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RESEARCH ARTICLE

Contributions of gains and losses to attentional capture and disengagement: evidence from the gap paradigm

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Abstract

It is known that movements of visual attention are influenced by features in a scene, such as colors, that are associated with value or with loss. The present study examined the detailed nature of these attentional effects by employing the gap paradigm—a technique that has been used to separately reveal changes in attentional capture and shifting, and changes in attentional disengagement. In four experiments, participants either looked toward or away from stimuli with colors that had been associated either with gains or with losses. We found that participants were faster to look to colors associated with gains and slower to look away from them, revealing effects of gains on both attentional capture and attentional disengagement. On the other hand, participants were both slower to look to features associated with loss, and faster to look away from such features. The pattern of results suggested, however, that the latter finding was not due to more rapid disengagement from loss-associated colors, but instead to more rapid shifting of attention away from such colors. Taken together, the results reveal a complex pattern of effects of gains and losses on the disengagement, capture, and shifting of visual attention, revealing a remarkable flexibility of the attention system.

Keywords Gains · Losses · Gap paradigm · Attentional capture · Attentional disengagement

Introduction

It has long been known that visual attention is captured by shiny things (James 1890), new objects (Christ and Abrams 2006; Yantis and Jonides 1984), and things that start to move (Abrams and Christ 2003; Smith and Abrams 2018), or change their motion direction (Pratt et al. 2010). Recently it has also become clear that attention is captured by objects that have some emotional significance (e.g., Huang et al. 2011; Mogg and Bradley 2016), or are associated with high value (Anderson et al. 2011), or with loss (Wang et al. 2013). The attentional capture occurs even when the stimuli do not themselves have any intrinsic value, but instead are learned to be associated with value during a brief training session (e.g., Anderson et al. 2011). And the attention capturing ability of valuable objects persists even after the objects are no longer valuable (e.g., Anderson and Yantis 2013; Anderson et al. 2011) and even when attending to them compromises performance on the participants' primary task or leads to punishment (Le Pelley et al. 2015, 2017). Taken together, the observations of *value-driven attentional capture*, as it is called, reveal a remarkable adaptability of the human attention system.

Much has already been learned about the mechanisms underlying value-driven attentional capture, but several key questions remain unanswered. We focus here on two of those questions. First, to what extent does value-driven capture reflect enhanced capture by, or delayed disengagement from, valuable stimuli. Second, to what extent do stimuli that are associated with losses also capture attention.

Enhanced capture or delayed disengagement

One issue that researchers have recently focused on centers around two very different interpretations that are possible for many of the reported effects. In particular, a common

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finding is that participants are slower to judge a target stimulus when a valuable distractor is present in the display, compared to when only one or more neutral distractors are present (Anderson et al. 2011; Failing and Theeuwes 2015; Wang et al. 2013). A typical interpretation of such a result is that attention was captured by the valuable distractor, thus delaying the movement of attention to the target that would be needed to evaluate it (e.g., Anderson et al. 2011; Theeuwes and Belopolsky 2012). However, a plausible alternative explanation is not that attention is more likely to be captured by a valuable than a neutral distractor, but instead that once attended, participants are slower to disengage attention from valuable distractors. Thus, according to this explanation, participants may be no more likely to attend to a valuable distractor compared to a neutral one, however, once attended, because attention dwells longer on a valuable distractor, it would have a greater adverse impact on target discrimination than a neutral one. Clearly, the two explanations (enhanced capture or delayed disengagement) are very different and would involve different mechanisms, so learning which one holds (or if both do) could be very informative with respect to the mechanisms underlying value-driven attentional capture.

Several studies have provided evidence to help distinguish between the enhanced capture and delayed disengagement explanations, yet each has some limitations. For example, Theeuwes and Belopolsky (2012) found that participants were more likely to unintentionally look to a high-value (compared to a low-value) distractor in a task that required them to look directly at a target. Such an effect was interpreted as indicating that the high-value distractor did indeed capture attention. Participants, however, did not dwell on the high-value distractor any longer than a low-value one after having fixated it, suggesting that the high-value target had no effect on the disengagement of attention. However, there is reason to question the use of the equivalent dwell times to conclude that disengagement did not differ. In particular, it is possible that the increased frequency of erroneous saccades directed to high-value distractors was actually caused by difficulty disengaging from such distractors in the first place (see also Müller et al. 2016). That is, even if attention is no more likely to be captured by a high-value compared to a low-value distractor, delayed disengagement from the high-value distractors might lead to more frequent erroneous saccades to them.

Pool et al. (2014) also attempted to distinguish between enhanced capture by valuable stimuli and delayed disengagement from such stimuli. In their experiment, they presented a target that was preceded by a brief peripheral cue that was either associated or not associated with a positive reward. Target discrimination was faster if the target appeared at the location of a valuable compared to a neutral cue, suggesting that the valuable cue had attracted attention. But discrimination was no different after valuable and neutral cues if the cues had been presented in a different location from the target. The latter result was interpreted as indicating that attention did not dwell longer on the valuable cue, a conclusion consistent with that of Theeuwes and Belopolsky (2012), discussed earlier. However, because the valuable cues captured attention more quickly than neutral ones (inferred from the results on trials where the target appeared at the cue location), the equivalent RTs on invalidly cued trials might actually reflect a delayed disengagement of attention from the valuable cue. Additionally, in the Pool et al. (2014) experiments, the cues were visible only very briefly (100 ms), so any disengagement from a cued location would have taken place after the offset of the cue, and thus would not have required removal of attention from a value-signaling stimulus.

Müller et al. (2016) also examined delayed disengagement and enhanced capture. In contrast to the conclusions of Theeuwes and Belopolsky (2012) and Pool et al. (2014), these researchers concluded that the attentional effects of a value-signaling distractor were almost entirely due to delayed disengagement from such distractors. In the critical condition of their study, a valuable cue was presented in one location and a neutral cue in another, followed by a target inside one of the cues. Participants were not faster to discriminate the target when it was in the valuable cue (compared to a baseline condition), as might have been expected if the valuable cue captured attention, but they were slower to discriminate the target when it was in the neutral cue, consistent with delayed disengagement from the valuable cue. Müller et al. (2016) argued that methodological differences between their study and those of Theeuwes and Belopolsky (2012) and Pool et al. (2014) account for the difference. Nevertheless, even in their study accepting the conclusion that value-driven capture effects are caused by delayed disengagement requires acceptance of the null hypothesis (see also Watson et al. 2020).

A recent study examined the issue using a paradigm that seems more likely to provide a good answer. In contrast to the earlier methods, Watson et al. (2020) studied conditions in which participants began some trials by fixating on a high-value or low-value distractor, and were then required to look away from that to a target shape. The results showed that participants were slower to look to the target when the distractor at fixation was high value, providing evidence consistent with delayed disengagement from the high-value stimulus. However, that conclusion assumes that participants were in fact attending to the object at fixation in the first place (at the beginning of a trial). If they were, then it is reasonable to conclude that the increased latencies for high-value stimuli must reflect delayed disengagement of attention from such stimuli. But in the Watson et al. experiment just described, the target never appeared at fixation, and as a result, it is quite possible that participants were in a diffuse attentional state at the beginning of the search—ready to inspect the peripheral stimuli in order to locate the target—and not attending to the object at fixation. Indeed, there is ample evidence of the absence of attention at fixation when a target is expected in the periphery (e.g., Mack and Rock 1998). Under such conditions, it would be reasonable to assume that the appearance of a valuable distractor at fixation could capture covert attention at the fixation point. As a result, the increased latency to look away from the valuable distractor in Watson et al.'s experiment might reflect enhanced capture by, and not delayed disengagement from, stimuli associated with high value, contrary to their conclusions.

One aspect of Watson et al.'s results provides good support for this alternative interpretation. In their Experiment 3, in which participants had to report the orientation of a line inside a target shape, targets were sometimes presented at fixation, surrounded by a cue that was colored either with the high-value-associated or low-value-associated color. In that experiment, participants were actually faster to identify the target when it was in the high-value color at fixation—a result that cannot be explained by disengagement but instead suggests that the high-value distractor at fixation actually captured attention, and facilitated target discrimination there.

The gap paradigm

Thus, it remains an open question whether the impairment in performance caused by the presence of a valuable distractor arises from the capture of attention by such distractors, delayed disengagement of attention from such distractors, or a combination of both. In the present study, we sought further insight into the issue by adopting a technique that has been specifically used to manipulate the need for attentional disengagement—the gap paradigm (Saslow 1967). In the gap paradigm task, participants make speeded saccades from a central location to a target that appears suddenly in the periphery under two conditions: In one condition, the object at fixation disappears shortly before the onset of the target, resulting in a "gap" between the two (the *gap* trials); in the other condition the fixation object remains on the display until the end of the trial, overlapping in time with the target (referred to as *overlap* trials). The typical result is that saccade latencies (measured from the onset of the target) are faster on the gap trials (e.g., Abrams et al. 1998; Fischer and Weber 1993)—a result that is believed to be caused by the participant's ability to disengage their attention from fixation (presumably a prerequisite to producing a saccade) when the fixation object disappears on the gap trials—in advance of target onset. On the overlap trials, however, attention cannot be disengaged from the fixation object until the target appears. Because disengagement takes some time, latencies on overlap trials include the time needed to disengage from fixation, and hence are longer than those on gap trials.

In the present experiments, we make use of the gap effect to study attentional disengagement from objects of value in a visual search task. Our general approach is to compare gap trials (trials that permit the early disengagement of attention prior to target onset) to overlap trials (trials that do not permit early disengagement) separately for fixation objects that do or do not signal high value. If the value-driven capture effects stem from delayed disengagement from objects of high value, then the early disengagement permitted on the gap trials should facilitate searches more for high-value than low-value fixation objects. In this way, the gap paradigm allows us to separately partition the effects of value on attentional disengagement and capture.

The gap paradigm has some advantages over the methods used previously that might better allow us to distinguish between attentional effects caused by enhanced capture by, as opposed to delayed disengagement from, valuable stimuli. In particular, following the common interpretation of the gap effect, any difference in saccade latencies between gap trials and overlap trials can be attributed to the pre-disengagement of attention in the gap trials. Any changes in that gap effect that depend on stimulus value can then be directly attributed to an effect of value on disengagement whereas results from many of the paradigms used to date are open to alternative interpretations, as we outlined earlier.

Use of the gap paradigm will also permit us to evaluate an additional explanation for value-driven attentional capture–specifically, the possibility that capture by a valuable object in the periphery is driven in part by more rapid disengagement from the currently attended location. Although not a likely explanation, it is logically possible, and our experiments will allow us to detect any such influences.

Application to gains vs. losses

The gap paradigm explicitly manipulates attentional disengagement. Given the advantages of the gap paradigm over some of the previous methods used to examine capture and disengagement for stimuli with value, in the present study we also used the paradigm to examine a second current issue regarding value-driven capture. In particular, existing studies are equivocal regarding the extent to which stimuli associated with high-value influence attention in the same manner as stimuli associated with a low or negative value. For example, Wang et al. (2013), using a procedure very similar to that of Anderson et al. (2011) showed that people were equally distracted by colors that had been previously associated with either monetary gains or losses, suggesting that features associated with both types of outcomes influence attention in similar ways. Similar conclusions have been reached by other researchers (e.g., Le Pelley et al. 2019;

Wentura et al. 2014). And attention also appears to be captured by stimuli that signal other negative outcomes, such as the potential for an electric shock (Nissens et al. 2017).

On the other hand, Becker et al. (2020) found no evidence of capture by colors associated with losses. They pointed out that earlier researchers who studied loss (e.g., Wang et al. 2013; Wentura et al. 2014) actually encouraged participants to attend to the loss-associated colors in training because responding quickly to targets in those colors could reduce or eliminate the potential loss that would be experienced. Becker et al. removed that contingency and found strong evidence of capture by rewarded colors but not by punished colors.

Additionally, Suh and Abrams (2020) found differences in capture by high-value and low-value stimulus features. In their experiments, participants responded to stimuli by moving a joystick either toward or away from the display, evoking avoidance or approach motivational states, respectively. They found that colors associated with high value captured attention when the rewards had been obtained with approach movements whereas colors associated with low value captured attention when paired with avoidance movements. Thus, these results suggest a distinction between the effects of high and low value on attention, but because the experiments did not explicitly involve losses the results might not apply to losses more generally (although it has been shown that the relative value of social rewards can modulate value-driven attentional capture: Jiao et al. 2015). In addition, although not directly related to visual attention, there is ample evidence from domains other than visual attention that rewards and punishments affect behavior in fundamentally distinct ways (e.g., Kubanek et al. 2015).

Current study

Overall, no clear picture has emerged regarding the attentional effects of stimulus features associated with losses. Because the gap paradigm is ideally suited to revealing separate effects of a manipulation on attentional capture and shift vs. attentional disengagement, it may be very helpful in identifying similarities and differences in the attentional effects of gains as opposed to losses. In the present study, we used the gap paradigm to separately examine attentional capture by gain-associated and loss-associated stimulus features.

General method

We conducted four separate experiments to examine the effects of gains and losses on both attentional capture and disengagement. In each experiment participants first served in a training phase in which they learned to associate specific colored shapes with either gains or losses. They then served in a test phase in which they were required to make eye movements either toward or away from the shapes that they had been trained with. The critical dependent variable was the eye movement latency. The general objectives of each experiment are summarized in Table 1 (with the details described in the following sections). When capture was being assessed (Experiments 1 and 3) participants looked *toward* targets that were colored and could be associated with either gains (Experiment 1) or losses (Experiment 3). When disengagement was being assessed (Experiments 2 and 4), participants looked *away from* shapes that were colored and could be associated with either gains (Experiment 2) or losses (Experiment 4).

Participants

Twenty-four participants were assigned to each of the four experiments and this sample size allowed for the detection of main effects of target color as well as interactions of target color with trial type of size $\eta_p^2 = 0.15$ with power $(1\text{-}\beta) = 0.80$ ($\alpha = 0.05$; G*Power software, Faul et al. 2007). Hence, ninety-six participants in total were recruited from Shandong Normal University. There were 12 women and 12 men in Experiment 1 ($M = 19.67$, SD = 1.34, range: 18–23) and Experiment 2 ($M = 19.21$, SD = 0.93, range 18–21); 14 females and 10 males in Experiment 3 ($M = 20.08$, SD = 1.11, range 18–22) and Experiment 4 ($M = 19.83$, SD = 0.85, range 19–22). All reported having normal or corrected-to-normal visual acuity and normal color vision and had never participated in similar experiments. Participants were paid ¥10–20 at the end of each experiment, depending on their performance in the training phase of the experiments. All participants in each experiment gave informed consent before experimentation, and all experiments reported in this article were approved by Shandong Normal University Human Research Ethics Advisory Panel (Psychology).

Table 1 Primary objectives and key features of the experiments

Experiment; objectives	Training phase stimuli	Test phase fixation circle	Test phase targets
1. Gains, capture	Colored squares	White circle	Colored square
2. Gains, disengagement	Colored circles	Colored circle	White square
3. Losses, capture	Colored squares	White circle	Colored square
4. Losses, disengagement	Colored circles	Colored circle	White square

Apparatus and procedure

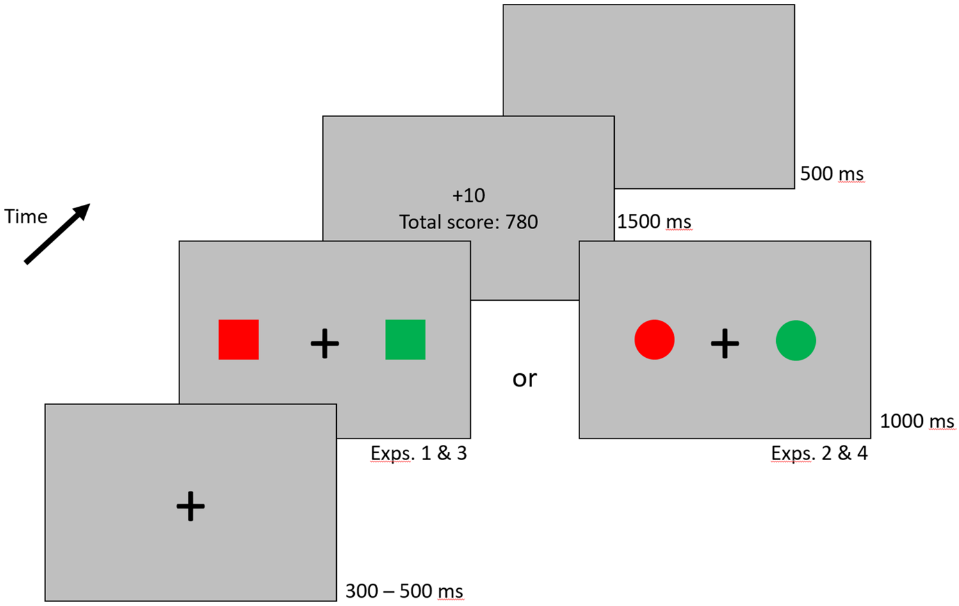
In each experiment, participants were seated in front of a 24″ LED monitor (resolution: 1920 × 1080 pixels, refresh rate: 100 Hz) with a gray (RGB: 128, 128, 128) background at a viewing distance of approximately 60 cm. Experiments were controlled by E-Prime 2.0 programs (Psychology Software Tools, Pittsburgh, PA). An Eyelink 1000 (SR Research, Ottawa, Ontario, Canada: 1000 Hz, < 0.5° accuracy) was used to monitor saccades.

Participants were tested individually and rested on a chinrest throughout the session. Each of the four experiments included a training phase followed by a test phase. At the beginning of the training phase, participants were instructed to maximize their payoff in a choice game. The sequence of events during each trial is shown in Fig. 1. Each trial started with a black fixation cross at the center of the screen for a variable duration (300, 400, or 500 ms). Then two-colored stimuli (1.15° × 1.15° squares in Experiments 1 and 3; 1.15° diameter circles in Experiments 2 and 4) simultaneously appeared 4.8° to the left and right of the fixation cross. Participants had to choose one of these two stimuli by pressing either “F” for the left stimulus or “J” for the right stimulus on a standard keyboard before the timeout of 1000 ms. After the response, visual feedback was centrally presented for 1500 ms indicating a gain (Experiments 1 and 2) or loss (Experiments 3 and 4) score for the response on that particular trial and the cumulative points earned in the session. There was a 500 ms blank screen between trials. The initial total score in Experiments 1 and 2 was 0, and in Experiments 3 and 4 was 2000. The colored stimuli were either red, green, or blue. In Experiments 1 and 2, one color was associated with a high reward, one with a low reward, and one with a zero reward. In Experiments 3 and 4, one color was associated with a high loss, one with a low loss, and one with a zero loss. When a high reward or high loss color was selected, the total points would be incremented or decremented, respectively, by 10 points on a randomly selected 90% of the trials and by one point on the remaining 10% of trials. For low reward and low loss colors, the percentages were reversed. If the participants were too slow or chose a zero reward or loss color, they would earn zero points. At the end of the session, the points were converted to payment at a rate of 0.015 RMB per point.

After the training phase, the test phase began. It is worth noting that, in this phase, participants did not receive any gains or losses. A standard 9-point calibration and validation procedure was employed to calibrate the eye tracker at the beginning of each block (one practice block and two experimental blocks in each experiment). The sequence of events on each trial is shown in Fig. 2. Each trial started with a black fixation cross at the center of the screen. Participants fixated on the fixation cross and the experimenter pressed a key to finish the drift correction. The fixation circle (1.15° diameter) then appeared at the center of the screen followed by a peripheral target square (1.15° × 1.15°) 10.66° to the left or right of fixation after a delay of 1000, 1100, or 1200 ms. On *gap* trials the fixation circle offset 200 ms before target onset; on *overlap* trials the fixation circle remained on the display. Participants were instructed to look at the target as quickly as possible within 2000 ms. After 2000 ms, the screen went blank and the trial ended; there was a 500 ms intertrial interval.

The colors of the fixation circle and targets in the test phase were manipulated to meet the objectives outlined in Table 1. In particular, when attentional capture was being

Fig. 1 The sequence of events during the training phase of the experiments. The points increment was zero or positive in Experiments 1 and 2, and zero or negative in Experiments 3 and 4. See the text for additional details



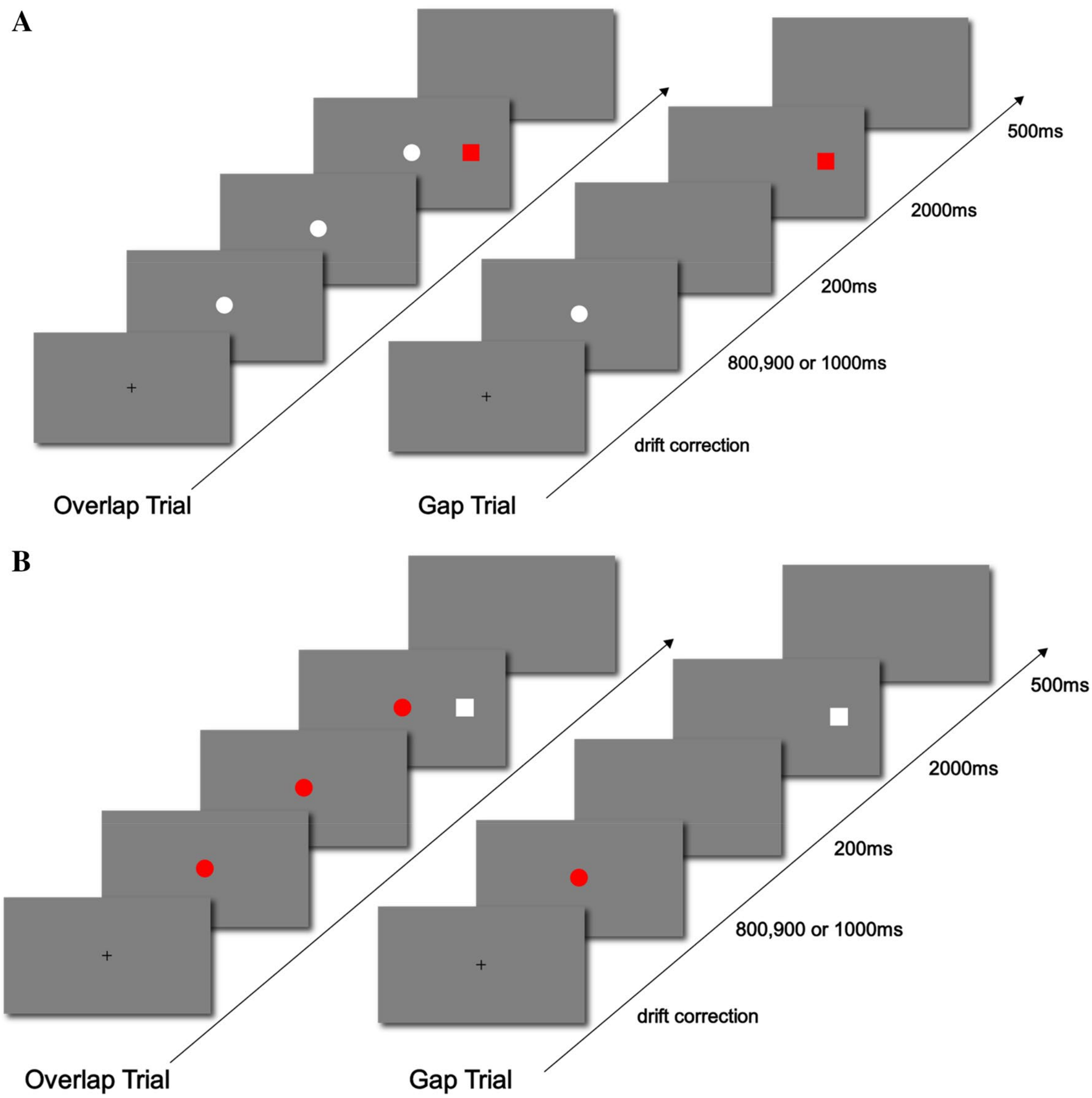


Fig. 2 **A** Sequence of events in the test phase of Experiments 1 and 3. **B** Sequence of events in the test phase of Experiments 2 and 4

assessed (Experiments 1 and 3), the fixation circle was always white whereas the targets were often presented in a color that was associated with gains or losses learned in the training phase. That is, the target in Experiments 1 and 3 could be either red, green or blue—colors that had been associated with gains or losses (including zero gain or loss for one color)—and also pink, yellow, dark blue, or deep purple—colors that were newly appearing in the testing phase and presumably had no association with value. Conversely, when attentional disengagement was being assessed (Experiments 2 and 4), the targets were always white but the fixation circle would be one of the colors just listed.

Design

The training phase consisted of one block of 8 practice trials and two blocks of 90 training trials each. The 180 training trials included 60 with each possible color combination (red and green, red and blue, green and blue), with an equal number of trials in which each color of a pair appeared on the left and the right sides, in random order. The test phase contained one block of 8 practice trials and two blocks of 96 test trials each. The 192 test trials included 48 trials where the colored object (either the fixation circle or the target) was in each of the colors from training (red, green, or blue), and 48 trials that included 12 trials of each of the four novel colors. The test trials were presented in a random order. Participants could rest for any length of time between blocks. The assignment of color to value (or loss) was balanced such that four participants received each of the six possible color/value assignments in each experiment, controlling for potential differences in the physical salience of different colors.

Data analysis

Training phase

Performance on the choice game was evaluated by calculating the mean probability and reaction time (RT) of the optimal choice for each participant. The optimal choice was defined as the response choosing the stimulus color that predicted the highest expected payoff for the trial (e.g., Failing and Theeuwes 2015). Given that the tasks in the training phase were very simple, most participants could learn the association between reward and color quickly. To assess that learning, we divided the training phase into six bins and statistically analyzed the first two and the last one bins. A repeated-measures analysis of variance (ANOVA) was used to analyze the probability and reaction time of optimal choice, with time bin and reward as within-subject factors. The reward (or loss) factor contained three levels: high-reward (loss) vs. low-reward (loss), high-reward (loss) vs. non-reward (loss), and low-reward (loss) vs. non-reward (loss). If participants can learn the association between color and reward, then the optimal choice probability and RT should change over time, with the probability higher (and RT shorter) when presented with a choice with a higher expected payout. It is worth noting, however, that some researchers have failed to find clear evidence of learning on the basis of the responses in the training phase, even though learned value had a strong effect on responses during the test phase (e.g., Anderson et al. 2011), so the most important results involve behavior during the test phase.

Test phase

Mean RTs were calculated for each participant. The RTs were defined as the time interval from target onset to the first valid saccade (saccades with amplitudes of 2° or more). Trials were excluded if the amplitude of the saccade was less than 2°, if the direction of the first saccade was opposite to the direction in which the target appeared, or if the RT was faster than 80 ms or slower than 800 ms. A repeated-measures analysis of variance (ANOVA) was used to analyze the probability and reaction time of optimal choice, with time bin and reward as within-subject factors. And Bayesian factor computed using JASP (https://jasp-stats.org/) was used to reflect the relative plausibility of the null hypothesis and alternative hypothesis (JASP Team 2020; Jeffreyes 1961).

Experiment 1

Experiment 1 was designed to examine the contribution of stimulus–reward associations to attentional capture and shifts of attention. In order to achieve this aim, participants learned the association between reward and color during the training phase, and we manipulated the colors of the target during the test phase. In this experiment, the stimuli in the training phase were colored squares, as were the targets in the test phase. The target colors were associated with high reward, low reward, no reward, or a new color had not appeared during training. The fixation circle was always colored white. Based on previous findings of value-driven capture, we expected reward to facilitate target-directed saccades for both gap and overlap trials. Such a result would be consistent with enhanced capture by, or enhanced shifting of attention toward, valuable stimuli. It is also possible that reward affects attentional capture indirectly by facilitating the disengagement of attention from its current location. In that case, the RT disadvantage of overlap compared to gap trials should be reduced for valuable targets because such targets could presumably facilitate the disengagement of attention that is also produced by the offset of fixation on the overlap trials.

Results and discussion

Training phase

The results of the training phase are shown in Table 2. The optimal choice probability and RTs were analyzed using a 3 (reward: high reward vs. low reward, high reward vs. non-reward and low reward vs. non-reward) × 3 (time bin: bin 1, bin 2 and bin 6) repeated-measures analysis of variance (ANOVA). For the probability, there were significant main effects of reward, $F(2, 46) = 7.64$, $p = 0.001$, $\eta_p^2 = 0.25$, and bin, $F(2, 46) = 15.44$, $p < 0.001$, $\eta_p^2 = 0.40$. The interaction

Table 2 Mean probability and RT of optimal choices during the training phase, separately for different reward combinations, from Experiment 1

Measure	Reward combinations	Bin		
		1	2	6
Probability	High vs. low	0.85 (0.04)	0.90 (0.03)	0.97 (0.01)
	High vs. non	0.67 (0.06)	0.85 (0.06)	0.94 (0.02)
	Low vs. non	0.70 (0.06)	0.70 (0.06)	0.76 (0.06)
RT (ms)	High vs. low	516 (22)	462 (20)	450 (14)
	High vs. non	520 (27)	477 (19)	457 (13)
	Low vs. non	583 (24)	570 (22)	559 (19)

Standard errors are shown in parentheses between the two factors was also significant, $F(4, 92)=2.56$, $p=0.044$, $\eta_p^2=0.10$, indicating that the influence of reward on optimal choice probability changed significantly over bins. Participants' optimal choice probability was higher when presented with options that included that high reward choice (Bonferroni correction was used for paired t test, the same below; high vs. low reward compared to low vs. non-reward: $t(23)=3.95$, $p=0.002$, $d=0.81$; high vs. low reward compared to high vs. non-reward: $t(23)=2.72$, $p=0.037$, $d=0.55$). For the RTs, there were main effects of reward, $F(2, 46)=28.72$, $p<0.001$, $\eta_p^2=0.56$, and bin, $F(2, 46)=4.67$, $p=0.014$, $\eta_p^2=0.17$. The interaction between the two factors was not significant, $F(4, 92)=1.21$, $p=0.313$, $\eta_p^2=0.05$. Participants' RTs were faster when the choice involved options that differed more in value. The results from the training phase show clearly that participants had learned about the values associated with the different colors.

Test phase

In total, 133 trials were excluded from analysis (2.88% of the total trials: 1.45% were error trials in which the direction of the first saccade was opposite to the target's location, 0.63% on which no saccade greater than 2° in amplitude was detected, and 0.80% on which the RT was faster than 80 ms or slower than 800 ms).

Performance in the test phase is shown in Fig. 3. RTs were submitted to a 2 (trial type: overlap trial vs. gap trial) × 4 (target color: high-reward, low-reward, non-reward and new) repeated-measures ANOVA. There was a significant main effect of trial type, $F(1, 23)=62.21$, $p<0.001$, $\eta_p^2=0.73$, $BF_{10}=1.78E+27$: RTs were shorter for gap trials ($M=201$ ms, SD = 39 ms) than for overlap trials ($M=232$ ms, SD = 41 ms), yielding the typical gap effect. This is believed to reflect the fact that participants were able to disengage attention from the fixation location before the onset of the target on the gap trials, thus facilitating the saccade RTs. There was also a main effect of target color, $F(3, 69)=5.35$, $p=0.002$, $\eta_p^2=0.19$, $BF_{10}=1.45$: RTs were significantly faster when the targets were the high-reward color ($M=211$ ms, SD = 37 ms) than the low-reward color ($M=217$ ms, SD = 41 ms, $t(23)=2.64$, $p=0.015$, $d=0.54$), non-reward color ($M=218$ ms, SD = 39 ms, $t(23)=2.33$, $p=0.029$, $d=0.47$) or a new color ($M=220$ ms, SD = 39 ms, $t(23)=5.00$, $p<0.001$, $d=1.02$). In addition, no significant differences in RTs among the latter three conditions (low vs. non: $t(23)=0.54$, $p=0.598$, $d=0.11$; new vs. low: $t(23)=1.85$, $p=0.078$, $d=0.38$; new vs. non: $t(23)=0.90$, $p=0.377$, $d=0.18$) were found. This serves to rule out an effect of selection history from training because any such effect would not influence the new color condition (Anderson and Halpern 2017; Le Pelley et al. 2016; Rusz et al. 2020; Sha and Jiang 2016; Wang et al. 2013). Importantly, trial type and target color did not interact, $F(3, 69)=0.62$, $p=0.602$, $\eta_p^2=0.03$, $BF_{10}=0.09$, indicating that the gap effect did not depend on the value associated with the target color. This suggests that the value-driven capture was not accomplished by facilitating the disengagement of attention from the fixation location, because in that case it would have been expected that the gap effect would have been reduced in the presence of high-value targets compared to low-value targets. Instead, the RT benefit to look at a high-value target appears to reflect the effects of reward value on the capture or shift of attention.

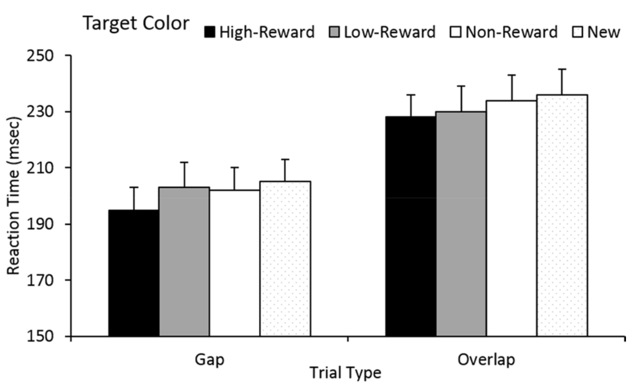


Fig. 3 Mean saccade RT from the test phase of Experiment 1 in which participants looked to targets of different colors. The legend indicates the reward that had been associated with the target color in the training phase. Error bars represent within-subject standard errors

Experiment 2

The aim of Experiment 2 was to examine the direct effects of reward value on attentional disengagement. The method was similar to that of Experiment 1 except that here we used a target that was always white, and instead manipulated the color of the fixation circle. During training, participants learned about the values of circles (as opposed to squares). In the test phase, the color of the fixation circle was associated with either a high-reward color, a low-reward color, a non-reward color, or a new color that had not appeared in the training phase. If the reward association affects attentional disengagement, then RTs to look to the peripheral target should be longer when the fixation circle is in a color associated with high reward. However, such prolonged RTs should occur on overlap trials only, because gap trials allow the pre-disengagement of attention when the fixation circle offsets, prior to target appearance. Thus, a bigger gap effect for high-value colors would provide evidence that value causes a delay in the disengagement of attention from valuable objects.

Results and discussion

Training phase

Due to a computer malfunction, the data from the training phase of one participant was lost; hence, we analyzed only 23 participants from the training phase (the test phase analysis includes data from all 24 participants). The choice probabilities and RTs, shown in Table 3, were both analyzed using a 3 (reward: high reward vs. low reward, high reward vs. non-reward and low reward vs. non-reward) × 3 (time bin: bin 1, bin 2, and bin 6) repeated-measures ANOVA. For the probability, there were significant main effects of reward, $F(2, 44) = 8.31$, $p = 0.001$, $\eta_p^2 = 0.27$ and bin, $F(2, 44) = 12.59$, $p = 0.003$, $\eta_p^2 = 0.36$, with optimal choices more likely when the high value item was included among the options, and for later time bins. The interaction between the two factors was not significant, $F(4, 88) = 0.67$, $p = 0.616$, $\eta_p^2 = 0.03$. For the RTs, choices were made more quickly when the choice options included a high reward, $F(2, 44) = 19.76$, $p < 0.001$, $\eta_p^2 = 0.47$ (high vs. low reward compared to low vs. non-reward: $t(22) = 5.11$, $p < 0.001$, $d = 1.07$, high vs. non reward compared to low vs. non reward: $t(22) = 4.48$, $p < 0.001$, $d = 0.93$). The main effect of bin was not significant, $F(2, 44) = 2.62$, $p = 0.084$, $\eta_p^2 = 0.11$, but there was a marginally significant interaction between reward and bin, $F(4, 88) = 2.36$, $p = 0.060$, $\eta_p^2 = 0.10$, showing that the change in RT with bin was caused mostly by the low vs. non-reward choice.

Table 3 Mean probability and RT of optimal choices during the training phase, separately for different reward combinations, from Experiment 2

Measure	Reward combinations	Bin		
		1	2	6
Probability	High vs. low	0.79 (0.05)	0.92 (0.03)	0.93 (0.04)
	High vs. non	0.71 (0.07)	0.83 (0.05)	0.91 (0.04)
	Low vs. non	0.61 (0.06)	0.68 (0.06)	0.80 (0.05)
RT (ms)	High vs. low	489 (25)	483 (27)	438 (20)
	High vs. non	500 (26)	479 (24)	456 (21)
	Low vs. non	549 (30)	599 (33)	548 (26)

Standard errors are shown in parentheses

Test phase

Data analysis in the test phase was the same as in Experiment 1. In total, 103 trials were discarded from analysis (2.24% of the total trials: 1.09% were error trials in which the direction of the first saccade was opposite to the target's location, 0.22% on which no saccade greater than 2° in amplitude was detected, and 0.93% on which the RT was faster than 80 ms or slower than 800 ms).

Saccade RTs, shown in Fig. 4, were submitted to a 2 (trial type: overlap trial vs. gap trial) × 4 (fixation color: high reward, low reward, non-reward and new) repeated-measures ANOVA, which revealed a main effect of trial type, $F(1, 23) = 37.37$, $p < 0.001$, $\eta_p^2 = 0.62$, $BF_{10} = 4.75E+24$: RTs were shorter for gap trials ($M = 182$ ms, SD = 30 ms) than for overlap trials ($M = 212$ ms, SD = 38 ms), yielding the typical gap effect. There was no significant main effect of fixation color, $F(3, 69) = 1.02$, $p = 0.390$, $\eta_p^2 = 0.04$, $BF_{10} = 0.04$, but, importantly, fixation color interacted with trial type, $F(3, 69) = 3.94$, $p = 0.012$, $\eta_p^2 = 0.15$, $BF_{10} = 0.32$. On the overlap trials, RT was significantly slower when the fixation circle was the high-reward color ($M = 217$ ms, SD = 39 ms) compared to the low-reward color ($M = 211$ ms, SD = 38 ms, $t(23) = 2.12$, $p = 0.045$, $d = 0.43$), the

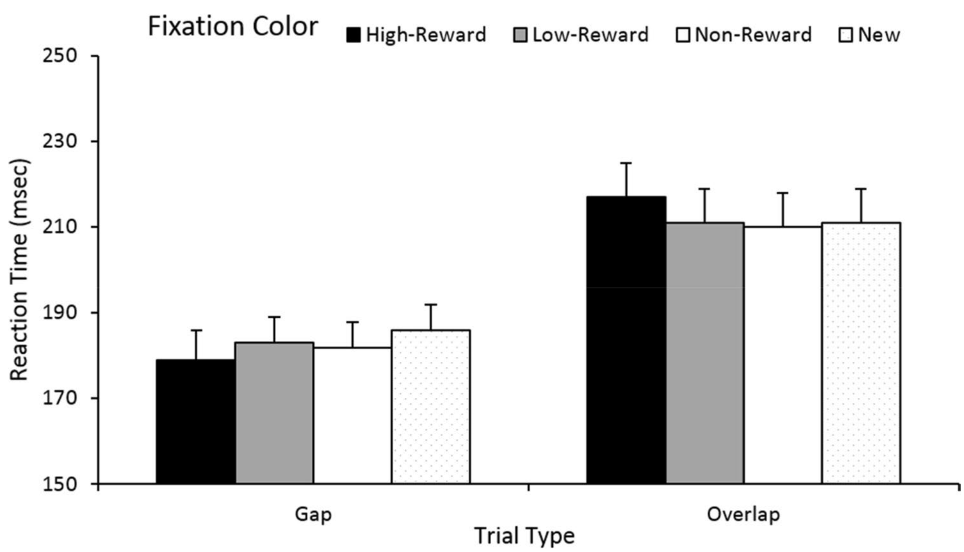


Fig. 4 Mean saccade RT from the test phase of Experiment 2 in which participants looked away from fixation circles of different colors. The legend indicates the reward that had been associated with the fixation color in the training phase. Error bars represent within-subject standard errors

non-reward color ($M = 210$ ms, $SD = 40$ ms, $t(23) = 2.11$, $p = 0.046$, $d = 0.43$) and the new color ($M = 211$ ms, $SD = 37$ ms, $t(23) = 2.09$, $p = 0.048$, $d = 0.43$). However, on the gap trials, RT was fastest when the fixation circle was in the high-reward color ($M = 179$ ms, $SD = 33$ ms), significantly so when compared to the new color trials ($M = 186$ ms, $SD = 31$ ms, $t(23) = 3.72$, $p = 0.001$, $d = 0.76$). This may reflect increased alertness associated with the high-value color.

The overall pattern reveals a strong impact of value on the disengagement of attention. First, consider the overlap trials. On those trials, participants needed to disengage attention from the (still visible) fixation circle in order to look to the target. Saccade latencies there were longest when the fixation circle was in the high-value color. This result occurred despite the fact that the RTs from the gap trials suggest that there might have been a general alerting effect associated with the high-value color—speeding latencies on those trials when the fixation circle was in the high-value color (Cao et al. 2021). Such an alertness effect, if anything would have reduced any costs associated with the requirement to disengage attention from the high-value (and visible) fixation circle on the overlap trials, yet a significant cost was observed there anyway. Taken together the results show that it does indeed take longer to disengage attention from an object whose color is associated with high value.

Experiment 3

Experiments 1 and 2 showed that reward-association affects both attentional capture and shift, and attentional disengagement. In Experiments 3 and 4, we assessed the effect of loss-association on attentional capture and disengagement. To do that, participants learned to associate specific colors with different magnitudes of loss during the training phase. In the test phase here, they made saccades to targets with colors associated with those losses. As noted earlier, some researchers have found that losses produce attentional effects similar to those of gains, whereas others have found some differences. Using the gap effect to examine the question, as we do here, may help to clarify the situation.

Results and discussion

A total of 3.45% of trials were discarded (159 trials), 1.91% were saccade direction errors, 0.22% were trials on which no saccade was detected, and 1.32% on which the RT was faster than 80 ms or slower than 800 ms. Analyses of the training phase and the test phase were the same as in the previous experiments.

Training phase

The optimal choice probabilities and RTs, shown in Table 4, were analyzed using a 3 (loss: high loss vs. low loss, high loss vs. non loss and low loss vs. non loss) × 3 (time bin: bin1, bin2, and bin6) repeated-measures ANOVA. For the probability, the main effects of loss, $F(2, 46) = 3.90$, $p = 0.027$, $\eta_p^2 = 0.15$, and bin, $F(2, 69) = 29.91$, $p < 0.001$, $\eta_p^2 = 0.57$, were significant: Participants were more likely to pick the optimal choice when the combination of high vs. low loss was presented, and in the later time bins. The two factors did not interact, $F(4, 92) = 0.44$, $p = 0.78$, $\eta_p^2 = 0.02$, indicating that the influence of loss on choice probability was learned very quickly and did not change over time. For the RTs, there were also significant main effects of loss, $F(2, 46) = 16.87$, $p < 0.001$, $\eta_p^2 = 0.42$, and bin, $F(2, 46) = 13.61$, $p < 0.001$, $\eta_p^2 = 0.37$. Paralleling the choice probabilities, RTs were faster when the combination of high vs. low loss was presented, high vs. non loss compared to low non loss ($t(23) = 4.08$, $p < 0.001$, $d = 0.83$, high vs. low loss compared to high vs. non loss: $t(23) = 4.61$, $p < 0.001$, $d = 0.94$). However, the two factors were not interacted, $F(4, 92) = 1.37$, $p = 0.251$, $\eta_p^2 = 0.06$. Results from the training phase show that the participants had learned about the losses associated with the different colors.

Test phase

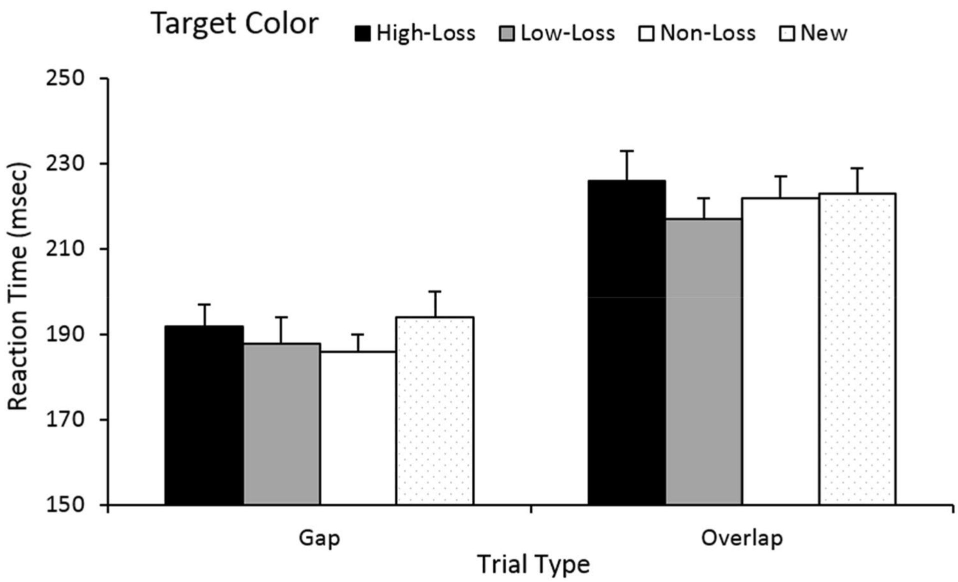
Saccade RTs, shown in Fig. 5, were submitted to a 2 (trial type: overlap trial vs. gap trial) × 4 (target color: high-loss, low-loss, non-loss and new) repeated-measures ANOVA. There was a main effect of trial type, $F(1, 23) = 95.43$, $p < 0.001$, $\eta_p^2 = 0.81$, $BF_{10} = 2.46E+31$, with RT on gap trials ($M = 190$ ms, $SD = 24$ ms) significantly faster than on overlap trials ($M = 222$ ms, $SD = 26$ ms), yielding a typical gap effect. There was also a main effect of target color, $F(3, 69) = 3.32$, $p = 0.025$, $\eta_p^2 = 0.13$, $BF_{10} = 0.094$: RT was significantly longer when the

Table 4 Mean probability and RT of optimal choices during the training phase, separately for different combinations of loss, from Experiment 3

Measure	Loss combinations	Bin 1	Bin 2	Bin 6
Probability	High vs. low	0.81 (0.04)	0.91 (0.03)	0.99 (0.01)
	High vs. non	0.68 (0.06)	0.82 (0.04)	0.93 (0.03)
	Low vs. non	0.74 (0.06)	0.85 (0.04)	0.97 (0.01)
RT (ms)	High vs. low	573 (21)	497 (21)	481 (15)
	High vs. non	633 (22)	599 (25)	579 (25)
	Low vs. non	580 (22)	523 (18)	496 (17)

Standard errors are shown in parentheses

Fig. 5 Mean saccade RT from the test phase of Experiment 3 in which participants looked to targets of different colors. The legend indicates the loss that had been associated with the target color in the training phase. Error bars represent within-subject standard errors



target was the high-loss color ($M=209$ ms, SD = 25 ms) compared to the low-loss color ($M=202$ ms, SD = 26 ms, $t(23)=2.84$, $p=0.009$, $d=0.58$) and the non-loss color ($M=204$ ms, SD = 22 ms, $t(23)=2.12$, $p=0.045$, $d=0.43$). These results indicate that attentional capture was reduced and the attentional shift was slowed when the target was associated with a greater loss. The difference between the low-loss color and non-loss color was not significant, helping to rule-out an influence of selection history. RTs to the high-loss color also did not differ from those to a new color ($M=208$ ms, SD = 26 ms, $t(23)=0.22$, $p=0.828$, $d=0.04$). Finally, RT was significantly faster when the target was the low-loss color compared to a new color ($t(23)=3.00$, $p=0.006$, $d=0.61$), perhaps suggesting a limited influence of selection history, although such an influence cannot account for the slower RTs in the high-loss condition. Importantly, the interaction between the two factors was not significant, $F(3, 69)=1.17$, $p=0.329$, $\eta_p^2=0.05$, $BF_{10}=0.14$, indicating that the gap effect did not depend on the magnitude of the loss. Because of that, we can conclude that loss associated with the peripheral target color did not alter the time needed to disengage attention from the (non-colored) fixation circle.

Overall, the results indicate that loss-association impeded the shift of attention toward the target associated with high loss—a result opposite to what we observed for targets of high value (in Experiment 1)—suggesting that gains and losses have distinctly different effects on attention. Confirming that conclusion, an ANOVA comparing Experiments 1 and 3 revealed a significant interaction between experiment and target/fixation color, $F(3, 138)=5.30$, $p=0.002$, $\eta_p^2=0.10$.

Experiment 4

Experiment 4 was designed to directly examine the effects of loss-association on attentional disengagement. Here we manipulated the color of the fixation circle during the test phase. If loss-association impairs attentional disengagement (as was found for gains in Experiment 2), the RTs should be longer to look away from fixation circles associated with high losses. Alternatively, if loss-association facilitates attentional disengagement then RT should be shorter to look away from high-loss fixation circles. In either case, such effects should be observed only on overlap trials because gap trials permit the early disengagement of attention, prior to target onset.

Results and discussion

Training phase

The results (shown in Table 5) show that participants were sensitive to the magnitude of the losses. The choice probability and RTs were analyzed using a 3 (loss: high loss vs. low loss, high loss vs. non-loss and low loss vs. non-loss) × 3 (time bin: bin 1, bin 2, and bin 6) repeated-measures ANOVA. For the probability, the main effect of loss was significant, $F(2, 46)=4.55$, $p=0.016$, $\eta_p^2=0.11$. The main effect of bin was also significant, $F(2, 46)=30.98$, $p<0.01$, $\eta_p^2=0.57$. However, the interaction between them was not significant, $F(4, 92)=1.61$, $p=0.178$, $\eta_p^2=0.07$. For the RT, the main effect of loss was significant, $F(2, 46)=13.55$, $p<0.001$, $\eta_p^2=0.37$, and the effect

Table 5 Mean probability and RT of optimal choices during the training phase, separately for different combinations of loss, from Experiment 4

Measure	Loss combinations	Bin		
		1	2	6
Probability	High vs. low	0.76 (0.06)	0.93 (0.03)	0.96 (0.02)
	High vs. non	0.59 (0.07)	0.79 (0.06)	0.87 (0.05)
	Low vs. non	0.69 (0.06)	0.73 (0.06)	0.94 (0.03)
RT (ms)	High vs. low	560 (32)	518 (27)	467 (16)
	High vs. non	589 (29)	584 (31)	549 (22)
	Low vs. non	519 (23)	498 (22)	476 (17)

Standard errors are shown in parentheses

of time bin was also significant, $F(2, 46) = 5.78$, $p = 0.006$, $\eta_p^2 = 0.20$. However, the two factors did not interact, $F(4, 92) = 1.42$, $p = 0.233$, $\eta_p^2 = 0.06$. Results from the training phase show that the participants had learned about the losses associated with the different colors.

Test phase

Data analysis was similar to the earlier experiments. In total, 3.54% of trials were discarded (163 trials), 1.32% were saccade-direction errors in which the direction of the first saccade was opposite to the target's side, 0.93% were trials on which no saccade was detected, and 1.28% were trials on which the RT was faster than 80 ms or slower than 800 ms.

The saccade RTs, shown in Fig. 6, were submitted to a 2 (trial type: overlap trials vs. gap trials) × 4 (fixation color: high-loss, low-loss, non-loss and new) repeated-measures ANOVA. There was a significant main effect of trial type, $F(1, 23) = 61.63$, $p < 0.001$, $\eta_p^2 = 0.73$, $BF_{10} = 1.42E+25$, with RTs shorter for gap trials ($M = 178$ ms, SD = 29 ms) than for overlap trials ($M = 206$ ms, SD = 36 ms), yielding a gap effect. There was no main effect of fixation color, $F(3, 69) = 2.15$, $p = 0.102$, $\eta_p^2 = 0.09$, $BF_{10} = 0.18$, nor did color interact with trial type, $F(3, 69) = 0.23$, $p = 0.875$, $\eta_p^2 = 0.01$, $BF_{10} = 0.07$. Although the effect of fixation color was not significant, it is worth noting that the numerically fastest latencies were in the high-loss condition for both gap and overlap trials, showing that participants were clearly not slower to disengage from such colors.

General discussion

In the present study, we employed the gap paradigm to address questions about value-driven attentional capture. In particular, we sought to learn about the extent to which features associated with gains and features associated with losses influence attention by either altering the capture and shifting of attention, or by influencing the disengagement of attention.

Experiment 1 showed, as others have shown (e.g., Anderson et al. 2011), that reward can facilitate attentional capture and shifting. Participants moved their gaze, and presumably their attention, to targets more quickly when the target color was previously associated with a high reward than when it was not. The effect was equally strong on both the gap trials, in which the early offset of fixation meant that the time needed to disengage attention was not included in the reaction time, and the overlap trials, in which the reaction time is assumed to have included the time needed to disengage attention from the fixation circle. Thus, value affected the capture and shift of attention, but not attentional disengagement from a neutral fixation circle.

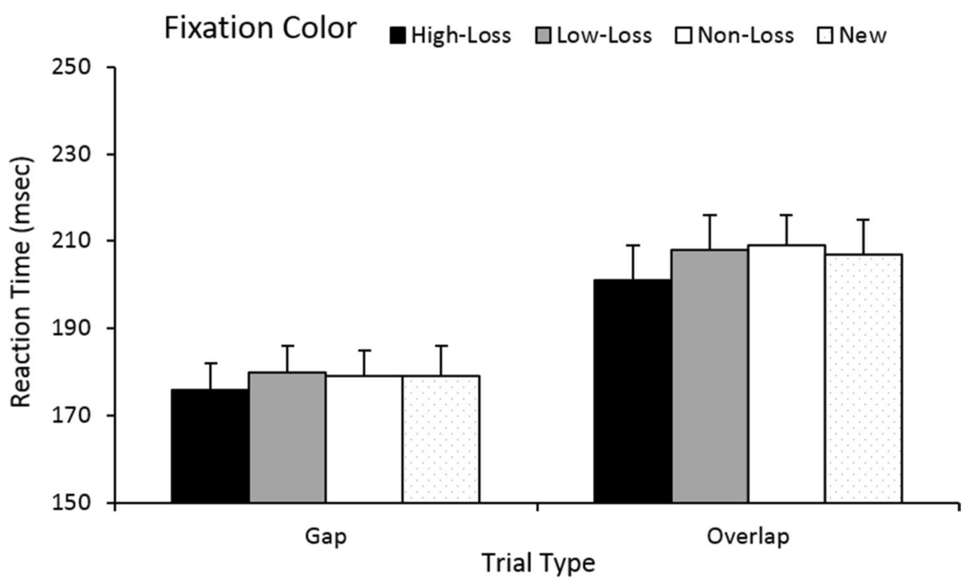


Fig. 6 Mean saccade RT from the test phase of Experiment 4 in which participants looked away from fixation circles of different colors. The legend indicates the loss that had been associated with the fixation color in the training phase. Error bars represent within-subject standard errors

Experiment 2 showed that the value of a fixated object can affect disengagement of attention from that object. In that experiment, participants were slower to look away from a color associated with high gains—an effect that occurred only on the overlap trials, when the (sometimes high-value) fixation circle remained visible until the target appeared. Taken together, Experiments 1 and 2 show that attention is both drawn to, and inhibited from disengaging from, features associated with high value.

Experiments 3 and 4 showed that features associated with losses also influence attentional capture and disengagement, but in a very different way from the effects of features associated with gains. In Experiment 3, subjects were slower to look to target colors associated with high losses. And in Experiment 4, participants were faster to look away from such colors. Because the effects were equivalent on both gap and overlap trials, the results indicate that features associated with loss affect the capture or shifting of attention, but not attentional disengagement.

Enhanced capture and delayed disengagement for rewards

As noted earlier, while it is clear that features associated with value capture attention (e.g., Anderson et al. 2011), there has been some uncertainty regarding the extent to which such features might also impede attentional disengagement. Theeuwes and Belopolsky (2012) reported that people did not dwell longer on valuable distractors, suggesting that value has no effect on disengagement. Similar conclusions were reached by Pool et al. (2014) in their study. On the other hand, Müller et al. (2016) and Watson et al. (2020) each concluded that attention was indeed impeded from disengagement from valuable stimuli. The method used here has some advantages over the earlier methods because the gap paradigm was specifically designed to separately assess effects of capture and effects of disengagement. And we found clear evidence of capture by value-associated features (Experiment 1) and impeded disengagement from such features (Experiment 2).

One possible reason for the discrepancy between our findings and those of Pool et al. (2014) is that they used primary rewards in their study (chocolate odors), finding that participants were not slower to disengage attention from such stimuli. However, we used secondary rewards, a visual symbol representing monetary gain (and participants were indeed slower to disengage from such rewards). Primary rewards are more directly related to physiological needs (Gottfried 2011) whereas secondary rewards acquire value or significance more related to psychological needs. Perhaps this difference accounts for the different effects on attention. Additionally, Theeuwes and Belopolsky (2012) used targets that were color singletons in their eye-movement study, possibly overpowering any tendency for people to dwell longer while fixating valuable stimuli.

Gains vs. losses

We were also able to learn more about the differences in the attentional effects of features associated with losses as opposed to those associated with gains. As noted earlier, some researchers have found that attention is captured by loss-associated features in a manner similar to the capture by features associated with gains (Le Pelley et al. 2019; Wang et al. 2013; Wentura et al. 2014), whereas others have found no such evidence (Becker et al. 2020), or that the effect of low-value might depend on the action needed to respond to the stimulus (Suh and Abrams 2020). In the present experiments, we found clear evidence that attention avoids loss-associated features. Participants were slower to look to colors associated with high losses, and faster to look away from such colors, with no apparent alteration in attentional disengagement from such colors.

More generally, studies of the attentional effects of threatening and aversive stimuli have also found a range of effects. Van Damme et al. (2008) found that threat-related stimuli could cause delayed disengagement. Such a response could be of practical significance because delayed disengagement would permit a more thorough evaluation of potentially dangerous stimuli. On the other hand, others have shown that if the stimuli are sufficiently aversive, the stimuli may lead to attentional avoidance (Pflugshaupt et al. 2005). The latter result is more similar to what we found in Experiments 3 and 4, perhaps consistent with the reality that monetary loss is indeed aversive (and one might wish to avoid it) yet not especially dangerous or threatening (and hence there would be no benefit to prolonged inspection).

Conclusion

In summary, the present study shows that stimuli previously associated with monetary gain or loss can modulate attentional capture and shift, and attentional disengagement even when the stimuli no longer predict gain or loss. Specifically, reward can both facilitate attentional capture and shift and impede attentional disengagement, whereas loss impedes attentional capture and shift. The distinctly different effects of gains and losses reveal a remarkable flexibility of the attention system.

Supplemental material

The original data are available on the Open Sciences Framework at: https://osf.io/qfgj5/.

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Declarations

Conflict of interest The authors have no conflicts of interest to declare with respect to the authorship or publication of this article.

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