Bottom-Up and Top-Down Attention in Value-Based Choice

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Abstract:

Value-based choices can be affected both by bottom-up attention (perceptual properties of the stimuli) and top-down attention (goals of the decision maker, such as values of the choice options). Established cognitive computational models of attention suggest that visual attention can drive choices toward salient stimuli if their salience is congruent with the task goals (i.e., choosing options with higher value). Using a simple two-alternative forced-choice paradigm and eye tracking, we decompose the effects of bottom-up and top-down attention by manipulating both the physical properties of the stimuli (adjusting contrast and orientation) and their value to the decision maker (by adjusting rewards assigned to the stimuli). We find that while task-congruent salience can increase accuracy and decrease response time, this effect does not impact choices when salience is task-irrelevant.

Keywords: attention; value-based choice; eye-tracking

Introduction

Attention is one of the important drivers of choice. Previous computational research showed that attention to choice options or their features can affect value-based decisions in many domains, from food choice to reinforcement learning (Konovalov & Krajbich, 2016; Krajbich, 2019; Smith & Krajbich, 2019). Salient items tend to attract visual attention (Wolfe & Horowitz, 2017), and attention to salient stimuli can affect value integration (Kunar et al., 2017; Towal et al., 2013; Tsetsos et al., 2012).

However, it is still unclear how exactly bottom-up attention - typically driven by the salience of the choice options - interacts with top-down attention, driven by the decision-maker's goals (such as rewards or intrinsic values). While many previous studies in the value-based domain used naturalistic stimuli or subjective values, the goal of this study is to use objective rewards and carefully controlled visual salience to disentangle the effects of bottom-up and top-down attentional drivers.

Specifically, individuals in the study chose between two stimuli with two potentially relevant features, one of which (contrast) could drive bottom-up effects, while the other one (orientation) served as a control. The study was preregistered (https://osf.io/emv6s). Based on previous computational work manipulating visual salience and research introducing attentional drift-diffusion models, we predicted that stimuli with higher visual salience should attract more visual attention (measured using gaze duration and saccades). This should lead to higher accuracy and shorter response times (RT) when the goal of the perceptual task is congruent with the assigned values. This effect could also drive choice biases in the task where choices are based on an irrelevant feature (orientation). In this abstract, we will focus on the behavioral results as the analysis of the eye-tracking data is still a work in progress.

Methods

72 subjects completed the task. On each trial of the task, subjects chose between two Gabor patches presented in white on a black background and placed in the middle of the left and right parts of a computer screen (Figure 1).

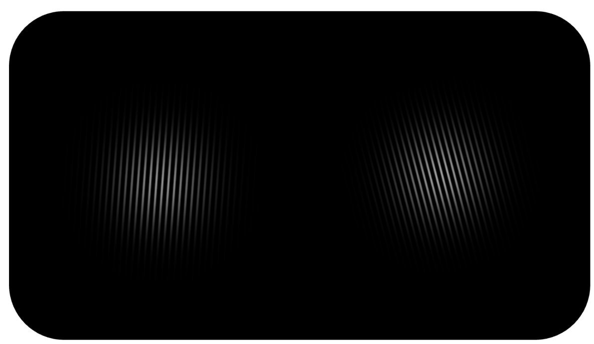

Figure 1: Two-alternative forced-choice task.

The patches had four possible orientations slightly tilted from left to right and four possible contrasts, with equal objective distance between each of the four values. All possible pairs of patches with these 4x4 properties formed 256 trials of a single block.

Each subject completed four blocks of trials. Each block had one of the following tasks: (1) "Choose the brighter patch"; (2) "Choose the darker patch"; (3) "Choose the patch more tilted to the left"; (4) "Choose the patch more tilted to the right." We will label conditions 1 and 2 as the contrast task and conditions 3 and 4 as the orientation task. The block order was randomized.

Subjects were assigned to one of the two between-subject reward conditions. In the “Binary reward” condition, they received 1 point for a correct answer and 0 for an incorrect one. In the “Scaled reward” condition, they received 1-4 points based on the level of the relevant feature. At the end of the experiment, the sum of all points from all trials was converted to British pounds, with an equal expected payoff between the two conditions.

We presented the stimuli using MATLAB and Psychtoolbox and recorded subjects’ eye movements at 1000 Hz using an Eyelink 1000 eye tracker.

Results

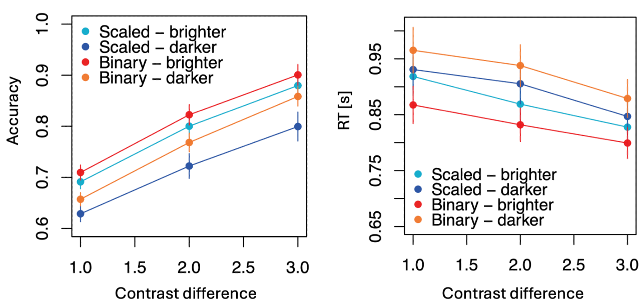

Figure 2: Accuracy and response times (RT) in the contrast task, split by the task (choose brighter or darker) and reward condition (binary and scaled).

In the contrast task, as typical for perceptual discrimination tasks, we found that easier choices (with higher absolute differences in contrast) were faster ($p < 0.001$) and more accurate ($p < 0.001$) (Figure 2).

As preregistered, we found that subjects were more accurate ($p < 0.001$) and faster ($p < 0.001$) when they had to detect the brighter patch. As Figure 2 shows, there was a small overall difference (3 p.p.) in accuracy between the binary and scaled reward conditions, but it was not statistically significant ($p = 0.35$).

We also did not find a significant effect of the reward condition on RT ($p = 0.75$). However, there was a significant interaction between the reward condition and task condition ($p = 0.002$), with a strong difference in RT between “choose brighter” and “choose darker” conditions in the binary reward condition and no difference in the scaled reward condition.

In the orientation task, we also found choice difficulty effects in both RT and accuracy ($p < 0.001$). However, as predicted, the direction of the task (left or right) did not influence accuracy ($p = 0.8$), with a small effect on RT ($p = 0.03$). Importantly, we did not find an effect of the visual salience of a stimulus on its choice probability ($p > 0.49$), suggesting that the salience effect did not impact choices when salience was task-irrelevant, and the attentional system can potentially override irrelevant, but salient features.

Conclusion

Our results demonstrate that bottom-up and top-down attentional systems can potentially have an interactive effect on value-based choice. We are planning to develop these findings further by including the analysis of eye-tracking data and applying computational modeling that can simultaneously capture choices, RT, and gaze durations.

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