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Diminishing sensitivity and absolute difference in value-driven attention

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Kim and Beck (2020b) demonstrated that value-driven attention is based on relative value rather than absolute value, suggesting that prospect theory is relevant to our understanding of value-driven attention. To further this understanding, the present study investigated the impacts of diminishing sensitivity on value-driven attention. According to diminishing sensitivity, changes in outcomes have greater impacts nearer the reference point of 0 than farther from the point. Thus, the difference between $1 and $100 looms larger than that between $901 and $1000, due to their different ratios (100/1 > 1000/901). However, according to the absolute difference hypothesis, the differences should have similar impacts due to the absolute differences being the same (100 – 1 = 1000 – 901). Experiment 1 investigated whether diminishing sensitivity operates in the modified value-driven attention paradigm while controlling the impact of absolute differences. In the training phase, 100-point and 1000-point color targets had references of 1-point and 901-point color targets, respectively. In the test phase, 100-point color distractors attracted attention more than 1000-point color distractors, supporting the diminishing sensitivity hypothesis. Experiment 2 examined the absolute difference hypothesis while controlling the impact of diminishing sensitivity. Contrary to the absolute difference hypothesis, the test phase showed that 1000-point color distractors (compared with 10-point colors for a 990 absolute difference in the training phase) failed to attract attention more than 100-point color distractors (compared with 1-point colors, for a 99 absolute difference). These results suggest that diminishing sensitivity rather than absolute difference influences value-driven attention, further supporting the relevance of prospect theory to value-driven attention.

Introduction

A selection process exists in perception via selective attention, the process of focusing on a particular stimulus out of many alternatives (Broadbent, 1958; Kahneman, 1973; Treisman & Geffen, 1967). This selection process is similar to the process of making a choice among available alternatives in decision-making (Edwards, 1954). Therefore, although decision-making and selective attention occur in different cognitive stages, they share a core concept of selection. Furthermore, the selection processes interact functionally. Attending to an item leads to an increase in the likelihood of choosing the item (Krajbich, Armel, & Rangel, 2010; Stewart, Hermens, & Matthews, 2016), and the decision to search for an item facilitates attention toward the item (Desimone & Duncan, 1995; Kim & Beck, 2020a; Kim & Cho, 2016; Wolfe, 1994). In addition to the conceptual similarity and functional link, decision-making and selective attention share a critical factor affecting selection, *value*. More valuable items are more likely to be chosen in decision-making (Von Neumann & Morgenstern, 1947) and are more likely to be attended to in perception (Anderson, Laurent, & Yantis, 2011). However, decision-makers do not objectively evaluate the value of items, but distort it (Kahneman & Tversky, 1979; Thaler, 1980). The value distortion in decision-making occurs in a predictable way according to the psychological principles in the value function of prospect theory (Tversky & Kahneman, 1981). Then, the critical question is if the value distortion found in decision-making will occur in selective attention. In line with this, previous work

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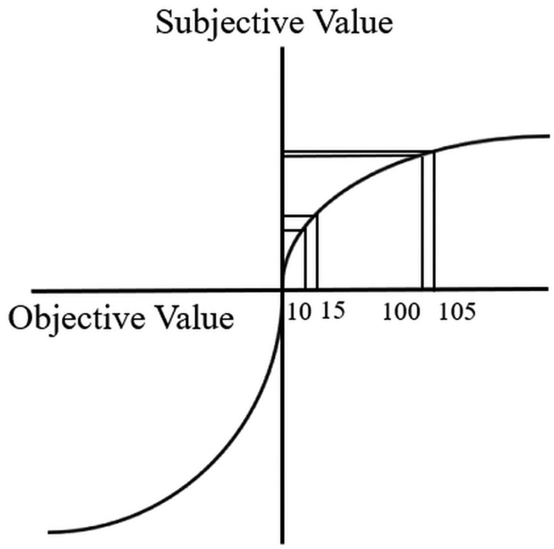

Figure 1. A typical value function of prospect theory demonstrating diminishing sensitivity. The value function describes how objective value (absolute value, outcomes) is psychologically (subjectively) distorted. Specifically, the difference between 10 and 5 and the difference between 100 and 105 are equal on the objective-value axis but differ on the subjective-value axis.

shows that attention is attracted based on relative value rather than absolute value (Kim & Beck 2020b). The present study expands on this previous work by investigating whether when a valuable item attracts attention, the value of the item is distorted on the basis of the diminishing sensitivity principle of prospect theory (Kahneman & Tversky, 1979).

Prospect theory in selective attention

Traditional economic theory suggests how decision-makers should behave to maximize benefits, postulating that decision-makers are rational. As a result, economic theory does not fit with how people actually make a choice. To explain how decision-makers actually behave, prospect theory (Kahneman & Tversky, 1979; Tversky & Kahneman, 1992) posits that decision-makers are irrational and explains how objective (absolute) value (e.g., money, time, health) is distorted due to the following psychological principles: reference dependence, diminishing sensitivity, and loss aversion. The principles are described in the value function (see Figure 1). According to reference dependence, value is determined from a reference point so that relative value (e.g., higher, lower) but not absolute value (e.g., $5, 100 points, 10 minutes) is critical. A reference point can move, and multiple reference points may exist depending on a given situation. Diminishing sensitivity further specifies the impact of relative value by suggesting that the proportion of a difference is critical so that earning an additional $5 leads to more pleasure when $10 was expected than when $100 was expected (15:10 > 105:100). The difference between $10 and $15 looms bigger psychologically than the difference between $100 and $105, although the objective (absolute) difference is the same. Loss aversion suggests that people are more sensitive to potential losses than gains. Prospect theory has been extensively validated and used in economics, marketing, and politics because it predicts how people *actually* make a decision (Barberis, 2013). Kahneman was awarded the 2002 Nobel Memorial Prize in Economics for developing prospect theory, and Tversky would surely have shared the prize if he had not passed away in 1996 (Barberis, 2013). The 2017 Nobel Memorial Prize winner in Economics, Richard Thaler, played a pivotal role in applying prospect theory to economics and establishing the field of behavioral economics (Kahneman, 2011).

Interestingly, Kahneman and Tversky took advantage of basic principles of perception (e.g., Weber–Fechner law) to develop prospect theory. The two psychologists drew from the understanding that basic cognitive principles operate across the early (perception) and later (decision-making) cognitive stages. For example, Kahneman and Tversky (1979, p. 277) stated:

> An essential feature of the present theory is that the carriers of value are changes in wealth or welfare, rather than final states. This assumption is compatible with basic principles of perception and judgment. Our perceptual apparatus is attuned to the evaluation of changes or differences rather than to the evaluation of absolute magnitudes. When we respond to attributes such as brightness, loudness, or temperature, the past and present context of experience defines an adaptation level, or reference point, and stimuli are perceived in relation to this reference point. Thus, an object at a given temperature may be experienced as hot or cold to the touch depending on the temperature to which one has adapted. The same principle applies to non-sensory attributes such as health, prestige, and wealth.

This statement, in line with Thaler (1980, 1999), indicates that prospect theory may extend to selective attention. In addition, the probability weighting function (another aspect of prospect theory) was demonstrated to operate in selective attention (Vincent, 2011). Also, decision-making and selective attention share a core concept of selection (Edwards, 1954; Kahneman, 1973) and interact functionally (Desimone & Duncan, 1995; Kim & Beck, 2020a; Krajbich et al., 2010; Stewart et al., 2016; Wolfe, 1994). These allude to the extendibility of reference dependence and diminishing sensitivity to selective attention. In line with this, Kim and Beck (2020b) demonstrated that the reference dependence principle of prospect theory is present in selective attention. In the current study, we expand on this previous research to show that diminishing sensitivity is also present in selective attention.

Reference dependence in selective attention

Reference dependence suggests that the value of an object is determined by a reference point of the object. For example, when you have expected to gain $1, receiving $10 will give rise to pleasure. When you have expected to gain $20, receiving $10 will lead to disappointment. The reference points of 1 and 20 determine the subjective value of 10. That is, prospect theory suggests that relative value (high or low compared with a reference point), not absolute value ($10), is critical to perceived value.

Kim and Beck (2020b) demonstrated that reference dependence operates in selective attention by applying the reference dependence principle to value-driven attention. Value-driven attention (Anderson et al., 2011; Bucker & Theeuwes, 2017; Chelazzi, Perlato, Santandrea, & Della Libera, 2013; Della Libera & Chelazzi, 2009; Hickey, Chelazzi, & Theeuwes, 2010; Le Pelley, Pearson, Porter, Yee, & Luque, 2019; Mine & Saiki, 2015; Roper, Vecera, & Vaidya, 2014) suggests that more valuable stimuli are attended more. Therefore, value-driven attention is useful for exploring whether more valuable stimuli are attended more based on the value function (the psychological principles) of prospect theory. However, the classic paradigm of value-driven attention (Anderson, 2016) is not sufficient to test if the value function of prospect theory applies to selective attention.

The classic paradigm of value-driven attention consists of training and test phases (e.g., Anderson et al., 2011). In a typical training phase where associative learning between color and reward occurs, search targets are red and green. One of the two target colors is randomly selected and presented among different color stimuli on each trial. Therefore, both target colors are potential targets on each trial during the training phase. After locating the target (either red or green), participants are asked to report whether the orientation of a line inside the target is horizontal or vertical by pressing a corresponding key. Response time for pressing the key is measured. Reward is given for a correct response. Critically, red is associated with high reward and green with low reward (color–reward associations counterbalanced across participants). In a typical test phase, it is examined if the more valuable color (red), previously associated with higher reward in training, attracts attention more than the less valuable color (green), previously associated with lower reward in training. In the test phase, color is task-irrelevant because search targets are unique shapes (e.g., a white diamond among white circles, a white circle among white diamonds). Critically, on some trials, one of distractors is equiprobably either red or green. Despite color being task-irrelevant and no reward being given in the test phase, search is slower when red distractors, the previously high-valued color in training, are presented than when green distractors, the previously low-valued color in training, are presented. The delay with the high-valued compared with the low-valued color distractors suggests that more valuable stimuli attract attention more.

The results of the classic paradigm, however, cannot demonstrate if the value-driven attention effect was due to relative or absolute value (Anderson, 2016). The test target colors (red and green) are reference points for one another during the training phase in the classic paradigm. Red is both absolutely and relatively high compared with green, making the classic paradigm unable to answer whether high-valued color distractors capture attention more because they are associated with a higher relative or absolute value.

Kim and Beck (2020b) demonstrated that reference dependence operates in selective attention by modifying the classic paradigm to allow for reference dependence to be tested. Unlike in the typical value-driven attention paradigm, in Kim and Beck (2020b) the test target colors (red and green) had different reference points in the training phase. For example, while target colors were red and yellow in blocks 1, 3, and 5, they were green and blue in blocks 2, 4, and 6. Then, in blocks 1, 3, and 5, rewards were given for only red and yellow (never for green and blue), allowing red and yellow to be one context and compared with each other. In blocks 2, 4, and 6, rewards were given for only blue and green (never for red and yellow), allowing green and blue to be the other context and compared with each other. Accordingly, red and green had yellow and blue reference points, respectively, in the training. This allowed for the independent manipulation of the relative and absolute value of the test target color (red and green). In the test phase, red and green were presented as distractor colors like the classic paradigm. Kim and Beck (2020b) found evidence that the relatively high-valued color distractors delayed search compared with the relatively low-valued color distractors when the absolute value of the colors was the same. However, the absolutely high-valued color distractors did not delay the search compared with the absolutely low-valued color distractors when the relative value of the colors was the same. The findings suggest that more valuable stimuli receive higher attentional priority due to relative but not absolute value, and reference points play a critical role in determining subjective value (reference dependence). Reference dependence in selective attention (Kim & Beck, 2020b) is consistent with Anderson's assumption that, "although never directly manipulated in a single experiment, it has become clear that relative or normalized value, rather than associated value in an absolute sense, biases attention” (Anderson, 2016, p. 28).

Diminishing sensitivity in selective attention

The present study extends on Kim and Beck (2020b) by investigating what type of relative value is critical in attentional priority: diminishing sensitivity (proportional difference) versus absolute difference. The diminishing sensitivity principle reflects the basic psychological principle of the Weber–Fechner law, which states that people respond to changes in physical stimuli by comparing the changed value to the original value (Kahneman & Tversky, 1979); therefore, not only is the relative value important, but the *proportion* of the difference between the value and the reference is also critical (Thaler, 1980, 1999). For example, it is easier to notice the difference of 1 kg between 1 kg and 2 kg than between 10 kg and 11 kg (Stevens, 1957). In line with this, the value function of prospect theory shows that the marginal impact of a change diminishes with the distance from a regular reference point of 0 (Kahneman & Tversky, 1979). That is, diminishing sensitivity explains that relative values (e.g., \$2 is more than \$1; \$11 is more than \$10) are based on a relative difference (\$2/\$1 = 2; \$11/\$10 = 1.1) rather than an absolute difference (\$2 – \$1 = \$1; \$11 – \$10 = \$1).

The diminishing sensitivity principle has been demonstrated empirically in judgment and decision-making tasks. Thaler (1980) showed that \$5 seems like a lot to save on a \$25 radio but not much on a \$500 television. This is because the difference between 20 and 25 looms larger than the difference between 495 and 500, although the actual difference is the same, \$5. This foundational finding was replicated in Tversky and Kahneman (1981), where people were more sensitive to the difference between \$10 and \$15 than between \$120 and \$125, indicating that the difference between 10 and 15 was psychologically larger than the difference between 120 and 125. However, according to the economic theory, only absolute differences should matter (Tirole, 1988). This idea follows from rational utility maximization and is an unchallenged assumption in economic theory. Thus, in the example of Tversky and Kahneman (1981), the economic theory suggests that the impact of the differences should be psychologically similar because the absolute differences are the same (15 – 10 = 125 – 120). In Kim and Beck (2020b), absolute differences and diminishing sensitivity (proportional differences) of rewards were not controlled. Thus, the present study expands on this previous research by examining if diminishing sensitivity operates in selective attention by using the empirical finding from decision making (Thaler, 1980; Tversky & Kahneman, 1981) and modifying the value-driven attention paradigm (Kim & Beck, 2020b).

Experiment 1

In the training phase (see Figure 2), associative learning occurs between color and reward. Test target colors were paired with reference target colors within particular context blocks to control reference points of the test target colors. Across participants, the test target colors (red or green), the reference target colors (yellow or blue), and the block order (ABABAB or BABABA) were fully counterbalanced. For ease of explanation, we will provide an example of what a given participant could have received. In this example, in blocks 1, 3, and 5, one of two target colors (red and yellow) was randomly chosen and presented on each trial. Red gave 100 points and yellow gave 1 point on each trial when a correct response was made. Therefore, the 100-point

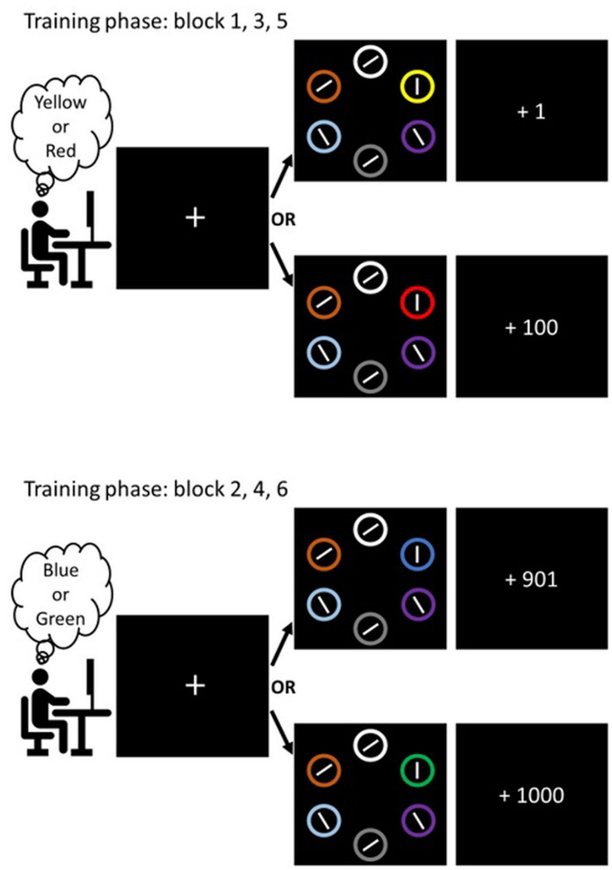

Figure 2. Examples of the training phase in Experiment 1. In blocks 1, 3, and 5, search targets are yellow and red, giving 1 point and 100 points, respectively. In blocks 2, 4, and 6, search targets are blue and green, giving 901 points and 1000 points, respectively.

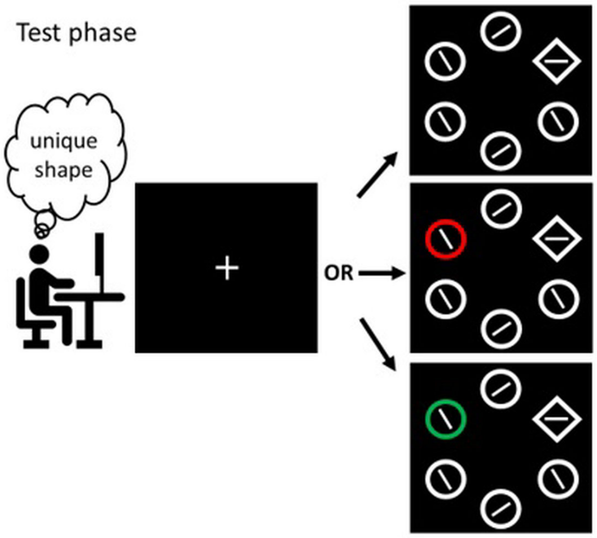

Figure 3. Examples of the test phase. Search targets are unique shapes. On half of the trials, no color distractor was presented (top). On the remaining half, one of distractors was equiprobably either red (middle) or green (bottom). No reward was given in the test phase.

color and the 1-point color were available targets in the blocks. A reference point was set within each block rather than between blocks because a reference point is chosen among available alternatives (Elliott, Agnew, & Deakin, 2008; Kahneman & Tversky, 1979; Thaler, 1980, 1999; Tremblay & Schultz, 1999). In previous experiments investigating relative value, availability was a core factor in determining a reference point (Elliott et al., 2008; Tremblay & Schultz, 1999). Therefore, the 1-point color became a reference point of the 100-point color based on availability. In blocks 2, 4, and 6, one of two target colors (green and blue) was randomly presented on each trial. Green gave 1000 points, and blue gave 901 points. Therefore, the 1000-point color and the 901-point color were available targets in the blocks, and the 901-point color became a reference point of the 1000-point color. Across participants, test target colors (red or green) were randomly assigned to 100 or 1000, reference target colors (yellow or blue) were randomly assigned to 1 or 901, and blocks (1, 3, and 5 or 2, 4, and 6) were randomly assigned between high (1 point and 100 points) or low (901 and 1000 points) relative context for each participant.

In the test phase (see Figure 3), search targets were defined by a unique shape; therefore, color was task-irrelevant. Also, no reward was given in the test phase. Critically, on some trials, one of distractors was either red (which had been the 100-point color with the reference point of the 1-point color in the training phase) or green (which had been the 1000-point color with the reference point of the 901-point color in the training phase). According to the diminishing sensitivity principle (Kahneman & Tversky, 1979; Thaler, 1980), the difference between 100 and 1 should be psychologically bigger than the difference between 1000 and 901, although the objective (absolute) difference is the same.

If the diminishing sensitivity principle operates in selective attention, the 100-point color distractor should attract attention more than the 1000-point color distractor. Accordingly, search should be delayed more when the 100-point color distractor is presented than when the 1000-point color distractor is presented during the test phase: the *diminishing sensitivity hypothesis*. In contrast, if attentional selection operates according to economic theory, the 1000-point color distractor and the 100-point color distractor should attract attention similarly because the absolute value differences are the same (1000 – 901 = 100 – 1) in the training phase: the *absolute difference hypothesis*.

Method

Participants

Seventy-two undergraduate students with normal or corrected-to-normal vision participated for course credit (mean age = 19.3 years; 51 female). G*Power was used to calculate the needed sample size. We used a power of 0.8 and an alpha of 0.05. To determine the effect size, we looked to the Kim and Beck (2020b) study, which had an effect size of 0.30 (Cohen's *d*) for the critical comparison between high-value and low-value color distractors in the test phase. For the current study, we predicted a small to medium effect size because proportional differences increased (from 18 times to 90 times) compared with Kim and Beck (2020b). Therefore, we ran the G*Power test with an effect size of 0.40 and found that a minimum sample size was 52.

Apparatus and stimuli

Stimuli were presented on a 20-inch monitor. The distance between the participants and the monitor was approximately 60 cm but was not constrained. Experiments were programmed and administered using MATLAB (MathWorks, Natick, MA) and Psychophysics Toolbox software.

In the training phase (see Figure 2), each trial consisted of fixation, search, blank, and feedback displays. The background of the screen was black for all displays. In the fixation display, a white cross bar was presented in the center of the screen. In the search display, six circles (1.4° diameter each) were presented around an invisible circle (5° radius). Inside a target object, a horizontal or vertical white line was presented, and inside each distractor object, a white line tilted 45°

to the left or right was presented. One of the six circles was a target color (yellow, red, green, or blue), and the others were distractor colors (orange, purple, aqua, white, and gray). In the search display of the test phase (see Figure 3), the search target was a unique shape: a circle among diamonds or a diamond among circles. On half of the trials, all of the objects were white. On the other half of trials one of non-target objects was equiprobably either red or green. In the search display in the training and test phases, the fixation cross was removed considering that there is a close coupling of covert attention and overt attention in value-driven attention (Anderson & Yantis, 2012; Le Pelley et al., 2019), and in a pilot test participants reported fatigue due to a requirement to use covert attention (eyes had to remain on the fixation cross during search).

Design

The experiment consisted of 720 training trials followed by 384 test trials. The independent variable is the value of the test target colors. In the training phase, correct responses earned 100 and 1000 points for the test target colors, red and green, respectively (the reverse association for half of the participants). For the reference target colors, correct response earned 1 point and 901 points for blue and yellow, respectively (the reverse association for half of the participants). The 100-point test target and the 1-point reference target were presented in blocks 1, 3, and 5 (in blocks 2, 4, and 6 for half of the participants). The 1000-point test target and the 901-point reference target were presented in blocks 2, 4, and 6 (in blocks 1, 3, and 5 for half of the participants). Within each block, each of the two target colors (one test target color and one reference target color) were presented on 50% of trials. The test target colors (red or green), the reference target colors (yellow or blue), and the block order (ABABAB or BABABA) were fully counterbalanced across the participants. Therefore, stimuli differences were controlled between the 100-point and 1000-point test targets, and proximity (the last [sixth] block of the training phase was the 1-point and 100-point color context for half of the participants and the 901-point and 1000-point color context for the other half) from the training to test phase was controlled between the test targets. Critically, the test targets had a different reference target in the context blocks (Kim & Beck, 2020b).

Procedure

In the training phase, participants were instructed to find a circle with one of the two target colors and report the orientation of the line inside the circle by pressing the N-key for a horizontal line or M-key for a vertical line as quickly and accurately as possible. On each trial, the fixation display was presented for 400 ms, followed by the search display until a response was made. After the response, there was a blank display for 50 ms and then a feedback display for 900 ms. In the feedback display, earned points (e.g., +100) were presented when a correct response was made within 1500 ms. For incorrect responses, "+0 (wrong)" was presented. For correct but slow responses (over 1500 ms), "+0 (too slow)" was presented.

Participants first completed 40 practice trials during the training phase. In the first 20 practice trials, the target colors were the same as the target colors in the first, third, and fifth training blocks (e.g., red and yellow). In the second 20 practice trials, the target colors were the same as those of second, fourth, and sixth training blocks (e.g., green and blue). Before each practice, oral and written instructions regarding the target colors were provided. Before each of the six training blocks, written instruction regarding the target colors was provided. Participants were informed that they would receive points when fast and correct responses were made, and the experiment would finish earlier as they received more points. However, unbeknownst to the participants, earned points did not affect the number of trials in the experiment. Non-monetary rewards have shown to be effective in guiding human behaviors such as attention (Beck, Goldstein, van Lamsweerde, & Ericson, 2018; Kim & Beck, 2020b) and decision-making (Tversky & Kahneman, 1981).

The test phase followed immediately after the training phase. Participants were instructed to search for a unique shape (a circle among diamonds or a diamond among circles) and report the orientation of the line in the unique shape; therefore, color was task-irrelevant. Also, they were informed that reward points were not given in the test phase. The timing of each screen and required response was the same as in the training phase, but the search display was replaced with the shape singleton search display. During 20 practice trials, an experimenter checked and confirmed that participants understood the singleton shape detection instructions. Then, 384 randomly ordered test trials were given. On 96 of the 384 trials, one of non-target objects was green. On another 96 trials, one of the non-target objects was red. On the remaining 192 trials, all objects were white.

Results

The dependent variables are accuracy and response time (RT) recorded from the onset of the search display. Only correct responses were included in analyses of RTs (incorrect trials: 4.1% in training phase and 6.9% in test phase). Also, trials in which RT was shorter than 150 ms (<0.01% in the training phase, <0.01% in the test phase) or longer than 1500 ms (1.1% in the training phase, 4.6% in the test phase) were excluded from the analysis. The first three trials of each block in the training phase and of the test phase were also excluded from the analysis to allow some time to change the attentional control settings.

Training phase

Given that the 100-point color and 1000-point color were presented separately in the 1-point and 100-point context and the 901-point and 1000-point context, respectively, we examined if the contexts influenced task performance in the training phase. Two-way within-subject analyses of variance (ANOVAs) were conducted on RT and accuracy with two within-subject variables: context (the 1-point and 100-point context and the 901-point and 1000-point context) and within-block value (low-value colors, 1-point color and 901-point color, reference target colors; high value colors, 100-point color and 1000-point color, test target colors).

For RT, the main effect of within-block value was not significant: low ($M = 674$ ms, $SE = 8$ ms) and high ($M = 678$ ms, $SE = 9$ ms), $F(1, 71) = 2.01$, $p = 0.16$, $\eta_p^2 = 0.028$. The main effect of context was also not significant: the 1-point and 100-point context block ($M = 681$ ms, $SE = 9$ ms) and the 901-point and 1000-point context block ($M = 673$ ms, $SE = 9$ ms), $F(1, 71) = 2.82$, $p = 0.097$, $\eta_p^2 = 0.038$. The interaction between context and within-block value was also not significant, $F(1, 71) = 0.96$, $p = 0.33$, $\eta_p^2 = 0.013$. For accuracy, the main effect of the within-block value was significant: low ($M = 95.5\%$, $SE = 0.3\%$) and high ($M = 95.9\%$, $SE = 0.3\%$), $F(1, 71) = 4.74$, $p = 0.033$, $\eta_p^2 = 0.063$. However, given the direction of the RT difference, the main effect of within-block value seemed to be due to a speed–accuracy tradeoff. Therefore, inverse efficiency scores (RT/accuracy) were used as a dependent variable. No difference in inverse efficiency scores between low ($M = 708$, $SE = 9$) and high ($M = 709$, $SE = 9$) color was found, $t(71) = 0.2$, $p = 0.84$, suggesting that the main effect of within-block value resulted from a speed–accuracy tradeoff. The main effect of context was also significant: the 1-point and 100-point context ($M = 95.4\%$, $SE = 0.3\%$) and the 901-point and 1000-point context ($M = 95.9\%$, $SE = 0.3\%$), $F(1, 71) = 5.42$, $p = 0.023$, $\eta_p^2 = 0.072$. Higher accuracy for the 901-point and 1000-point colors may be due to participants being more motivated in the 901-point and 1000-point context. If this carried over to the test phase, it would increase the strength of the 1000-point color distractor attracting attention compared to the 100-point color distractor attracting attention in the test phase. Note that the direction of this carry-over effect is the opposite of the prediction of the diminishing sensitivity hypothesis. The interaction between the context and the within-block value was not significant, $F(1, 71) = 1.26$, $p = 0.27$, $\eta_p^2 = 0.017$.

To directly see whether an individual's facilitation difference between the contexts in the training phase influenced an individual's value-driven attention effect in the test phase, correlation analyses were conducted between a facilitation difference and a value-driven attention effect. A facilitation difference was calculated by subtracting RT, accuracy, and inverse efficiency for the 1000-point and 901-point context from RT, accuracy, and inverse efficiency for the 100-point and 1-point context. A value-driven attention effect was calculated by subtracting RT for 1000-point color distractor presence from RT for 100-point color distractor presence. No significant correlations were found: $r(70) = –0.181$, $p = 0.128$ for RT; $r(70) = –0.187$, $p = 0.117$ for accuracy; and $r(70) = –0.180$, $p = 0.131$ for inverse efficiency. The results indicated that a facilitation difference between the 1-point and 100-point color context and the 901-point and 1000-point color context did not influence a value-driven attention effect of the 100-point color distractor and the 1000-point color distractor.

To examine whether value-driven attention operates based on proportional difference or absolute difference, the 100-point target color and the 1000-point target color were compared on RT and accuracy. Mean accuracy during the training phase was not different between when the target was the 100-point (compared to 1-point) color ($M = 95.7\%$, $SE = 0.3\%$) and the 1000-point (compared to 901-point) color ($M = 96.0\%$, $SE = 0.3\%$), $t(71) = 0.96$, $p = 0.34$, $d = 0.11$. Mean RT was not different between when the target was the 100-point (compared to 1-point) color ($M = 684$ ms, $SE = 9$ ms) and the 1000-point (compared to 901-point) color ($M = 673$ ms, $SE = 10$ ms), $t(71) = 1.90$, $p = 0.062$, $d = 0.22$. This lack of differences is typical in the training phase of the value-driven attention paradigm, not a lack of difference in learned associated value between the colors (e.g., Anderson, 2015; Anderson et al., 2011; Anderson, Leal, Hall, Yassa, & Yantis, 2014; Kim & Beck, 2020b; Roper et al., 2014; Wang, Yu, & Zhou, 2013).

Test phase

One-way within-subject ANOVAs on mean RT and mean accuracy were conducted to explore how the three distractor conditions (100-point color distractors, 1000-point color distractors, no color distractors) influenced search.

For accuracy, the main effect of distractor condition was not significant, $F(2, 142) = 2.55$, $p = 0.08$,

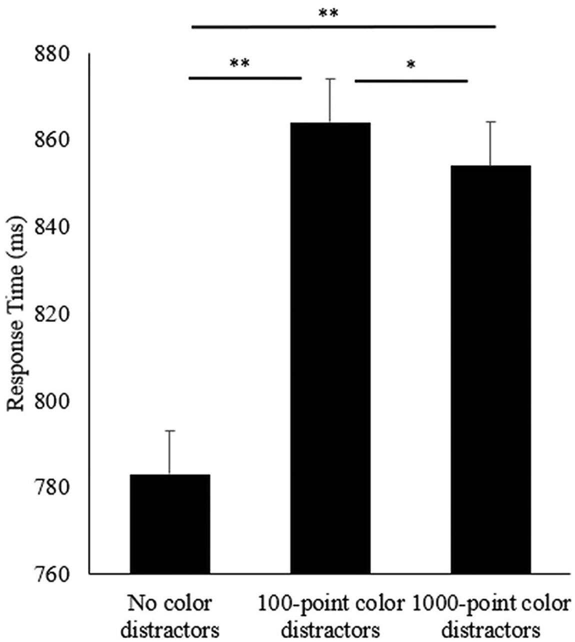

Figure 4. Response times of the test phase in Experiment 1. Error bars represent standard error of the mean (*p < 0.05; **p < 0.001).

$\eta_p^2 = 0.035$: 100-point color distractors condition (M = 92.9%, SE = 0.5%), 1000-point color distractors condition (M = 93.1%, SE = 0.4%), and no color distractors condition (M = 93.8%, SE = 0.4%).

For RT, there was a main effect of type of distractor, $F(2, 142) = 193.91$, $p < 0.001$, $\eta_p^2 = 0.73$ (see Figure 4). Planned comparisons revealed that mean RT was slower when the 100-point color distractors (M = 865 ms, SE = 10 ms) were presented than when no color singleton distractors (M = 783 ms, SE = 9 ms) were presented, $t(71) = 18.21$, $p < 0.001$. Mean RT was slower when the 1000-point color distractors (M = 855 ms, SE = 10 ms) were presented than when no color distractors were presented (M = 783 ms, SE = 10 ms), $t(71) = 15.61$, $p < 0.001$. These slower RTs reflect that the singleton color distractors slow processing of the target due to the distractors' physical saliency and associated rewards.

Most importantly, mean RT was slower when the 100-point color distractors were presented than when the 1000-point color distractors were presented, $t(71) = 2.27$, $p = 0.026$, $d = 0.27$ (see Figure 4). The findings imply that the 100-point color distractor attracted attention more than the 1000-point color distractor. This delay is further supported by Bayes analysis (Cauchy of 0.5): Bayes factor (BF_{+0}) = 3.54 (van Doorn et al., 2020) indicated that the prediction of more attention to the 100-point (compared to 1-point) color distractor than the 1000-point (compared to 901-point) color distractor was 3.54 times more favored than the null.

Discussion

Search was delayed more so when the 100-point color distractors were presented than when the 1000-point color distractors were presented, suggesting that the 100-point color distractors attracted attention more than the 1000-point color distractors. This finding is in line with the previous findings of Thaler (1980) and Tversky and Kahneman (1981). The proportional distance between 100 and its reference point 1 is larger than the proportional distance between 1000 and its reference point 901 (100:1 > 1000:901). Therefore, according to diminishing sensitivity, the difference between 1 and 100 should loom larger than the difference between 901 and 1000, although the absolute difference (100 – 1 = 1000 – 901) was the same. Accordingly, the results of Experiment 1 demonstrated that the diminishing sensitivity principle of prospect theory operates in selective attention.

In this experiment, the absolute difference hypothesis predicted comparable attraction effects between the 100-point and 1000-point color distractors. Therefore, it was possible that the finding that the 100-point color distractor attracted attention more than the 1000-point color distractor was due to both the proportional difference effect (the 100-point than the 1000-point color distractors attract more attention) and absolute difference effect (the 100-point and the 1000-point color distractors attract attention with similar strength). Experiment 2 resolves the question by varying the absolute differences while controlling the impact of the diminishing sensitivity (proportional difference).

Experiment 2

Experiment 2 investigated whether the absolute difference or the proportion influences attentional selection when the impact of diminishing sensitivity is controlled. In line with the findings of more sensitivity to the difference between $10 and $15 than $120 and $125 (Tversky & Kahneman, 1981) and more sensitivity to the difference between $20 and $25 than $495 and $500 (Thaler, 1980), Tversky and Kahneman (1981) and Thaler (1980) suggested that the effort to save $5 on a $50 purchase would be similar to the effort to save $15 on a $150 purchase due to the same proportion (50:5 = 150:15). In addition, Kahneman and Tversky (1982) suggested that the amount of money required for someone to forego a 50% chance of winning $100, $200, $500, $1000, and $2000 are roughly proportional to the size of the bet. For example, to forego a 50% chance of $100 someone would need roughly $35, and to forego a $1000 bet that person would need roughly $350. Thus, as the size of the stake has increased by a factor of 10, the amount needed to forego the bet increases by almost the same factor. The proportional nature of value seen in prospect theory is consistent with the Weber–Fechner law (Thaler, 1980, 1999). These findings regarding the same proportion (Kahneman & Tversky, 1982; Thaler, 1980; Tversky & Kahneman, 1981) were subsequently verified in various scenarios empirically and computationally in monetary and non-monetary domains (Azar, 2011; González-Vallejo, Harman, Mullet, & Sastre, 2012; for a review, see González-Vallejo, 2002).

In Experiment 2, in the training phase, the 100-point and 1000-point target colors have 1-point and 10-point reference target colors, respectively. The ratio between 1 and 100 is the same as the ratio between 10 and 1000 (100:1 = 1000:10), allowing control of the impact of diminishing sensitivity between the 100-point and the 1000-point color distractors. Thus, if the ratios but not the absolute differences matter, the strength of attention to the 100-point color distractors should be similar to the strength of attention to the 1000-point color distractors. However, the absolute difference is larger for the 1000-point distractor (990) versus the 100-point distractor (99). Thus, if absolute differences influence attentional selection, then the 1000-point color distractor should attract attention more than the 100-point color distractor, delaying search time when the 1000-point color distractors are present compared to when the 100-point color distractors are present.

Method

Participants

Based on the same power analysis for Experiment 1, 72 undergraduate students (mean age = 19.5 years; 61 females) with normal or corrected-to-normal vision participated for course credit.

Apparatus, stimuli, design, and procedure

The apparatus, stimuli, design, and procedure were identical to those for Experiment 1. The only difference was the reward point allocation during training. In the training phase, the 100-point and 1000-point test color targets had the 1-point and 10-point reference color targets, respectively. Like Experiment 1, the test target colors (red or green), the reference target colors (yellow or blue), and the block order were fully counterbalanced across the participants. Thus, both stimuli differences and proximity from the training to test phase were controlled between the test target colors.

Results

As in Experiment 1, incorrect trials (5.4% in the training phase, 8.5% in the test phase), trials in which RT was shorter than 150 ms (<0.01% in the training phase, <0.01% in the test phase), and trials in which RT was longer than 1500 ms (1.2% in the training phase, 5.0% in the test phase) were excluded from the analysis.

Training phase

To check if the contexts influenced task performance in the training phase, two-way within-subject ANOVAs were conducted on RT and accuracy with two within-subject variables: context (the 1-point and 100-point context and the 901-point and 1000-point context) and the within-block value, either low-value color (1-point color and 901-point color, reference target colors) or high-value color (100-point color and 1000-point color, test target colors).

For RT, the main effect of the context was not significant: 1-point and 100-point context ($M = 685$ ms, $SE = 9$ ms) and the 901-point and 1000-point context ($M = 678$ ms, $SE = 9$ ms), $F(1, 71) = 1.99$, $p = 0.16$, $\eta_p^2 = 0.027$. The main effect of the within-block value was also not significant: low ($M = 683$ ms, $SE = 8$ ms) and high ($M = 680$ ms, $SE = 9$ ms), $F(1, 71) = 1.20$, $p = 0.28$, $\eta_p^2 = 0.017$. The interaction between the context and the within-block value was also not significant, $F(1, 71) = 0.31$, $p = 0.58$, $\eta_p^2 < 0.01$. For accuracy, the main effect of the context was not significant: 1-point and 100-point context ($M = 94.3\%$, $SE = 0.5\%$) and the 901-point and 1000-point context ($M = 94.4\%$, $SE = 0.5\%$), $F(1, 71) = 0.2$, $p = 0.65$, $\eta_p^2 < 0.01$. However, the main effect of the within-block value was significant: low ($M = 94.1\%$, $SE = 0.5\%$) and high ($M = 94.5\%$, $SE = 0.5\%$), $F(1, 71) = 5.01$, $p = 0.028$, $\eta_p^2 = 0.066$. This higher performance in the high (test target colors) than in the low (reference target colors) color would be due to visually different colors used and/or the high colors being more valuable than the low color. The interaction between the context and the within-block value was not significant, $F(1, 71) = 0.4$, $p = 0.53$, $\eta_p^2 < 0.01$.

To check whether an individual's facilitation difference between the contexts influenced an individual's value-driven attention effect in the test phase, correlation analyses were conducted between a facilitation difference and a value-driven attention effect. No significant correlations were found: $r(70) = 0.049$, $p = 0.68$ for RT, $r(70) = -0.026$, $p = 0.83$ for accuracy; $r(70) = 0.051$, $p = 0.67$ for inverse efficiency. These results suggest that a facilitation difference did not influence the value-driven attention effect.

To examine whether value-driven attention operates based on proportional difference or absolute difference, the 100-point target color and the 1000-point target color were compared on RT and accuracy. Mean accuracy was not different between when the target color was the 100-point color (compared with 1-point, $M = 93.1\%$, $SE = 0.4\%$) or the 1000-point color (compared with 10-point, $M = 93.8\%$, $SE = 0.4\%$),

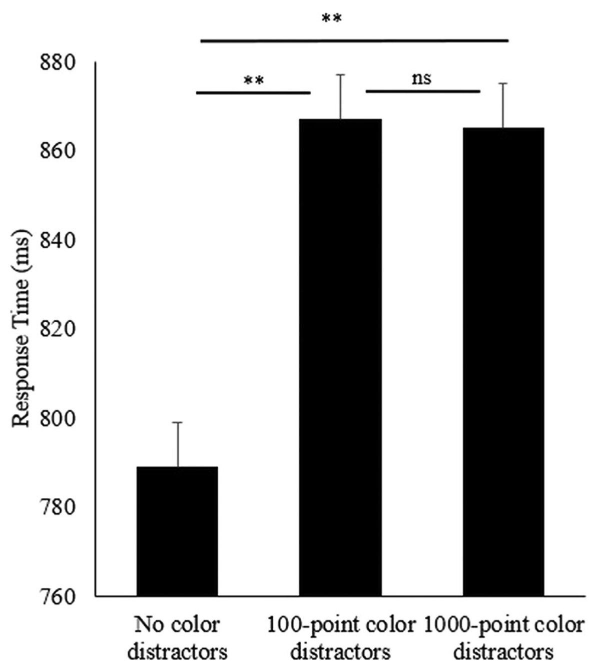

Figure 5. Response times of the test phase in Experiment 2. Error bars represent standard error of the mean. (**$p < 0.001$; ns, $p > 0.05$).

$t(71) = 0.76$, $p = 0.45$, $d = 0.09$. Mean RT was not different between when the target color was a 100-point color ($M = 684$ ms, $SE = 9$ ms) or a 1000-point color ($M = 676$ ms, $SE = 9$ ms), $t(71) = 1.42$, $p = 0.17$, $d = 0.17$.

Test phase

As in Experiment 1, one-way within-subject ANOVAs on mean RT and mean accuracy were conducted to explore how the three distractors (100-point color distractors, 1000-point color distractors, no color distractors) influenced search.

For accuracy, the type of distractor affected search accuracy, $F\ (2,142) = 7.0$, $p = 0.001$, $\eta_p^2 = 0.09$. Post hoc comparisons revealed that accuracy was lower when the 100-point distractors appeared ($M = 91.1\%$, $SE = 0.6\%$) than when no distractors appeared ($M = 92.7\%$, $SE = 0.5\%$), $t(71) = 4.16$, $p < 0.001$. Accuracy was lower when the 1000-point distractors appeared ($M = 91.7\%$, $SE = 0.6\%$) than when no distractors appeared ($M = 92.7\%$, $SE = 0.5\%$), $t(71) = 2.42$, $p = 0.018$. Mean accuracy was not different between when the 100-point distractors appeared ($M = 91.1\%$, $SE = 0.6\%$) and when the 1000-point distractors appeared ($M = 91.7\%$, $SE = 0.6\%$), $t(71) = 1.11$, $p = 0.27$, $d = 0.13$.

For RT (see Figure 5), the type of distractor influenced RT of search, $F(2, 142) = 192.2$, $p < 0.001$, $\eta_p^2 = 0.73$. Planned comparisons revealed that mean RT was slower when the 100-point color distractors were presented ($M = 867$ ms, $SE = 10$ ms) than when no color distractors were presented ($M = 789$ ms, $SE = 9$ ms), $t(71) = 18.44$, $p < 0.001$. Mean RT was slower when the 1000-point color distractors were presented ($M = 865$ ms, $SE = 10$ ms) than when no color distractors were presented ($M = 789$ ms, $SE = 9$ ms), $t(71) = 16.04$, $p < 0.001$. Importantly, mean RT was not different between when the 100-point color distractors were presented ($M = 867$ ms, $SE = 10$ ms) and when the 1000-point color distractors were presented ($M = 865$ ms, $SE = 10$ ms), $t(71) = 0.61$, $p = 0.54$, $d = 0.07$ (see Figure 5), suggesting that the strength of the attention to the two color distractors was similar. In addition, the Bayes factor (BF_{0-}) = 8.24 (van Doorn et al., 2020) indicates that the prediction of more attention to the 1000-point color distractor than the 100-point color distractor was 8.24 times less favored than the null.

Discussion

In this experiment, the impact of the diminishing sensitivity was controlled because the ratio between 1 and 100 and the ratio between 10 and 1000 were the same (Kahneman & Tversky, 1982; Thaler, 1980; Tversky & Kahneman, 1981). For the 1000-point distractor, the absolute difference from the training reference was higher than for the 100-point distractor. However, search speed was not delayed when the 1000-point color distractors were presented compared with when the 100-point color distractors were presented. This finding suggests that the attentional capture effect of the distractors was little influenced by absolute value differences, inconsistent with economic theory.

General discussion

The current study examined whether value-driven attention reflects proportional differences or absolute differences by applying the foundational findings for diminishing sensitivity from Thaler (1980) and Tversky and Kahneman (1981) in the modified value-driven attention paradigm (Kim & Beck, 2020b). Experiment 1 showed that when the 100-point color and the 1000-point color were compared to the 1-point color and the 901-point color, respectively, in the training phase, the 100-point color distractors attracted attention more than the 1000-point color distractors in the test phase. The results of Experiment 1 are consistent with previous findings (Thaler, 1980; Tversky & Kahneman, 1981) indicating that the difference between \$20 and \$25 is psychologically larger than the difference between \$495 and \$500 although the absolute difference is the same (Thaler, 1980). Therefore, the former comparison (between 20 and 25) influenced decision-making more than the latter comparison (between 495 and 500). In line with this, in Experiment 1, although the absolute difference between 1 and 100 was the same as the absolute difference between 901 and 1000, the psychological difference was larger between 1 and 100 than 901 and 1000. The former comparison (between 1 and 100) influenced selective attention more than the latter comparison (between 901 and 1000); accordingly, the 100-point color distractors attracted attention more than the 1000-point color distractors, demonstrating the diminishing sensitivity principle in selective attention.

In Experiment 2, the 100-point color and 1000-point color were compared to the 1-point color and 10-point color, respectively, in the training phase. Therefore, the diminishing sensitivity impacts were controlled; for example, the psychological value difference between 5 and 50 is similar to that between 15 and 150 due to the same proportion (Thaler, 1980, 1999). Also, the absolute value and the absolute value difference were highest for the 1000-point color distractor. However, the 1000-point color distractor did not attract attention more so than the 100-point color distractor in the test phase. This, combined with the results from Experiment 1, further supports the conclusion that absolute value and the absolute difference are not used to prioritize stimuli for selective attention. Additionally, Experiment 2 reduces the possibility that the 100-point color distractor attracting attention more than the 1000-point color distractor in Experiment 1 is due to using the specific high relative value of 100 and specific low relative value of 1000 rather than diminishing sensitivity. If so, the 100-point color distractor should have attracted attention more than the 1000-point color distractor in Experiment 2.

Implications for prospect theory

Previous studies (Kim & Beck, 2020b; Vincent, 2011) have shown that prospect theory extends to selective attention. Kim and Beck (2020b) demonstrated that reference dependence operates in selective attention. The authors found that the value affecting the allocation of attention relied on a reference point of the value, suggesting that relative value, not absolute value, is critical in selective attention. Vincent (2011) demonstrated that the weighting function is applied in selective attention. According to the weighting function (Kahneman & Tversky, 1979), decision-makers overweight low expectation levels and underweight high expectation levels. Vincent (2011) found that, during visual search, participants overweighted the probability of a search target appearing at a particular location when the probability was low but underweighted the probability when it was high. The patterns of the bias fit with the weighting function of prospect theory. In line with the previous studies, the current study further shows the extendibility of prospect theory to selective attention.

The current study demonstrated that the foundational findings for the diminishing sensitivity principle from Kahneman and Tversky (1979) and Thaler (1980) are also found with the modified value-driven attention paradigm (Kim & Beck, 2020b), suggesting that the diminishing sensitivity principle operates in selective attention. Also, the value of the reference target color played a critical role in determining the value of the test color, suggesting that the reference dependence principle operates in selective attention (Kim & Beck, 2020b). These findings suggest that prospect theory extends to selective attention.

Implications for value-driven attention literature

The previous studies using the classic value-driven attention paradigm showed that a more valuable item attracts more attention (for reviews, see Anderson, 2016; Failing & Theeuwes, 2018; Rusz, Le Pelley, Kompier, Mait, & Bijleveld, 2020). These findings are in line with the reference dependence and diminishing sensitivity principles. In the classic paradigm (e.g., Anderson et al., 2011), associative learning between stimuli and reward for both a more valuable stimulus and a less valuable stimulus occurs in the same context (e.g., a training phase); accordingly, the two stimuli become reference points for one another. For example, when the more and less valuable stimuli are associated with 15 and 10 points, respectively, the objective values of the two will be subjectively represented as shown in Figure 1. Therefore, the findings in the previous literature indicating that the more valuable stimulus (15) attracts attention more than the less valuable stimulus (10) do not violate the reference dependence and diminishing sensitivity principles.

The previous findings with the classic paradigm, however, could not demonstrate the principles of prospect theory. In the classic paradigm, the more valuable stimulus (15) is both absolutely and relatively high-valued compared to the less valuable one (10) because they are reference points for one another. Therefore, it is unclear if relative value (reference dependent), not absolute value, is critical to capturing attention (Anderson, 2016). Also, it is unclear if the psychological sensitivity is constant (linear), increases (convex), or decreases (concave) as objective value increases. Therefore, although the previous findings in the classic paradigm are in line with the principles of prospect theory, it was unknown whether the psychological value is distorted according to the principles of prospect theory.

In the value-driven attention literature, the lack of exploration as to whether the value of items is distorted by the psychological principles in prospect theory may be because prospect theory was researched largely in the economic literature (e.g., behavioral economics) (Barberis, 2013); Kahneman and Thaler received Nobel Prizes in economics. Moreover, most studies in the value-driven attention literature used the classic value-driven attention paradigm, which does not allow the independent manipulation of relative and absolute value (Anderson, 2016). However, reference dependence plays a critical role (e.g., each item having separate reference points) in testing the diminishing sensitivity principle, such as in Kahneman and Tversky (1982), Tversky and Kahneman (1981), Thaler (1980), and the current study. The present study used the modified value-driven attention paradigm (Kim & Beck, 2020b) because a reference point of each stimulus (color) can be manipulated independently, as in Kahneman and Tversky (1982), Tversky and Kahneman (1981), and Thaler (1980). Thus, the use of the modified paradigm allowed verification that value-driven attention occurs on the basis of reference dependence and diminishing sensitivity.

Influences of top–down task goals (Bacon & Egeth, 1994) and bottom–up physical saliency (Theeuwes, 1992) on attentional allocation were controlled between two test target colors to measure value-driven attention effects in the present study, as was done in previous value-driven attention research (Anderson et al., 2011). In the training, the test target colors (red and green), reference target colors (yellow and blue), and block order (ABABAB and BABABA) were fully counterbalanced across participants. Therefore, top–down task goals and bottom–up physical saliency could not account for the value-driven attention effect in the present study, allowing for the test of diminishing sensitivity on value-driven attention.

An important methodological component of the current design is the ability to establish different reference points within blocks during training. This method is consistent with previous diminishing sensitivity research (Azar, 2011; Kahneman & Tversky, 1982; Thaler, 1980; Tversky & Kahneman, 1981), value-driven attention research (Anderson, 2015), and neuroimaging research on relative value (Elliott et al., 2008; Tremblay & Schultz, 1999). In the current study, participants were explicitly informed of two target colors in each context in the training. For example, participants would know that target colors were red and yellow in context 1 and green and blue in context 2. Therefore, the reference point for red became yellow, which was an available color in context 1, rather than green and blue which were available colors only in context 2. The 100-point stimulus had a reference point of a 1-point stimulus because these stimuli (but not the 901-point nor 1000-point stimuli) were available targets in the 1-point and 100-point block. A reference point was established within a block rather than between blocks because a reference point is made among concurrently available alternatives (Kahneman & Tversky, 1979; Tremblay & Schultz, 1999). The flexibility of changing a reference point (Kahneman & Tversky, 1979) is consistent with the findings of a prior behavioral study (Anderson, 2015) and imaging studies (Elliott et al., 2008; Tremblay & Schultz, 1999). For example, value-driven attention relies on the context in which the stimuli–reward associative learning occurs, indicating context dependence of value-driven attention (Anderson, 2015). Brain imaging studies have shown that reference points can be set within a single trial based on available alternatives, indicating that reference points can be adjusted rapidly and flexibly (Elliott et al., 2008; Tremblay & Schultz, 1999). Furthermore, data in the current study also supports little influence of between-block reference points. If reference points were set between blocks, 1000-point color distractors should have attracted more attention than the 100-point color distractors in Experiments 1 and 2. Therefore, consistent with Kim and Beck (2020b) the current study offers support for the ability to establish two separate value-driven contexts within a training session.

The present study extends on the research of Kim and Beck (2020b) by showing the importance of relative difference rather than absolute difference in value-driven attention. In Experiment 2 in Kim and Beck (2020b), the relative value of two test colors was higher, as in Experiment 1 in the current study. However, in the previous experiment, the relative difference (7.6 vs. 1.9) and absolute difference (39.2 vs. 45) of the two higher values were both not systematically controlled. In Experiment 1 of the current study, the absolute difference (99 vs. 99) was the same, whereas the relative difference varied (100 vs. 1.1). However, given the current finding that relative difference rather than absolute difference is critical, in Kim and Beck (2020b) the 7.6 relative difference color might attract attention to some degree more than the 1.9 relative difference color regardless of absolute difference. Although value-driven attention effects of the two colors were not statistically different, the direction of the slight numerical difference was consistent with the proportional difference hypothesis. The lack of evidence might be because the magnitude of the difference of relative differences (7.6 vs. 1.9) was insufficient to produce different value-driven attention effects. However, the effect was evident in the current study when the magnitude of the difference of two relative differences (100 vs. 1.1) was much larger.

The current study used a non-probabilistic schedule (e.g., always 100 points for red targets) unlike Kim and Beck (2020b), where a probabilistic schedule was used, such as 110 points (50%) or 90 points (50%) for red targets. A non-probabilistic schedule was used here because the expected value (absolute value) was 100 points regardless of task performance in the non-probabilistic schedule, whereas it might be slightly higher or lower than 100 points depending on task performance in the probabilistic schedule.

Therefore, the non-probabilistic schedule was applied to strengthen the manipulation.

Limitations

Reaction time from manual responses is commonly used to measure the attentional capture of singleton distractors (Anderson, 2016; Anderson et al., 2011). However, it is possible that the reaction time reflects costs other than attention capture (cf. Folk, 2013; Folk & Remington, 1998). A more sensitive measure could be used to further validate the current findings. For example, further research using eye-tracking (Le Pelley, Pearson, Griffiths, & Beesley, 2015) and electrophysiological approaches (Hickey, McDonald, & Theeuwes, 2006; see also McDonald, Green, Jannati, & Di Lollo, 2013) would help specify the nature of the diminishing sensitivity of the value-driven attention effect.

Using eye movements to measure the impact of diminishing sensitivity on value-driven attention will be important to further validate the current findings. In the current study, we measured the effect using RT, and the effect in Experiment 1 was small ($d = 0.27$). It was too small to find an interaction across Experiments 1 and 2, $F(1, 142) = 1.32$, $p = 0.25$, $\eta_p^2 = 0.01$, without increasing the sample size substantially (G*Power estimates that a sample size of 782 is needed). Given that the effect is small when measuring RT, measuring eye movements may be more suitable for a sensitive measure of the effect (Anderson & Kim, 2019). Eye movements are a more direct measure of attention than RT which is affected by factors other than attention (e.g., Goldstein & Beck, 2018; Zelinsky & Sheinberg, 1995). For example, the time to first fixate the distractor with the higher relative value should be shorter and/or the frequency of fixating the distractor should be higher.

The findings of the present study provide behavioral evidence supporting the diminishing sensitivity principle (proportional differences) rather than linear function (absolute differences). However, exact metrics of the diminishing sensitivity value function cannot be described with only the behavioral evidence from the two relative values tested here. Therefore, further behavioral evidence and computational research should be conducted to identify exact metrics of the diminishing sensitivity.

Future directions

Prospect theory has contributed considerably to understanding the *actual* decision-making processes in various fields of society, such as marketing, economics, and politics: mental accounting (Thaler, 1999) and nudge effects (Thaler & Sunstein, 2009). Accordingly, the investigation of whether prospect theory extends to different cognitive stages could be similarly impactful. In line with this, the outstanding question is how the loss aversion principle is applied in selective attention. Although there are value-driven attention studies (Barbaro, Peelen, & Hickey, 2017; Wentura, Müller, & Rothermund, 2014) where reward-associated stimuli and loss-associated stimuli are presented, they have failed to find evidence that loss-associated stimuli attract attention more than reward-associated stimuli. This may be because loss and reward are based on different cognitive systems due to their being linked to negative and positive emotional states, respectively (Breiter, Aharon, Kahneman, Dale, & Shizgal, 2001). Thus, an attentional priority of loss- over reward-associated stimuli may not be general; instead, it may require certain task situations. Accordingly, whether the loss aversion principle is applied in selective attention may have to be further investigated in other attention task paradigms.

Another outstanding question is how the mechanism of selective attention reflecting the principles of prospect theory is implemented in the brain. One potential way involves the dopamine system in the midbrain. The dopaminergic processes modulate the attentional allocation to reward-associated stimuli (Anderson, 2017, 2019; Anderson et al., 2016, 2017; Hickey et al., 2010) and reflect subjective value in decision-making (Lak, Stauffer, & Schultz, 2014; Trepel, Fox, & Poldrack, 2005). That is, the dopaminergic system is closely associated with value-driven attention and value-based decision making and could provide further insight.

Conclusion

The current study showed reference dependence and diminishing sensitivity in selective attention. This aligns with the idea that the basic principles of perception are the foundation of prospect theory (Kahneman & Tversky, 1979; Thaler, 1980, 1999). Furthermore, the present study contributes to the understanding of the mechanism of value-driven attention, showing that the psychological value reflecting reference dependence and diminishing sensitivity, not objective value, plays a role in attentional allocation.

Keywords: prospect theory, diminishing sensitivity, reference dependence, value-driven attention, selective attention

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