control; a further study [20] also found evidence consistent with greater reward-related capture among recovering opioid addicts, though this finding was confounded with a difference in selection history. These results suggest two possibilities: (1) individuals who are *generally* more likely to have their behavior come under the control of reward-related stimuli have a greater risk of drug use; or (2) greater levels of drug use lead to greater capture by stimuli related to non-drug reward, perhaps via sensitization of neural pathways related to reward processing [75,76]. It remains for future research to establish the causal direction here.

On the flip-side, emotional disorders such as anxiety and depression have been linked with biased attention to negative emotional information [see for reviews: 77,78]. This raises the idea that studies of attentional capture by stimuli learned to be signals of punishment (see below) might provide a laboratory model of processes involved in the development and maintenance of anxiety. We are not aware of any studies that have assessed capture by punishment-related stimuli in anxious or depressed individuals; this could be a priority for future research.

Dysfunction of the relationship between learning and attention may also be implicated in schizophrenia, and particularly the psychotic (positive) symptoms such as hallucinations and delusions. Prominent theories of schizophrenia argue that these arise due to inappropriate perceptual and motivational significance being assigned to external and internal events [79,80]. Such 'aberrant salience' is argued to arise through dopamine dysregulation and the misallocation of attention to irrelevant stimuli [79,81,82]. Although reward learning appears to be relatively intact in individuals diagnosed with schizophrenia [83,84], an interesting avenue for future research could be whether schizophrenia is associated with heightened susceptibility to attentional capture by distractors that have been associated with reward or punishment, using the paradigms reviewed here.

All the studies reviewed above have examined capture of spatial attention; that is, selection of stimuli that occur in a particular location in space. Learned reward also influences selection of stimuli that occur at a particular moment in time [33,34••].[2] In these studies, participants viewed a rapid stream of images of landscapes and had to identify a rotated target image in this stream. A distractor image (either a bird or a car) could appear before this target. Distractors from one category signaled that a correct response to the target would earn monetary reward; distractors from the other category signaled that a correct response would not be rewarded. Critically, participants were less accurate on trials where the target was shortly preceded by an image from the reward-signaling category. That is, accuracy was lower on trials which influenced participants' final payoff than on trials that were unrewarded and hence 'didn't matter'. The implication is that the reward-related distractor was more

[2] We note that other studies have used similar procedures [e.g. Refs. 39,40] but have been excluded from the current review because selection history was introduced as a confound during the initial conditioning phase (e.g. a binary choice task where participants had to repeatedly choose some stimuli more than others in order to maximize reward).

likely to command attention and hence (temporarily) reduce perceptual processing and conscious perception of a subsequent target.

## Attentional capture by punishment-related stimuli

Up to this point, we have considered the effect of rewards on attentional prioritization. In the next section, we review research looking at the effect of punishments, in order to establish whether punishment-related stimuli also capture attention. More generally, the question is 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 represent meaningful outcomes for the individual), or by the valence of that outcome (whether it is affectively positive [appetitive] or negative [aversive]). The opposing effects of appetitive and aversive outcomes on behavior are well documented—we approach things that signal reward and avoid those that signal punishment—with different neural pathways and populations of dopaminergic neurons supporting these different responses [41–43]. However, a distinct set of dopaminergic neuronal populations and networks is activated by motivationally salient stimuli regardless of valence, and it has been argued that these systems might support initial attentional orienting toward stimuli that should motivate behavior (whether that behavior is approach or avoidance: [41–44]).

Consistent with this latter idea, a number of recent studies of both spatial and temporal selection have demonstrated attentional prioritization of stimuli that signal aversive outcomes, including electric shock [45,46,47••,48–50], loud noises [51–53] and loss of money [34••,50,54]. In all cases, punishment-related stimuli were more likely to capture attention when they were presented as distractors, interfering with participants' ongoing goal to respond to a distinct target. For example, Schmidt *et al.* [48] had an initial Pavlovian conditioning phase in which presentation of one color signaled delivery of electric shock, while another color signaled that no shock would be delivered. In a subsequent visual search task, responses to a target were slower when the display contained a distractor rendered in the previously-shock-related color than the 'safe' color. In the domain of temporal attention, studies have shown that detection of a target in a rapid stream of images is impaired if that target is shortly preceded by a distractor that has previously signaled loss of money [34••], or an aversive noise [53].

Some studies have attempted to establish whether rewards or punishments have a greater effect on attentional capture by directly comparing, within subjects, whether distractor stimuli that have previously signaled monetary gain versus loss (of equal magnitude) interfere to the same degree with ongoing visual search for a target [21•,50,54,55]. Results from these studies are mixed, with some suggesting that attentional capture is similar in magnitude across both loss and reward trials [50,54] and others reporting that while both loss and reward-related distractors caused interference, these effects were stronger for reward-related distractors [21•,55]. That said, it is not easy to directly compare effects of rewards and punishments in this way, since gains and losses that are objectively of equal magnitude may not be perceived as being 'motivationally equivalent' by participants [56].

Regardless of the relative magnitude of reward versus punishment effects, the studies described in this section suggest that punishment-related stimuli receive attentional priority even when they are presented as distractors, consistent with the idea that learning about aversive outcomes modulates attentional capture just as for rewards. This idea is intuitive: it makes sense to have a perceptual system that prioritizes detection of punishment-signaling stimuli, since rapidly identifying these stimuli may allow us to take appropriate action to minimize or avoid the effect of punishment. But what happens after initial detection? Do punishment-related distractors maintain attention, or is initial orienting followed by avoidance [57,58]? The evidence on this issue is currently unclear. One recent study found that attention was maintained at the location of a fear-related stimulus for a prolonged period (at least 1000 ms) [59•]; another found evidence consistent with punishment-related stimuli capturing attention at short latencies, but repelling attention at longer latencies [51]; still further studies have found little difference between punishment-related and neutral stimuli at long latencies [34••,47••,53]. Further evidence is needed to establish the temporal dynamics of the attentional prioritization of punishment-related stimuli, which will shed important light on perceptual-cognitive processing of aversive events and its effect on behavior.

## Interactions between learning and attention

Inherent to the studies reviewed above is the assumption that learning of the predictive relationships between specific cues and outcomes has shaped the direction and focus of attention. Influential models of learning and attention, however, argue for a *bidirectional* relationship between learning and attention [61,62] and it has been demonstrated that attention directed toward cues will also influence the rate at which learning novel information about those cues occurs [e.g. following a shift in the degree to which it is predictive of a relevant outcome: 63–65,66••]. Together these studies demonstrate that attention is essential for our interaction with the complex environment, allowing for effective and efficient exploration of novel scenarios and also directing exploitation of what has been previously learned. In contrast to traditional accounts which have argued that attention is selective due to inherent capacity limitations [67,68] it has in fact been suggested that attention is functionally selective, as a means of constraining learning [66••,69,70]. Within this context it is not surprising that cues that signal reward and punishment have such profound effects on attention, as these are essential signals for adaptation and survival which should, under most conditions, receive attentional priority. However, as was outlined in the introduction, it is not always adaptive to prioritize stimuli that have previously been associated with reward or punishment and a change in circumstances requires flexible updating of attentional priorities. Individual differences that underlie the ability to ignore task-irrelevant but motivationally salient distractors remain to be elucidated but are likely to include differences in reward/punishment sensitivity and executive control capacity [22,60••,71].

## Conclusions

The research reviewed here suggests that pairing a stimulus with either reward or punishment will increase the likelihood that it subsequently captures attention, even when it is presented as a task-irrelevant distractor such that attention to this stimulus is contrary to participants' current goals. This review has also highlighted the gaps in the literature: more studies are required that investigate attentional capture by stimuli signaling loss/punishment (in particular with regard to establishing the temporal dynamics of these effects), along with more studies systematically varying the motivational significance of outcomes (including outcome devaluation). Understanding the interaction between incentive salience—developed through learning about rewards and punishments—and attention is crucial for a better understanding of the role these processes play in psychopathology.

## Conflict of interest statement

Nothing declared.

## Funding

Poppy Watson is supported by Australian Research Council grant DP170101715. Daniel Pearson is supported by an Australian Government Research Training Program Scholarship.

## References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- • of special interest
- •• of outstanding interest


1. Corbetta M, Shulman GL: **Control of goal-directed and stimulus-driven attention in the brain**. *Nat Rev Neurosci* 2002, **3**:201-215.

2. Yantis S: **Goal-directed and stimulus-driven determinants of attentional control**. In *Attention and Performance*. Edited by Monsell S, Driver J. MIT Press; 2000.

3. Awh E, Belopolsky AV, Theeuwes J: **Top-down versus bottom-up attentional control: a failed theoretical dichotomy**. *Trends Cogn Sci* 2012, **16**:437-443.

4. Failing M, Theeuwes J: **Selection history: how reward modulates selectivity of visual attention**. *Psychon Bull Rev* 2018, **25**:514-538.

5. Le Pelley ME, Mitchell CJ, Beesley T, George DN, Wills AJ: **Attention and associative learning in humans: an integrative review**. *Psychol Bull* 2016, **142**:1111-1140.

6. Kyllingsbaek S, Schneider WX, Bundesen C: **Automatic attraction of attention to former targets in visual displays of letters**. *Percept Psychophys* 2001, **63**:85-98.

7. Qu Z, Hillyard SA, Ding Y: **Perceptual learning induces persistent attentional capture by nonsalient shapes**. *Cereb Cortex* 2017, **27**:1512-1523.

8. • Sha LZ, Jiang YV: **Components of reward-driven attentional capture**. *Atten Percept Psychophys* 2016, **78**:403-414.
The authors critically analyze the existing evidence for the role of value in value-driven attentional capture.

9. Feldmann-Wüstefeld T, Uengoer M, Schubö A: **You see what you have learned. Evidence for an interrelation of associative learning and visual selective attention**. *Psychophysiology* 2015, **52**:1483-1497.

10. Gottlieb J: **Attention, learning and the value of information**. *Neuron* 2012, **76**:281-295.

11. Gottlieb J, Hayhoe M, Hikosaka O, Rangel A: **Attention, reward, and information seeking**. *J Neurosci* 2014, **34**:15497-15504.

12. Kadel H, Feldmann-Wüstefeld T, Schubö A: **Selection history alters attentional filter settings persistently and beyond top-down control**. *Psychophysiology* 2017, **54**:736-754.

13. Le Pelley ME, Vadillo M, Luque D: **Learned predictiveness influences rapid attentional capture: evidence from the dot probe task**. *J Exp Psychol Learn Mem Cogn* 2013, **39**:1888-1900.

14. Engelmann JB, Pessoa L: **Motivation sharpens exogenous spatial attention**. *Emotion* 2007, **7**:668-674.

15. Anderson BA, Halpern M: **On the value-dependence of value-driven attentional capture**. *Atten Percept Psychophys* 2017, **79**:1001-1011.

16. Anderson BA, Yantis S: **Persistence of value-driven attentional capture**. *J Exp Psychol Hum Percept Perform* 2013, **39**:6-9.

17. Failing M, Theeuwes J: **Exogenous visual orienting by reward**. *J Vis* 2014, **14**:6.

18. Theeuwes J, Belopolsky AV: **Reward grabs the eye: oculomotor capture by rewarding stimuli**. *Vision Res* 2012, **74**:80-85.

19. Anderson BA, Kuwabara H, Wong DF, Gean EG, Rahmim A, Brašić JR, George N, Frolov B, Courtney SM, Yantis S: **The role of dopamine in value-based attentional orienting**. *Curr Biol* 2016, **26**:550-555.

20. Anderson BA, Faulkner ML, Rilee JJ, Yantis S, Marvel CL: **Attentional bias for non-drug reward is magnified in addiction**. *Exp Clin Psychopharmacol* 2013, **21**:499-506.

21. • Barbaro L, Peelen MV, Hickey C: **Valence, not utility, underlies reward-driven prioritization in human vision**. *J Neurosci* 2017, **37**:10438-10450.
Using naturalistic scene viewing the authors argue that objects previously associated with reward are more distracting than those associated with punishment.

22. Hickey C, Chelazzi L, Theeuwes J: **Reward guides vision when it's your thing: trait reward-seeking in reward-mediated visual priming**. *PLoS One* 2010, **5**:e14087.

23. Hickey C, Peelen MV: **Neural mechanisms of incentive salience in naturalistic human vision**. *Neuron* 2015, **85**:512-518.

24. Hickey C, van Zoest W: **Reward-associated stimuli capture the eyes in spite of strategic attentional set**. *Vis Res* 2013, **92**:67-74.

25. Anderson BA: **The attention habit: how reward learning shapes attentional selection**. *Ann N Y Acad Sci* 2016, **1369**:24-39.

26. Balleine BW, O'Doherty JP: **Human and rodent homologies in action control: corticostriatal determinants of goal-directed and habitual action**. *Neuropsychopharmacology* 2010, **35**:48-69.

27. Dickinson A: **Actions and habits: the development of behavioural autonomy**. *Philos Trans R Soc Lond B Biol Sci* 1985, **308**:67-78.

28. Pool E, Brosch T, Delplanque S, Sander D: **Where is the chocolate? Rapid spatial orienting toward stimuli associated with primary rewards**. *Cognition* 2014, **130**:348-359.

29. • Luque D, Beesley T, Morris RW, Jack BN, Griffiths O, Whitford TJ, Le Pelley ME: **Goal-directed and habit-like modulations of stimulus processing during reinforcement learning**. *J Neurosci* 2017, **37**:3009-3017.
The authors use outcome devaluation to identify the time course of neural components indexing habitual and goal-directed attentional processes.

30. Le Pelley ME, Pearson D, Griffiths O, Beesley T: **When goals conflict with values: counterproductive attentional and oculomotor capture by reward-related stimuli**. *J Exp Psychol Gen* 2015, **144**:158-171.

31. Failing M, Nissens T, Pearson D, Le Pelley M, Theeuwes J: **Oculomotor capture by stimuli that signal the availability of reward**. *J Neurophysiol* 2015, **114**:2316-2327.

32. Pearson D, Donkin C, Tran SC, Most SB, Le Pelley ME: **Cognitive control and counterproductive oculomotor capture by reward-related stimuli**. *Vis Cogn* 2015, **23**:41-66.

33. Le Pelley ME, Seabrooke T, Kennedy BL, Pearson D, Most SB: **Miss it and miss out: counterproductive nonspatial attentional capture by task-irrelevant, value-related stimuli**. *Atten Percept Psychophys* 2017, **79**:1628-1642.

34. •• Le Pelley ME, Watson P, Pearson D, Abeywickrama RS, Most SB: **Winners and losers: reward and punishment produce biases in temporal selection**. *J Exp Psychol Learn Mem Cogn* 2018. Advance online publication.
Participants were more likely to miss the target in a rapid stream of images when it was preceded by a distractor signaling availability of reward or punishment, relative to a neutral distractor. Demonstrates that rewards and punishments influence temporal selection.

35. Pearson D, Osborn R, Whitford TJ, Failing M, Theeuwes J, Le Pelley ME: **Value-modulated oculomotor capture by task-irrelevant stimuli is a consequence of early competition on the saccade map**. *Atten Percept Psychophys* 2016, **78**:2226-2240.

36. Tomie A, Grimes KL, Pohorecky LA: **Behavioral characteristics and neurobiological substrates shared by Pavlovian sign-tracking and drug abuse**. *Brain Res Rev* 2008, **58**:121-135.

37. Tunstall BJ, Kearns DN: **Sign-tracking predicts increased choice of cocaine over food in rats**. *Behav Brain Res* 2015, **281**:222-228.

38. • Albertella L, Copeland J, Pearson D, Watson P, Wiers RW, Le Pelley ME: **Selective attention moderates the relationship between attentional capture by signals of nondrug reward and illicit drug use**. *Drug Alcohol Depend* 2017, **175**:99-105.
This study is one of the first to highlight a link between illicit drug use and attentional bias for general (financial) reward.

39. Failing M, Theeuwes J: **Nonspatial attentional capture by previously rewarded scene semantics**. *Vis Cogn* 2015, **23**:82-104.

40. Rutherford HJV, O'Brien JL, Raymond JE: **Value associations of irrelevant stimuli modify rapid visual orienting**. *Psychon Bull Rev* 2010, **17**:536-542.

41. Bartra O, McGuire JT, Kable JW: **The valuation system: a coordinate-based meta-analysis of BOLD fMRI experiments examining neural correlates of subjective value**. *NeuroImage* 2013, **76**:412-427.

42. Bromberg-Martin ES, Matsumoto M, Hikosaka O: **Dopamine in motivational control: rewarding, aversive, and alerting**. *Neuron* 2010, **68**:815-834.

43. Volkow ND, Wise RA, Baler R: **The dopamine motive system: implications for drug and food addiction**. *Nat Rev Neurosci* 2017, **18**:741-752.

44. Cunningham WA, Van Bavel JJ, Johnsen IR: **Affective flexibility: evaluative processing goals shape amygdala activity**. *Psychol Sci* 2008, **19**:152-160.

45. Hopkins LS, Helmstetter FJ, Hannula DE: **Eye movements are captured by a perceptually simple conditioned stimulus in the absence of explicit contingency knowledge**. *Emotion* 2016, **16**:1157-1171.

46. Koenig S, Uengoer M, Lachnit H: **Attentional bias for uncertain cues of shock in human fear conditioning: evidence for attentional learning theory**. *Front Hum Neurosci* 2017, **11**.

47. •• Nissens T, Failing M, Theeuwes J: **People look at the object they fear: oculomotor capture by stimuli that signal threat**. *Cogn Emot* 2017, **31**:1707-1714.
The authors demonstrate involuntary oculomotor capture by stimuli that signal the possibility of receiving an electric shock.

48. Schmidt LJ, Belopolsky AV, Theeuwes J: **Attentional capture by signals of threat**. *Cogn Emot* 2015, **29**:687-694.

49. Schmidt LJ, Belopolsky AV, Theeuwes J: **Potential threat attracts attention and interferes with voluntary saccades**. *Emotion* 2015, **15**:329-338.

50. Wang L, Yu H, Zhou X: **Interaction between value and perceptual salience in value-driven attentional capture**. *J Vis* 2013, **13**:5.

51. Mulckhuyse M, Crombez G, Van der Stigchel S: **Conditioned fear modulates visual selection**. *Emotion* 2013, **13**:529-536.

52. Mulckhuyse M, Dalmaijer ES: **Distracted by danger: temporal and spatial dynamics of visual selection in the presence of threat**. *Cogn Affect Behav Neurosci* 2016, **16**:315-324.

53. Smith SD, Most SB, Newsome LA, Zald DH: **An emotion-induced attentional blink elicited by aversively conditioned stimuli**. *Emotion* 2006, **6**:523-527.

54. Wentura D, Müller P, Rothermund K: **Attentional capture by evaluative stimuli: gain- and loss-connoting colors boost the additional-singleton effect**. *Psychon Bull Rev* 2014, **21**:701-707.

55. Gupta R, Hur Y-J, Lavie N: **Distracted by pleasure: effects of positive versus negative valence on emotional capture under load**. *Emotion* 2016, **16**:328-337.

56. Kahneman D, Tversky A: **Choices, values, and frames**. *Am Psychol* 1984, **39**:341-350.

57. Hogarth L, Dickinson A, Duka T: **Selective attention to conditioned stimuli in human discrimination learning: untangling the effect of outcome prediction, valence, arousal and uncertainty**. In *Attention and Associative Learning: From Brain to Behaviour.* Edited by Mitchell CJ, Le Pelley ME. Oxford University Press; 2010.

58. Weierich MR, Treat TA, Hollingworth A: **Theories and measurement of visual attentional processing in anxiety**. *Cogn Emot* 2008, **22**:985-1018.

59. • Schmidt LJ, Belopolsky AV, Theeuwes J: **The time course of attentional bias to cues of threat and safety**. *Cogn Emot* 2017, **31**:845-857.
The temporal dynamics of counterproductive attentional bias toward a stimulus previously associated with electrical shock are investigated.

60. •• Jahfari S, Theeuwes J: **Sensitivity to value-driven attention is predicted by how we learn from value**. *Psychon Bull Rev* 2017, **24**:408-415.
The authors used a computational reinforcement learning model and correlated individual learning rate parameters in an instrumental learning task with the degree of attentional capture by reward in a subsequent visual search task.

61. Pearce JM, Hall G: **A model for Pavlovian learning: variations in the effectiveness of conditioned but not of unconditioned stimuli**. *Psychol Rev* 1980, **87**:532-552.

62. Mackintosh NJ: **A theory of attention: variations in the associability of stimuli with reinforcement**. *Psychol Rev* 1975, **82**:276-298.

63. Beesley T, Nguyen KP, Pearson D, Le Pelley ME: **Uncertainty and predictiveness determine attention to cues during human associative learning**. *Q J Exp Psychol* 2015, **68**:2175-2199.

64. Le Pelley ME, Beesley T, Griffiths O: **Overt attention and predictiveness in human contingency learning**. *J Exp Psychol Anim Behav Process* 2011, **37**:220-229.

65. Mitchell CJ, Griffiths O, Seetoo J, Lovibond PF: **Attentional mechanisms in learned predictiveness**. *J Exp Psychol Anim Behav Process* 2012, **38**:191-202.

66. •• Leong YC, Radulescu A, Daniel R, DeWoskin V, Niv Y: **Dynamic interaction between reinforcement learning and attention in multidimensional environments**. *Neuron* 2017, **93**:451-463.
The authors use eye tracking, neuroimaging, and computation reinforcement learning models to examine the bidirectional constraints of attention and learning on a trial-by-trial basis.

67. Broadbent D: *Perception and Communication*. Elsevier Science; 1958.

68. Kahneman D: *Attention and Effort*. Prentice-Hall; 1973.

69. Dayan P, Kakade S, Montague PR: **Learning and selective attention**. *Nat Neurosci* 2000, **3**:1218-1223.

70. Scalf PE, Torralbo A, Tapia E, Beck DM: **Competition explains limited attention and perceptual resources: implications for perceptual load and dilution theories**. *Front Psychol* 2013, **4**.

71. Yantis S, Anderson BA, Wampler EK, Laurent PA: **Reward and attentional control in visual search**. *Nebr Symp Motiv* 2012, **59**:91-116.

72. Field M, Cox WM: **Attentional bias in addictive behaviors: a review of its development, causes, and consequences**. *Drug Alcohol Depend* 2008, **97**:1-20.

73. Wiers RW, Field M, Stacy AW: **Passion's slave? Conscious and unconscious cognitive processes in alcohol and drug abuse**. In *The Oxford Handbook of Substance Use and Substance Use Disorders.* Edited by Sher KJ. Oxford University Press; 2016.

74. Berridge KC, Robinson TE, Aldridge JW: **Dissecting components of reward: 'liking', 'wanting', and learning**. *Curr Opin Pharmacol* 2009, **9**:65-73.

75. Robinson TE, Berridge KC: **The psychology and neurobiology of addiction: an incentive-sensitization view**. *Addict Abingdon Engl* 2000, **95**:S91-117.

76. Flagel SB, Akil H, Robinson TE: **Individual differences in the attribution of incentive salience to reward-related cues: implications for addiction**. *Neuropharmacology* 2009, **56**:139-148.

77. Goodwin H, Yiend J, Hirsch CR: **Generalized anxiety disorder, worry and attention to threat: a systematic review**. *Clin Psychol Rev* 2017, **54**:107-122.

78. Mogg K, Bradley BP: **Anxiety and attention to threat: cognitive mechanisms and treatment with attention bias modification**. *Behav Res Ther* 2016, **87**:76-108.

79. Kapur S: **Psychosis as a state of aberrant salience: a framework linking biology, phenomenology, and pharmacology in schizophrenia**. *Am J Psychiatry* 2003, **160**:13.

80. Nelson B, Whitford TJ, Lavoie S, Sass LA: **What are the neurocognitive correlates of basic self-disturbance in schizophrenia? Integrating phenomenology and neurocognition: Part 2 (Aberrant salience)**. *Schizophr Res* 2014, **152**:20-27.

81. Fletcher PC, Frith CD: **Perceiving is believing: a Bayesian approach to explaining the positive symptoms of schizophrenia**. *Nat Rev Neurosci* 2009, **10**:48-58.

82. Griffiths O, Langdon R, Le Pelley ME, Coltheart M: **Delusions and prediction error: re-examining the behavioural evidence for disrupted error signalling in delusion formation**. *Cognit Neuropsychiatry* 2014, **19**:439-467.

83. Roiser JP, Stephan KE, den Ouden HEM, Barnes TRE, Friston KJ, Joyce EM: **Do patients with schizophrenia exhibit aberrant salience?** *Psychol Med* 2009, **39**:199-209.

84. Bansal S, Robinson BM, Geng JJ, Leonard CJ, Hahn B, Luck SJ, Gold JM: **The impact of reward on attention in schizophrenia**. *Schizophr Res Cogn* 2018, **12**:66-73.

85. Belopolsky AV: **Common priority map for selection history, reward and emotion in the oculomotor system**. *Perception* 2015, **44**:920-933.

86. Klink PC, Jentgens P, Lorteije JAM: **Priority maps explain the roles of value, attention, and salience in goal-oriented behavior**. *J Neurosci* 2014, **34**:13867-13869.

87. Itti L, Koch C: **Computational modelling of visual attention**. *Nat Rev Neurosci* 2001, **2**:194-203.

88. Theeuwes J: **Perceptual selectivity for color and form**. *Percept Psychophys* 1992, **51**:599-606.

89. McTeague LM, Gruss LF, Keil A: **Aversive learning shapes neuronal orientation tuning in human visual cortex**. *Nat Commun* 2015, **6**:7823.