Interaction between value and perceptual salience in value-driven attentional capture

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Previous research demonstrated that associating a stimulus with value (e.g., monetary reward) can increase its salience and induce a value-driven attentional capture when it becomes a distractor in visual search. Here we investigate to what extent this value-driven attentional

organism and the term *perceptual salience* to describe the local feature contrast of the stimulus. Two alternative hypotheses exist concerning their relationship. One possibility is that value works independently to increase the salience of the stimulus. An object will gain value-based salience irrespective of its perceptual salience once it has been associated with value. Alternatively, the increased salience of the value-laden stimulus is caused by the interaction between the value attached to the stimulus and the perceptual salience of the stimulus. If so, whether or not an object can gain value-based salience and capture attention would be modulated by its perceptual salience.

Results of the previous studies (e.g., Anderson et al., 2011a, 2011b), do not allow us to test these possibilities because value was always associated with a stimulus of high perceptual salience (e.g., color). Theeuwes (1991, 1992) showed that in visual search, responses to a unique shape in the visual field were slowed by a unique color distractor; however, responses to a unique color were unaffected by the presence of a unique shape distractor. By manipulating the perceptual load along the task-relevant or -irrelevant dimension of multidimensional (color + shape) objects in the central search array and by presenting congruent or incongruent flankers at periphery, Wei and Zhou (2006) also found that the interaction between perceptual load and flanker congruency was closely modulated by the relative perceptual salience between color and shape. In the present study, we crossed perceptual salience with value information such that the stimulus associated with value could be of higher perceptual salience (color) in Experiment 1, but of lower perceptual salience (shape) in Experiment 2. The empirical question was then whether the value-driven attentional capture would still be present when value was paired with a perceptually less salient distractor (shape).

Experiment 1 was intended to replicate Anderson et al. (2011b), which associated a critical color with monetary gain during learning. Here we used two critical colors, one associated with monetary gain and the other with loss. By presenting the gain- or loss-associated color as one of the distractors in the search for a unique shape in the test phase, we aimed to investigate whether a loss-associated distractor can capture attention in the same way as a gain-associated distractor. In Experiment 2, we associated a specific shape, rather than a color, with gain or loss during learning and presented it as a critical distractor in the search for a unique color in the test phase. There were three subexperiments in which the familiarity of the shape distractor and the strength of the association between value and shape distractor were manipulated. The design of Experiment 3 was essentially the same as that of Experiment 2 except that the unique shape was associated with physical pain rather than monetary gain or loss. We reasoned that physical pain could be more important for survival than money and thus may have higher value. It is possible that the lower ability of a stimulus of low perceptual salience (e.g., shape) in gaining value-based salience can be compensated for by being associated with pain stimulation.

Experiment 1

Method

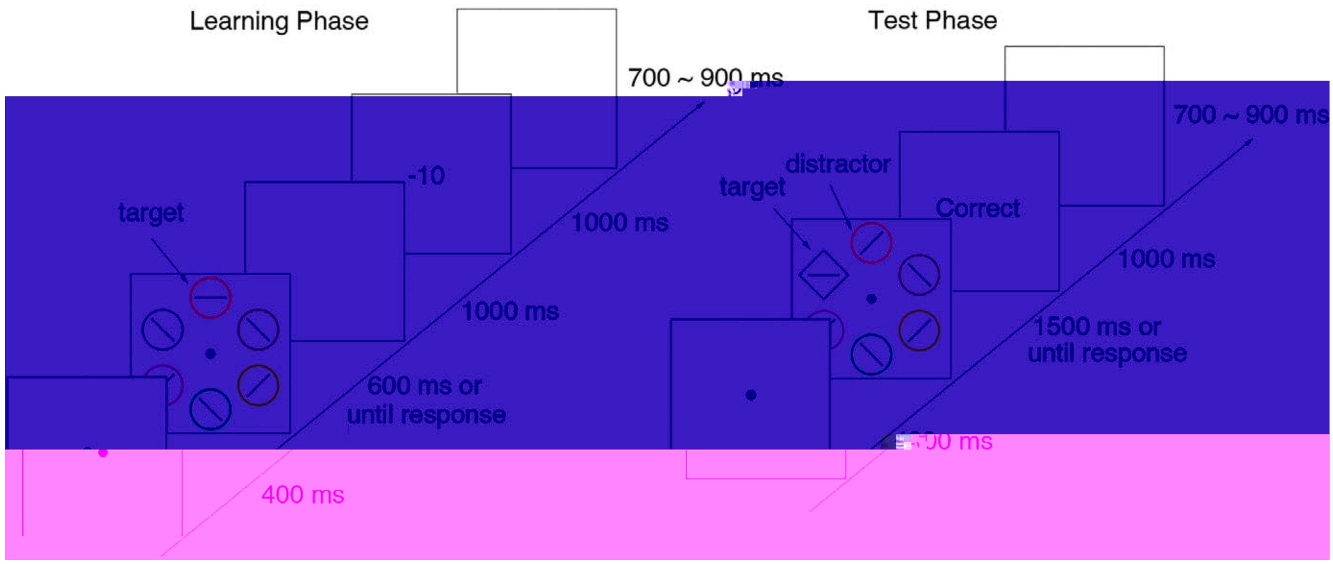
Participants

Forty-eight right-handed undergraduate and graduate students participated in Experiment 1, with half assigned to the experimental group (16 women, mean age: 21.0 years) and the other half assigned to the control group (15 women, mean age: 21.6 years). All the participants in this and the following experiments had normal or corrected-to-normal vision, and none of them reported a history of neurological or psychiatric disorders. Color blindness or weakness was assessed with Ishihara plates (Ishihara, 1917) when the participants were recruited. They all gave informed consent prior to the experiments in accordance with the Declaration of Helsinki. This study was approved by the Ethics Committee of the Department of Psychology, Peking University.

Stimuli and design

As in Anderson et al. (2011b), the whole experiment consisted of a learning phase (left panel, Figure 1) and a test phase (right panel, Figure 1). In both phases, participants searched for a target among distractors with equal distances between each two adjacent items.

Stimuli were presented at the center of a white screen. In both the learning and the test phases, items (each measured 2.5° × 2.5° in visual angle) were presented in an imaginary circle (5.3° radius) around the central fixation, which was a black dot (0.4° × 0.4°). In the learning phase, the six items in the search set were circles with different colors. Seven colors in total were used: red, blue, green, pink, yellow, brown, and black. For each participant, two colors chosen from red, green, and blue were defined as the target colors, one associated with monetary gain and one with loss. The assignment of the two colors and the association of each color with gain or loss were counterbalanced over participants, so that the physical salience of the two target colors could be controlled. Only one of the two target colors was presented in a specific trial while the five other colors (including the one not drawn as the target) were used as the five distractors, respectively. There was a black line segment in each of the six



colored circles. In the target circle, this line segment was presented horizontally or vertically; in the distractor circles this segment was tilted 45° to the left or the right. Participants were asked to discriminate the orientation of the line segment in the target circle (horizontal vs. vertical).

For the experimental group, the association of a target color with monetary gain or loss was established by presenting a feedback frame after button press indicating the points a participant received in that trial (left panel, Figure 1). For a gain-associated target, a correct response was followed by "+10" in the feedback frame, denoting the receipt of 10 points, while an incorrect response was followed by "+5," denoting the receipt of 5 points. For a loss-associated target, a correct response resulted in "–10," denoting the loss of 10 points, while an incorrect response resulted in "–15," denoting the loss of 15 points. Participants were told that the points accumulated during the learning phase would be proportionally exchanged to the final monetary reward and added to their basic payment (30 yuan, about US $5) for taking part in the experiment. For the control group, only a response feedback (correct vs. incorrect) was presented in the frame after button press.

In the test phase (right panel, Figure 1), the search target was a unique shape (i.e., target item) among other distractor items, for example, a diamond among five circles or a circle among five diamonds, with each item having a specific color. There was a critical distractor among the five distractors. For the experimental group, the gain-associated color appeared on the critical distractor in one third of the trials (gain trials) and the loss-associated color appeared on the critical distractor in another third of the trials (loss trials). In the remaining third of the trials, a novel color (purple, which was not used in the learning phase) appeared on the critical distractor (novel trials). Each of the other five items (including the target) had one color that appeared as a distractor color during learning. For the control group, the novel color and each of the two target colors that were not paired with reward during learning appeared in one third of the trials. Trials having the novel color formed the novel trials, and trials having one of the two target colors were combined to form neutral trials. For both groups, a response feedback, indicating correct versus incorrect response, was presented immediately after button press in each trial.

Procedures

Participants were tested individually in a soundproof and dimly lighted room. They were seated in front of a 19-inch CRT monitor screen with their head positioned on a chin rest. The eye-to-monitor distance was 70 cm.

In both the learning and test phases, each trial began with the presentation of the central fixation for 400 ms. The search frame was then presented and remained on the screen until a response was given or until the time limit was reached (600 ms in the learning phase and 1500 ms in the test phase). In the learning phase, the feedback (denoting gain or loss for the experimental group and correct or incorrect for the control group)

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was presented 1000 ms after button press and remained on the screen for 1000 ms. In the test phase, a response feedback (correct vs. incorrect) was presented immediately after button press, and the word remained on the screen for 1000 ms. In both phases, a blank screen was presented after feedback for a randomly varying interval of 700, 800, or 900 ms.

There were 180 trials for each of the two targets in the learning phase and 120 trials for each of the three conditions in the test phase. Trials in each phase were divided into six blocks of equal length, with a 2-min break between blocks. Trials in different experimental conditions were equally distributed in each block. A pseudo-randomized order of stimuli was created for each participant, preventing three consecutive items from the same condition or with the same responses. The target item appeared at different spatial locations with equal probability. The mapping between the two response buttons and the two task features (horizontal vs. vertical) was counterbalanced across participants. Participants were instructed to respond as quickly and accurately as possible and were provided with 20 practice trials prior to each of the two phases. Practice trials were the same as the experimental trials except that the monetary feedback was replaced by response feedback (correct vs. incorrect).

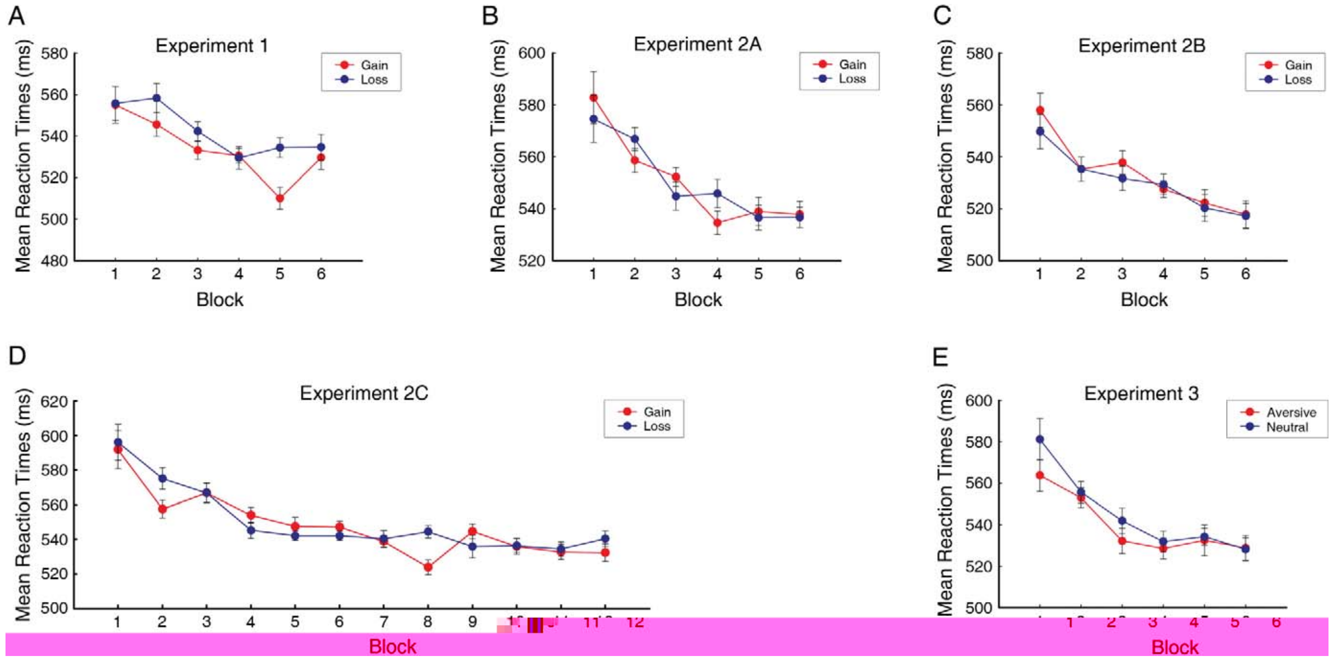
Results and discussion

For each experimental condition, omissions, incorrect responses, and trials with reaction times (RTs) $\pm$ 3 SDs beyond the mean RT for all the correct trials were first excluded from further analysis. Mean RT of the remaining trials in each condition was then calculated. Error rate was calculated as the proportions of the number of all omissions and incorrect trials against the total number of trials in a condition. Given that the rates of response error in either the learning or test phase did not show significant differences between experimental conditions (see Table 1), the following analyses in all the experiments focus on RTs.

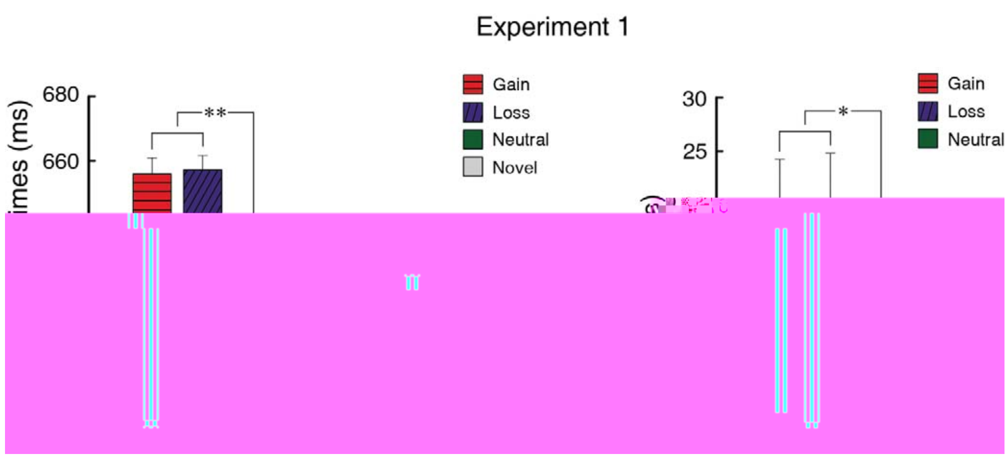
To examine how the responses to the gain- and loss-associated targets changed over time, we analyzed the data from each block in the learning phase separately. The 2 (target type: gain vs. loss) $\times$ 6 (block 1, 2, 3, 4, 5, and 6) repeated-measures analysis of variance (ANOVA) showed a main effect of block, $F(5, 115) = 10.0$, $p < 0.001$, $\eta^2 = 0.303$, and an interaction between target type and block, $F(5, 115) = 2.45$, $p < 0.05$, $\eta^2 = 0.096$, but no main effect of target type, $F(1, 23) = 2.03$, $p > 0.1$. For both targets, responses became increasingly faster over blocks (Figure 2A). In the test phase, there was a main effect of experimental condition, $F(2, 46) = 10.1$, $p < 0.001$, $\eta^2 = 0.305$, with RTs for the gain (656 ms) and loss (657 ms) trials longer than RTs for the novel trials (637 ms), $p < 0.005$ with Bonferroni correction (left panel, Figure 3). For the control group, the two color distractors, which received the same feedback during learning, were collapsed to form a neutral condition in the test phase. RTs for these neutral trials (623 ms) were longer than RTs for the novel trials (616 ms), $t(23) = 2.23$, $p < 0.05$ (left panel, Figure 3).

To examine whether the interference effect for the valued colors in the test phase can be attributed to the repeated exposures of the targets in the learning phase, for each participant in the experimental group, we subtracted RTs in the neutral condition from RTs in the gain and loss conditions, respectively; for each participant in the control group, we subtracted RTs in the novel trials from RTs in the neutral trials. We then compared the resulting effects (19 and 20 ms respectively for the gain and loss trials, and 7 ms for the neutral trials; right panel, Figure 3). The independent-sample t tests showed that the interference effects in the experimental group were significantly larger than the interference effect in the control group, $t(23) = 2.09$, $p < 0.05$ and $t(46) = 2.52$, $p < 0.05$, respectively, indicating that the interference caused by the valued colors in the test phase cannot be attributed simply to their repeated exposure in the learning phase. In addition, for both the experimental group and the control group, the interference effects were comparable when the shape of the color distractor in the test phase matched (19 ms for gain trials and 19 ms for loss trials in the experimental group, and 5 ms for neutral trials in the control group) or mismatched (19 ms for gain trials and 20 ms for loss trials in the experimental group, and 9 ms for the neutral trials in the control group) the shape of the color target in the learning phase, all $t < 1$.

Experiment 1 was designed to replicate the value-driven attentional capture observed in Anderson et al. (2011b). Several differences between the two studies should be noted. Firstly and most importantly, the two



target colors in Anderson et al. (2011b) were both associated with monetary gain in the learning phase, one with high reward and the other with low reward. In contrast, in the present study, one of the two target colors was associated with gain and the other with loss. We chose to investigate whether the loss-associated color could capture attention in the same way as the gain-associated color. Secondly, the amount of money in both the gain and loss trials during learning in the present experiment was dependent on the correctness of response, with correct responses incurring more gain or less loss and incorrect responses incurring less gain or more loss. This was to encourage participants to focus attention on the association between color and reward. Thirdly, the association between monetary gain and a specific color (red or green) was probabilistic in Anderson et al. (2011b; e.g., for the high-reward target, 80% of the correct responses resulted in a high reward while 20% resulted in a low reward) but was fixed in the present study (all the responses resulted in a gain or



loss). The fixed association helped to shorten the learning process (180 trials in this experiment vs. 1,008 trials in experiment 1 and 240 trials in experiment 3 in Anderson et al., 2011b). Finally, the critical distractor in a neutral trial was a color that had appeared in the learning phase in Anderson et al. (2011b) but was a novel color in this experiment. It is likely that this difference is the reason we observed a significant interference effect for the neutral trials, relative to the novel trials, in the control group in this experiment; whereas, Anderson et al. (2011b) observed a null effect for the target trials (equivalent to the neutral trials in this experiment), relative to the nontarget trials (in which the distractor color in the test phase appeared as a distract color in the learning phase), in their control group.

The results of Experiment 1 replicated and extended the finding of value-driven attentional capture in Anderson et al. (2011a, 2011b), demonstrating that loss-associated stimuli can capture attention in the same way as gain-associated stimuli. These results suggest that value-driven attentional capture can occur irrespective of the valence (positive vs. negative) attached to the stimuli. Experiment 2 was designed to investigate whether this pattern of effects can be found when stimuli of lower perceptual salience (e.g., shape, relative to color) are associated with monetary reward.

Experiment 2

There were three subexperiments in Experiment 2. Experiment 2A examined whether a shape that was paired with monetary gain or loss could gain value-based salience during learning and then interfere with the search for a unique color. Experiment 2B tested whether the interference effect observed in the experimental group of Experiment 2A was due to value-based attentional capture or was caused by the familiarity of the shape distractor. Experiment 2C was designed to investigate whether the value-driven attentional capture that did not occur in Experiments 2A and 2B could be observed by lengthening the learning of the pairing between the shape distractor and monetary reward.

Methods

Participants

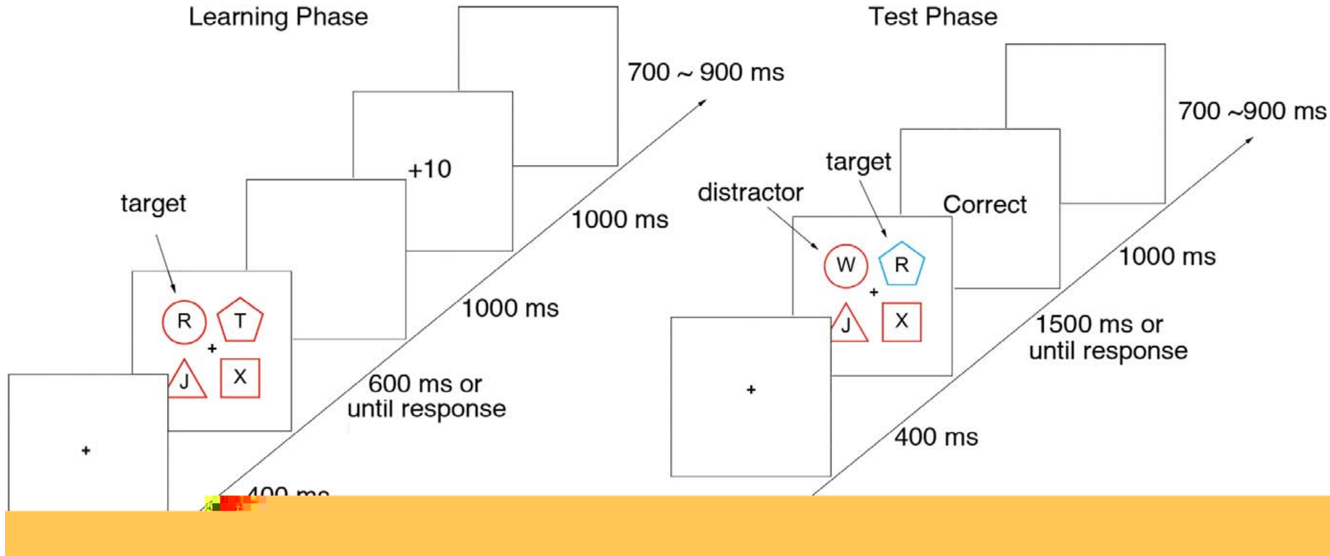
Forty-eight right-handed university students participated in Experiment 2A, with half of them assigned to the experimental group (12 women, mean age: 21.0 years) and the other half assigned to the control group (14 women, mean age: 22.5 years). A group of 24 right-handed students (13 women, mean age: 22.0 years), and another group of 24 right-handed students (15 women, mean age: 22.0 years) participated in Experiments 2B and 2C, respectively. These participants were not tested for Experiment 1.

Stimuli and design

Experiment 2 used essentially the same setting as Experiment 1, with the following exceptions. The fixation sign was a black cross ($0.5° \times 0.5°$). Given that the number of regular shapes that participants are familiar with is limited, we used only four search items. These items ($1.6° \times 1.6°$) were presented in an imaginary square ($3.8° \times 3.8°$), with each item located in one of the four quadrants (Figure 4).

In Experiment 2A, during the learning phase, four red items with different shapes were presented in the search frame. Two specific shapes chosen from square, diamond, and circle were defined as the target shapes, and triangle, pentagon, and the one not chosen as the target shape were used as the distractor shapes. For the experimental group, one of the two target shapes was associated with monetary gain and the other with loss; for the control group, there was no monetary reward but only a response feedback (correct vs. incorrect).

During the test phase, the target was a unique color, with either a red item among three blue distractors or a blue item among three red distractors. For the experimental group, the gain-associated shape appeared as the critical distractor in one third of the trials (gain trials) and the loss-associated shape in another one third of the trials (loss trials). In the remaining one-third of the trials, a novel shape (hexagon, which was not used in the learning phase) appeared as the critical distractor (novel trials). For the control group, the novel shape and each of the two target shapes that were not paired with reward during learning appeared in one-third of the trials, respectively. Trials including the novel shape formed the novel trials, and trials including one of the two target shapes were combined to form neutral trials. In both the learning and the test phases, there was a letter R (normal vs. mirrored) inside the



as the control for examining the potential interference effects for the gain and loss trials.

Procedures

In the learning phase, there were 192 trials for each of the two targets in Experiments 2A and 2B. These numbers were doubled in Experiment 2C. The number of trials for learning in Experiments 2A and 2B was slightly different from the number of trials in Experiment 1 (180 trials) due to the requirement of counterbalancing of stimuli over shape and spatial location.

Results

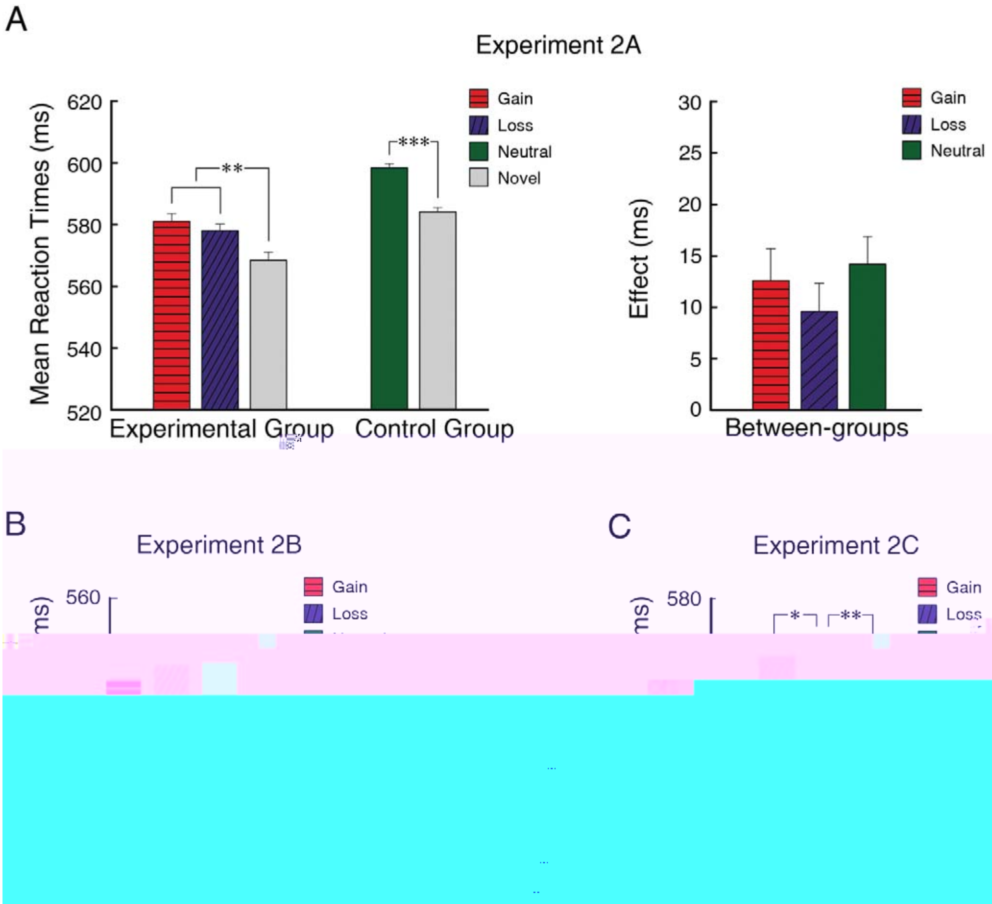
Experiment 2A

For the experimental group, RTs to the gain- and loss-associated targets in the learning phase (Figure 2B) showed no main effect of target type, $F < 1$, although there was a main effect of block, $F(5, 115) = 10.4$, $p < 0.001$, $\eta^2 = 0.311$, with RTs increasingly faster as the exposure to the learning trials increased. In the test phase, the main effect of the experimental condition was significant, $F(2, 46) = 11.0$, $p < 0.001$, $\eta^2 = 0.323$, with RTs for the gain (581 ms) and the loss (578 ms) trials longer than RTs for the novel trials (568 ms), $p < 0.01$ (left panel, Figure 5A). For the control group, RTs for the neutral trials (598 ms) were also longer than RTs for the novel trials (584 ms), $t(23) = 5.35$, $p < 0.001$ (left panel, Figure 5A). However, further analyses showed that the interference effects (13 and 10 ms, respectively, for the gain and loss trials) in the experiment group did not differ from the interference effect (14 ms) in the control group (right panel, Figure 5A), $t < 1$ and $t(46) = 1.21$, $p > 0.1$, respectively, indicating that the interference effects in the experimental group could be completely explained by the familiarity of the shape distractors.

Given that the color of the shape distractor in the test phase either matched or did not match the color of the shape target in the learning phase, we were allowed to examine whether the familiarity effect was caused by the familiarity with the feature (shape) or with the object (shape + color). For the experimental group, the interference effects were comparable when the color of the shape distractor matched (14 ms for gain trials and 11 ms for loss trials) or did not match (11 ms for gain trials and 8 ms for loss trials) the color of the target during learning, both $t < 1$. For the control group, the interference effect for the matched trials (17 ms) did not differ from that for the mismatched trials (11 ms), $t(23) = 1.58$, $p > 0.1$. These results suggested that the learning of a shape leads to a familiarity effect irrespective of its color.

Experiment 2B

In the learning phase, RTs to the gain- and loss-associated trials (Figure 2C) showed no main effect of target type, $F(1, 23) = 1.70$, $p > 0.1$, but a main effect of block, $F(5, 115) = 7.64$, $p < 0.001$, $\eta^2 = 0.249$. In the test phase, the main effect of experimental condition was



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not significant, $F < 1$, indicating comparable RTs for the gain, loss, and neutral trials (Figure 5B). The interference effects induced by the gain-associated distractor (–4 ms) and the loss-associated distractor (–1 ms) in Experiment 2B were significantly smaller than the interference effects in the experimental group of Experiment 2A (13 and 10 ms, respectively, for the gain and loss trials), $t(46) = 4.08$, $p < 0.001$ for gain trials, $t(46) = 2.02$, $p < 0.05$ for loss trials. Thus, there was no value-based attentional capture in this setup, consistent with the finding in Experiment 2A.

Experiment 2C

Analyses of RTs in the learning phase revealed a main effect of block, $F(11, 253) = 14.5$, $p < 0.001$, $\eta^2 = 0.386$, and an interaction between block and target type, $F(11, 253) = 4.54$, $p < 0.001$, $\eta^2 = 0.165$, but no main effect of target type, $F < 1$ (Figure 2D). Importantly, in the test phase, the main effect of the experimental condition was significant, $F(2, 46) = 6.50$, $p < 0.01$, $\eta^2 = 0.220$, with RTs for the loss trials (573 ms) significantly longer than RTs for the neutral trials (561 ms), $p < 0.01$, and longer than RTs for the gain trials (563 ms), $p < 0.05$. The difference between the latter two conditions was not significant, $p > 0.1$ (Figure 5C). Further analysis showed that the interference effect induced by the loss-associated shape in the matched trials (8 ms) did not differ from that in the mismatched trials (13 ms), $t < 1$.

Discussion

The lack of difference in the interference effect between the experimental group and the control group in Experiment 2A suggested that value-driven attentional capture did not occur in search for the color target when the monetary reward was associated with shape distractors. There are two possible accounts for the disappearance of value-driven attentional capture. First, the target shape in the learning phase indeed gained value-based salience but this gain- or loss-associated shape failed to override the high perceptual salience of the color target in the test phase. However, if this was the case, the salient color target should have dominated attentional capture, resulting in a smaller interference effect for the control group in Experiment 2A compared with the effect for the control group in Experiment 1, in which the search target was a unique shape. Statistical comparison of the two effects (14 ms in Experiment 2A vs. 7 ms in Experiment 1) did not support this suggestion, $t(46) = 1.76$, $p = 0.085$.

The alternative account assumes that the target shape in the learning phase failed to gain value-based salience; consequently the interference effect, relative to the novel trials, was simply due to the repeated exposure (familiarity) of the shape distractors in the gain and loss trials in the experimental group and in the neutral trials in the control group. This suggestion was confirmed by the null effect in Experiment 2B, in which the factor of familiarity was controlled and the gain and loss trials were compared with the neutral trials. This null effect also suggested that the interference effect in the control group of Experiment 1 was due to the familiarity of the color distractor rather than its former-target status. Considering the significant effect of color distractors in Experiment 1, one might conclude that, with the same amount of learning, a perceptually salient stimulus is more likely to gain value-based salience through association with monetary reward and induce the value-driven attentional capture than a perceptually less salient stimulus.

The reduced ability of a perceptually less salient stimulus to gain value-based salience, however, could be compensated for by more learning of the pairing between the stimulus and monetary reward. Experiment 2C showed that with prolonged exposure to gain- and loss-associated shapes in the learning phase, the less salient shapes were capable of interfering with color search, at least when the shapes were associated with loss. However, the gain-associated shapes continued to show no sign of value-based attentional capture even after the prolonged learning (384 trials). The asymmetry between gain- and loss-associated shapes in gaining value-based salience and in capturing attention may be due to individuals' increased sensitivity to loss, as compared with the equivalent amount of gain (Tom, Fox, Trepel, & Poldrack, 2007; Tversky & Kahneman, 1992). It appears that this differential sensitivity to the gain- or loss-associated stimulus occurs only when the distractor stimulus is perceptually less salient (as opposed to the perceptual salience of the target). Importantly, it also appears that, at least in certain circumstances (when the perceptual salience of the stimulus is low), the subjectively negative reinforcers (e.g., monetary loss) are stronger than positive reinforcers in assigning value to the stimulus.

To further test this argument and to show that different types of value can induce value-driven attentional capture, in Experiment 3 we associated pain stimulation with the less salient shape distractors and demonstrated that pain-associated distractors can capture attention, even with a short learning phase for the pairing between pain and shape.

Experiment 3

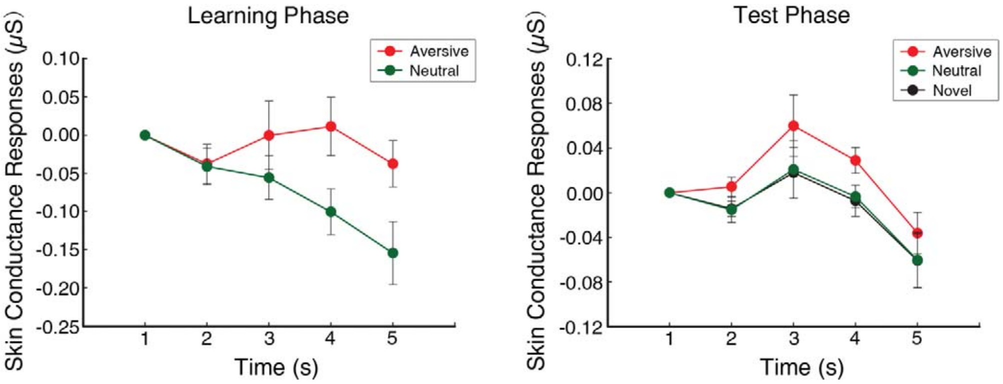
Method

Participants

Twenty-four right-handed university students (14 women, mean age: 22.3 years) participated in Experiment 3. They were not tested for Experiments 1 and 2.

Procedures

The design and procedures in Experiment 3 were essentially the same as those in Experiment 2A except that one of the two target shapes in the learning phase was paired with pain stimulation (aversive trials) and the other was not paired with any feedback (neutral trials). For the aversive target shape, pain stimulation was delivered in 75% of the trials while no pain stimulation was delivered in the other 25% of the trials (i.e., a procedure similar to that in Anderson et al., 2011b). The pain stimulation was delivered 300 ms after button press (i.e., judging whether the target letter was R or mirrored R) and lasted for 100 ms. In both phases, the varying interval before the next trial was set to be 1900, 2000, or 2100 ms. The longer time given in Experiment 3 was to ensure that the skin conductance responses (SCRs), measured from the onset of search display, could return to the baseline before the initiation of the next trial. The purpose of measuring SCRs was to test the reliability of our pain stimulation (Lim, Padmala, &-335.2perg1.10-1TD(initbsti.mrel7508.42)-33



formal experiment, we calibrated the intensity of shock according to the participants' sensitivity to pain. They were firstly given a very mild shock (10 V, duration 100 ms, 50 pulses/s), the voltage of which was gradually increased until the subjective rating of the level of pain reached 7 on a scale of 0 (unnoticeable) to 10 (very painful). The voltage of the electricity was rescaled for each participant every two blocks unless the participant reported, during the break, that his/her subjective rating of pain stimulation for the last few trials was 7. The voltage of the electricity during the learning phase for all the participants was lower than 80 V.

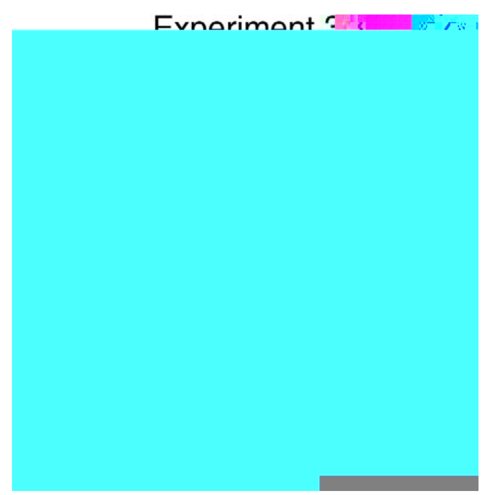
SCR recording

SCRs were recorded throughout Experiment 3. Two shielded Ag-AgCI electrodes, filled with standard NaCI electrolyte gel, were attached to the distal phalange of the index and third fingers of the participant's left hand. Signals were amplified and sampled at 200 Hz with a MP150 psychophysiological monitoring system (BioPac Systems, Santa Barbara, CA).

Results and discussion

To confirm the effectiveness of the pain stimulation, we firstly compared the SCRs elicited by the aversive and neutral trials in the learning phase. The magnitude of SCR was calculated by averaging signals in the 0–1 s, 1–2 s, 2–3 s, 3–4 s, and 4–5 s latency windows from the onset of the display of search items, respectively. It is clear in Figure 6 (left panel) that SCRs for the aversive and neutral trials started to diverge at the second time windows, with the aversive trials eliciting stronger SCRs. Statistical analyses showed that the difference between the two conditions was marginally significant in the 4th second, $t(23) = 1.84$, $p = 0.079$, and was significant in the 5th second, $t(23) = 2.14$, $p < 0.05$, indicating that the execution of pain stimulation was effective. In the test phase, although pain stimulation was no longer delivered, participants still showed increased SCRs to the shape previously associated with pain stimulation in the learning phase (right panel, Figure 6). A repeated-measures ANOVA, treating the time window as a within-participant factor, showed a marginally significant main effect of condition, $F(2, 46) = 3.02$, $p = 0.06$, $\eta^2 = 0.116$, indicating that a distractor previously associated with pain could trigger physiological responses even when pain stimulation was no longer present.

For RTs, the analysis of the two kinds of responses over time in the learning phase revealed a main effect of block, $F(5, 115) = 14.2$, $p < 0.001$, $\eta^2 = 0.382$, but no main effect of target type, $F(1, 23) = 1.06$, $p > 0.1$ (Figure 2E). In the test phase, the main effect of experimental condition was significant, $F(2, 46) = 14.8$, $p < 0.001$, $\eta^2 = 0.391$. Further tests showed that RTs for the aversive trials (576 ms) were longer than RTs for



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the novel (560 ms) and neutral (567 ms) trials, $p < 0.001$ and $p < 0.05$, respectively (Figure 7). The difference between the latter two was marginally significant, $p = 0.072$. Further analysis showed that the value-based effect for the matched trials (8 ms) did not differ from that for the mismatched trials (9 ms), $t < 1$, and the familiarity effect for the matched trials (9 ms) did not differ from that for the mismatched trials (6 ms) either, $t < 1$.

Experiment 3 revealed both a value-based interference effect and an interference effect induced by the familiarity of the shape distractor. The value-based effect, contrary to the null effect in Experiment 2B, was consistent with the suggestion that a negative reinforcer was stronger than a positive reinforcer in assigning value. Moreover, for the negative reinforcer, while the monetary loss and pain stimulation caused comparable interference effects relative to neutral trials (12 and 9 ms, respectively, $t < 1$), the association between monetary loss and the shape distractor required more learning relative to the association between pain stimulation and the shape distractor (384 vs. 96 trials). These results confirmed our hypothesis that pain stimulation is more efficient than money in assigning value.

Experiment 3 did not rule out the possibility that the interference effect induced by the aversive distractor and that induced by monetary gain- or loss-associated distractor could be due to different processes. Notebaert, Crombez, Van Damme, De Houwer, and Theeuwes (2010, 2011) argued that delayed responses in the presence of a pain-associated distractor were due to the prolonged disengagement of attention from the aversive stimulus, rather than stronger capture by the stimulus. This claim was based on their finding that the interference effect by the aversive distractor increased with the number of the competing distractors, a critical index to determine whether an interference effect is strictly due to attentional capture (Frischen, Eastwood, & Smilek, 2008; Wolfe, 1998). Given that we did not vary the search size and that the focus of the present study was on the interaction between value and perceptual salience in gaining access to attention, we leave this issue for further studies. We note that the same argument could also be applied to the interference effect induced by the monetary gain- or loss-associated distractors.

General discussion

The present study extended Anderson et al. (2011b) by showing that, in addition to the gain-associated attentional capture effect, there is attentional capture by the loss-associated (Experiments 1 and 2C) or pain-associated (Experiment 3) distractors in visual search. These findings demonstrate that the value behind attentional capture can be either positive or negative and can be either culturally or biologically determined. More importantly, results from the three experiments indicated that whether an object gains value-based salience and consequently captures attention depends crucially on the object's perceptual salience, relative to its environment or context, and on the nature of the value. If an object is of relatively low perceptual salience, as was the shape in Experiments 2A and 2B, the object might not be able to gain value-based salience and to induce value-driven attentional capture. If, however, the object of lower perceptual salience is associated strongly with value, either because of the value's significance (negativity) to individuals or because of the over-learning of the pairing between the (negative) value and the object (Experiments 3 and 2C), it is able to gain value-based salience and capture attention.

Considering the competing possibilities outlined in the Introduction, it is clear that the value-based salience of a stimulus is acquired through the interaction between the stimulus' perceptual salience and the value assigned to it. On the basis of the finding that the amount of the value-induced interference increases as a function of the amount of monetary gain, Anderson et al. (2011a) argued for a combined effect of value and perceptual salience in determining attentional priority. However, their results do not exclude the possibility that value alone operates to increase the overall salience because perceptual salience of the value-associated stimulus was kept constant in the study. In the present study, because we concurrently manipulated the value and perceptual salience of the learned target, we are able to strengthen the conclusion that value-based attentional priority is determined by the combined force of value and perceptual salience.

Based on the interaction between perceptual salience and value, we propose that perceptual salience may function as a gating mechanism for the association between a stimulus and value, and hence for the occurrence of value-driven attentional capture. Specifically, if an object is of relatively high perceptual salience (as is the case for color) it can gain value-based salience through pairing with monetary reward. If its perceptual salience is relatively low (as is the case for shape), it is not able to gain value-based salience until the learning of the pairing with monetary reward is intensive. Moreover, a perceptually salient object gains value-based salience irrespective of the valence (positive vs. negative) of the reinforcers; a perceptually less salient object, however, gains value-based salience only when strongly associated with negative reinforcers.

Another finding in this study was that, in visual search, distractors associated with physical pain are more likely to produce interference than distractors associating with monetary reward, as demonstrated by the comparison between Experiments 2C and 3. This finding can be related to the fact that pain is closely related to the emotion of fear, which, from an evolutionary perspective, is deeply rooted in biology and is crucial for survival and reproduction of a species (Ohman & Mineka, 2001; Phelps, Ledoux, & Place, 2005). Pain and fear can signal immediate challenge to survival and warn the organism to prepare for the worst (Amaral, 2006; Rogan, Leon, Perez, & Kandel, 2005). Monetary incentive, by contrast, is a cultural invention emerging relatively late in evolutionary history and is not directly related to survival. Therefore, pain stimulation could be more arousing than monetary reward and thus more potent in assigning value. It is for future research to determine whether the different types of value are underpinned by the same neural mechanism, forming a "common currency" (Levy & Glimcher, 2012) for attentional capture.

In addition to value-driven attentional capture, Experiments 1, 2A, and 3 consistently showed that an object that has repeated exposure during learning can cause interference as a distractor, relative to a novel object, in the later test phase. This familiarity-based effect, along with the value-based effect, suggests that both value and familiarity contribute to the past selection history of a stimulus and in turn determine attentional priority (Awh, Belopolsky, & Theeuwes, 2012). Moreover, both the familiarity-based and the value-based effects occurred in the test phase regardless of whether or not the other feature of the stimulus was the same as that of the former target during learning, suggesting that the attentional priority that is acquired through familiarity or value association can generalize to different stimuli sharing the learned feature (Anderson, Laurent, & Yantis, 2012).

Conclusion

By independently manipulating the perceptual salience and value of a crucial distractor in visual search, we found that value-driven attentional capture induced by the distractor previously associated with monetary reward disappeared when the perceptual salience of the distractor was low, but reappeared when the distractor was paired more strongly with monetary loss or was paired with pain stimulation. These results suggest that value and perceptual salience interacts to modulate the value-based attentional capture and the extent of value information capturing attention depends on the biological significance of the value attribute.

Keywords: attentional capture, fear conditioning, pain stimulation, perceptual salience, visual search

Acknowledgments

This study was supported by National Basic Research Program of China (973 Program: 2010CB833904) and by grants from the Natural Science Foundation of China (30110972, 91232708). We thank Mr. Stijn Massar for suggestions on the design of the experiments, Mr. Ciyang Qing for help with participant testing, and two anonymous reviewers for their constructive suggestions.

Commercial relationships: none.
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