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Pair-wise Comparison Difficulty Mediates the Attraction Effect

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Abstract

Introducing a third option (decoy), similar but inferior to one of the available options in a binary choice set, increases the choice share of the dominating option (target). This widely studied context effect is called the attraction effect. Studies demonstrating the attraction effect, even with perceptual stimuli, indicate the effect's ubiquity challenging cardinal models of value representation. Despite successful replications, recent studies using perceptual tasks have reported reversed attraction effects in typical attraction effect setups, questioning its domain generality. We attempt to reconcile this discordance by examining an unexamined confound in such experiments: asymmetry in pair-wise comparison difficulty. We suggest that studies reporting reversed effects with perceptual stimuli utilized stimuli that do not create an asymmetry of difficulty in comparisons across stimulus pairs. We designed a novel perceptual task using similar stimuli, such that attribute comparisons become hard, and reported a strong positive attraction effect instead. Extending a pair-wise ordinal comparison argument previously proposed in the literature, we further suggest that the lack of asymmetry in pair-wise comparison difficulty between target-decoy and competitor-decoy pairs reduces the attraction effect by breaching the asymmetric dominance of the decoy. Through a series of four experiments, we adduce evidence for this claim.

Keywords: Preference reversals, attraction effect, asymmetric dominance

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General Introduction

A widely studied cognitive bias in decision-making is the ’attraction effect’ (AE) or ’asymmetric dominance effect’, where the presence of a third option (the ’decoy’: D) influences decision-makers to prefer one of the original options (the ’target’:T) over the other (the ’competitor’:C). The phenomenon is practical and important as a behavioral nudge to influence consumers’ choices. It is theoretically important since it demonstrates a violation of an assumption in rational choice theory: regularity. The AE has been observed in a wide range of domains across species in the last four decades (Bateson et al., 2003; Choplin & Hummel, 2005; Farmer et al., 2017; Huber et al., 1982; Latty & Beekman, 2011; Lea & Ryan, 2015; Noguchi & Stewart, 2014; Parrish et al., 2015; Scarpi, 2011; Shafir et al., 2002; Trueblood, 2012; Zhen & Yu, 2016). Studies by Choplin and Hummel (2005) and Trueblood et al. (2013), which demonstrated AEs even in the perceptual domain, became essential milestones in establishing the ubiquity of the effect and challenging the possibility of cardinal representations of value in the brain.

Despite the robustness of the effect, many studies in the past decade have reported inconsistent results, including muted or reversed effects (Frederick et al., 2014; Yang & Lynn, 2014). More recently, Spektor et al. (2018) and Spektor et al. (2022) showed reversed effects with perceptual stimuli not arranged linearly. This failure of the phenomenon in the perceptual domain has led researchers to question its domain generality. In this paper, we offer a possible explanation for this diversity of results seen in experiments testing AEs with perceptual stimuli in the recent literature.

We hypothesized that studies reporting a negative AE posed a greater difficulty in dominance perception due to the relatively greater difficulty of target-decoy (TD) comparison in triangular arrangement than in horizontal one. In experiments 1 and 2, we used the stimuli (rectangles) that produced opposite effects when presented in two different arrangements (horizontal in (Trueblood et al., 2013) and triangular in (Spektor et al., 2018)).

Experiment 1 tested whether an oblique alignment makes TD comparison more difficult than a horizontal alignment. As a follow-up, in experiment 2, we ran a replication of the study with the triangular arrangement and tested if findings from experiment 1 drove the expected negative effect in experiment 2. We concluded that perceived dominance alone would not guarantee a positive AE; rather, an asymmetry of dominance would do it. Next, through experiments 3 and 4, we showed that the difficulty of TD comparison, relative to CD comparison, can be lowered endogenously via stimuli design.

Experiment 1

Introduction

Recent studies (Evans et al., 2021; Hasan et al., 2023) have highlighted the importance of the stimulus configuration in controlling the strength and direction of the AE. A horizontal arrangement of three rectangle stimuli produced a positive AE (Trueblood et al., 2013), but switching to a triangular layout reversed it (Spektor et al., 2018). Since the target's dominance over the decoy drives the AE (Huber et al., 1982), and TD pairs are more often oblique in a triangular layout (see Figure 1), we suspected oblique alignment as the cause. We hypothesized that pair-wise comparison is harder in oblique than in horizontal alignment. This is probably due to the ease of paying attention when stimuli are aligned horizontally compared to other directions (Tsal, 1989).

To test this, participants compared rectangles aligned obliquely and linearly and rated difficulty. As target-competitor (CT) pairs reflect indifference rather than dominance, we excluded them. While our primary focus was TD pairs, we included competitor-decoy (CD) pairs to compare decoy dominance in TD and CD pairs.

Method

Participants

Forty-two university students with normal or corrected-to-normal vision, aged 18–25 years, participated in the experiment.

Apparatus and Stimuli

The experiment was designed using JavaScript and conducted on laboratory computers with screen resolutions of 1920 px $\times$ 1080 px. Participants were presented with target-decoy pairs and competitor-decoy pairs, aligned either linearly or obliquely, with the order randomized. The vertical positions of the stimuli were jittered across trials. The stimuli pair for each trial was derived from a set of triplets.

Following Spektor et al. (2018), one set of rectangles was created using a bivariate normal distribution with a mean height of 170 pixels and a mean width of 250 pixels. The variance for each attribute was 25 pixels, and there was no correlation between the variances, allowing for variability in the task. A second set of rectangles had the same values and matched in area but were vertically oriented instead of horizontally. One of these sets was considered the target, while the other was the competitor.

The third set (i.e., decoy rectangles) was created such that, in the attribute space, it was placed close to one alternative for half the trials and close to the other alternative for the remaining half. We included all three types of decoys: range, frequency, and range-frequency decoys (Huber et al., 1982). In each trial, either a target-decoy pair or a competitor-decoy pair was displayed (Refer to Figure 2 for examples). Participants completed 24 trials in total.

Procedure

Participants were instructed to select the rectangle that appeared larger in area in each trial. After making their choice, they completed a rating task in which they rated the difficulty of their last decision on a 7-point Likert scale, where one represented "extremely easy" and seven represented "extremely difficult."

Results and Discussion

A paired samples t-test to compare perceived difficulty ratings for obliquely aligned and horizontally aligned TD pairs of stimuli showed a significant difference in ratings, $t(41) = 5.150$, $p < .001$, Cohen's $d = 0.795$. A similar trend was observed with CD pairs as well. Oblique CD pairs were perceived as more difficult to compare than horizontally aligned CD pairs. $t(41) = 2.308$, $p = 0.026$, Cohen's $d = 0.356$. Collapsing the data across both TD and CD pairs, the difference in difficulty scores between the oblique and horizontally aligned stimuli was also significant. The oblique pairs were perceived as more difficult; $t(41) = 5.285$, $p < .001$, Cohen's $d = 0.577$.

Experiment 2

Introduction

From Experiment 1, we observed that TD pairs were perceived to be more difficult to compare when in an oblique position compared to a horizontal position. With an equal representation of all six possible configurations of stimuli in a triangular arrangement, each subject encounters two-thirds of the trials with a TD pair in the oblique position and one-third with the TD pair in the horizontal position (see Figure 1). If the difference in perceived difficulty between the comparisons of the oblique and horizontal TD pairs translates into a difference in the perceived dominance of the decoy by the target, this could explain the overall negative AE (RST < 0.5) reported in previous studies. Based on this reasoning, we hypothesized that the weighted sum of two times the mean RST for TD_Oblique and the mean RST for TD_Horizontal should be less than 1.5 (derivation included in the Appendix). Formally,

$$H_0 : 2 \cdot \mu_{\text{TD\_Oblique}} + \mu_{\text{TD\_Horizontal}} \geq 1.5$$

$$H_1 : 2 \cdot \mu_{\text{TD\_Oblique}} + \mu_{\text{TD\_Horizontal}} < 1.5$$

Method

Participants

Thirty-eight volunteers with normal or corrected-to-normal vision, aged 18–25 years, participated in the experiment.

Apparatus and Stimuli

This experiment was designed using Opensesame 4.0.1 (Mathôt et al., 2012) and conducted on similar laboratory computers. The stimuli were similar to those in Experiment 1. We fixed the mean height and mean width as 50 pixels and 80 pixels, similar to those used in both Trueblood et al. (2013) and Spektor et al. (2018) to produce opposite effects. The shift from larger stimuli in Experiment 1 ($170\,\text{px} \times 250\,\text{px}$) to smaller stimuli in Experiment 2 ($50\,\text{px} \times 80\,\text{px}$) is unlikely to affect the results because triangular arrangements, which we replicate here, have shown negative AEs for both smaller and larger stimuli (Spektor et al., 2018). In Experiment 1, we explored one potential reason for negative effects in triangular arrangements by focusing on linear and oblique subsets of this configuration. The decoy creation method, including range, frequency, and range-frequency decoys, remained consistent with Experiment 1.

Procedure

In each trial, participants were instructed to select one of the three rectangles with the largest area, presented in a triangular formation.

Results and Discussion

We conducted a one-sample t-test on the weighted sum of the mean RST for TD_Oblique and TD_Horizontal to compare it against the constant, 1.5. There was no significant difference between this weighted sum and the hypothesized value of 1.5, $t(71) = 0.996, p = 0.837,$ Cohen's $d = 0.166$. We then performed a two-tailed one-sample t-test on overall RST. To our surprise, we were unable to replicate the negative AE reported in previous studies. We found that overall RST $(M = 0.511, SD = 0.063)$ tended to be more than 0.5, though not significantly different from the null value $(M = 0.5); t(35) = 1.078, p = 0.288.$ Cohen's $d = 0.180.$ The reason for this discrepancy between our results and previous studies could be attributed to a major difference our experiment had from theirs: the controlled order of stimuli ensuring equal representation of 6 possible configurations. It should be noted that neither Spektor et al. (2018) in their triangular arrangement of stimuli nor Trueblood et al. (2013) in their linear arrangement of stimuli had controlled for presentation configuration.

Next, when all trials were divided into three equal subsets, with three possible base pairs (base of the triangle with C, T, and D as vertices): CD, CT, and DT, we observed that RST_{CD} ($M = 0.445$, $SD = 0.144$) was significantly less than 0.5, $t(35) = -2.295$, $p = 0.028$, Cohen's $d = -0.383$. RST_{TD} ($M = 0.564$, $SD = 0.165$) was significantly greater than 0.5, $t(35) = 2.351$, $p = 0.024$, Cohen's $d = 0.392$. RST_{CT} ($M = 0.522$, $SD = 0.088$) was not significantly different from 0.5, $t(35) = 1.504$, $p = 0.142$, Cohen's $d = 0.251$.

We ran two linear mixed-effect models—one with only *BasePair* and another with only *TD_Position* as the predicting variables—and compared them based on AIC and BIC scores (details in the Appendix). The results indicated that *BasePair* plays a more crucial role in explaining average RST results than *TD_Position*. In other words, more than *where the TD pair was*, what mattered most was *what the horizontal pair was*. In line with the additional results from Experiment 1, where oblique pairs (including both CD and TD pairs) were generally perceived as more difficult to compare than horizontal pairs, the results from Experiment 2 support the idea that the pair presented horizontally at the base of the triangle determines the choice in the trial, effectively acting as the *salient pair* in that trial.

This means when the competitor-decoy pair was made salient, the competitor — objectively greater in area than the decoy — was chosen more often, suggesting that participants compared the two along a common currency: area. The results, otherwise, suggest that the decoy's dominance by the target may be the necessary condition for the AE, but an asymmetric dominance of the decoy is required for sufficiency, and the lack of this asymmetry leads to a null effect.

Experiment 3

Introduction

Taking into account our results from experiment 2 and other studies involving perceptual stimuli that did not show standard AEs (Spektor et al., 2018, 2022), we suggest that the decoys in these studies were not asymmetrically dominated. Following the pairwise ordinal comparison argument dominant in the literature (discussed in the next subsection Pair-wise comparison), we claim that the low CD comparison difficulty mutes the AE by breaching the asymmetric dominance of the decoy.

Over the years, the asymmetry in the context of the AE gradually became implicitly linked to an attribute-based definition. For example, Bhatia (2013) discusses that the decoy is dominated by the target in both attributes, whereas it is 'better' than the competitor in one attribute. However, the original article on AE subscribed to an item-based definition of asymmetric dominance. The first line from Huber et al. (1982) reads, "An asymmetrically dominated alternative is dominated by one item in the set but not by another." Throughout the paper, we follow this item-based definition of asymmetric dominance. Figure 3 shows the placements of the items in the attribute space for the AE.

Pair-wise comparison

Decades of research on sequential sampling models for multi-alternative, multi-attribute choice indicate that information is processed sequentially, with the focus shifting to compare and evaluate subsets of options throughout the deliberation process (Roe et al., 2001; Usher & McClelland, 2004). The prominent models of choice (Evans et al., 2021; Kornienko, 2013; Noguchi & Stewart, 2018; Ronayne & Brown, 2017; Russo & Dosher, 1983; Trueblood et al., 2014; Wollschläger & Diederich, 2012) assume that this subset is a pair. Moreover, eye-tracking studies (Noguchi & Stewart, 2014) also suggest that comparisons of alternatives are pairwise along a single attribute dimension. Similarly, inference based on ordinal comparisons taken into account by Srivastava and Schrater (2015) allows pairwise comparisons of alternatives. We adopt this last model to provide a simple explanation of the AE as it explicitly considers the decoy's dominance asymmetry as part of the model's working. According to the model, the dominant option gains valuation by winning more comparisons by simply counting votes. The decoy is inferior to the target considering both attributes, and is easily dominated by it. However, in target-competitor comparisons, decision-makers are usually indifferent. In such a case, for the target to win the final vote count, the competitor-decoy comparison should not be an easy one favoring the competitor, i.e., the decoy should be asymmetrically dominated: it should be dominated by the target but not by the competitor. Based on this prediction of the model under consideration, we designed a novel perceptual task where CD comparison is difficult. We achieved this by making the inter-attribute trade-off difficult. We hypothesized that even with a triangular arrangement of the perceptual stimuli, we would get a positive AE.

Method

Participants

Thirty-eight students with normal or corrected-to-normal vision, aged 18–25 years, participated in the study.

Apparatus and Stimuli

The experiment was designed using JavaScript and conducted on similar laboratory computers.

In each trial, the stimuli consisted of three different black-colored shapes on a white background. These shapes were arranged in a triangular formation around the center of the screen, with their vertical positions jittered across trials.

Each stimulus in the experiment was derived from a base rectangle, with four distinct sections removed. These sections consisted of two pairs of inward-facing isosceles triangles, where the bases of the triangles were equal to and touched the four sides of the rectangle, resulting in a star-like shape. Figure 5, panels A and B, display two sample trials.

The stimulus creation process closely followed the methods from Experiments 1 and 2. The shape characteristics were determined by two key parameters: the base rectangle's width and the height of the removed triangles. Specifically, for the first out of the two sets of core stimuli, the mean rectangle width (μ_{w_1}) was set to 180 px, while the mean triangle height (μ_{d_1}) was set to 40 px. The respective variances were 30 px ($\sigma^2_{w_1}$) and 40 px ($\sigma^2_{d_1}$), with no correlation between the two.

Additionally, the height H_1 for the shape was determined by adding a random adjustment to the width. This adjustment was drawn from a normal distribution with a mean of 20 px and a standard deviation of 5 px. The value of H_2, representing the second height, was set equal to H_1.

The participants were instructed that the shapes represented objects drawn with sand, and their task was to identify which of the three given shapes would require the least amount of extra colored sand to be extended into a perfect square. Of the two core shapes, one had a wider base rectangle and a larger removed triangle height, while the other had a narrower base rectangle and a proportionally smaller removed triangle height. For simplicity, we refer to the wider shape as "W" (wide) and the narrower shape as "N" (narrow).

To generate the stimuli, the W shapes were created first using the width and height distributions mentioned above. Then, ensuring that both W and N shapes required the same amount of extra area to form a perfect square, the N shapes were derived. Based on observations from a pilot study, we learned that participants showed a tendency to select the W shape disproportionately. To mitigate this bias, in the main experiment, 10 pixel was added to the computed width of the N shape, denoted as w_2, to balance the preference for the wide stimulus.

As in Experiment 1, the third set (i.e., decoy shapes) was created such that, in the attribute space, it was placed close to one alternative and made inferior to it for half the trials and close to the other alternative and made inferior to it for the remaining half. We included all three types of decoys: range, frequency, and range-frequency decoys (Huber et al., 1982).

Before the main experiment, each participant completed a feedback-based practice session where they were presented with 10 pairs of shapes in random order. In five trials, the W stimulus was the expected answer, and in five trials, the N stimulus was the expected answer. Participants could click on each black shape to transform it into a perfect square, with the extra-filled portion highlighted in red. When a shape was clicked, a numerical value representing the extra sand required (e.g., 21,458 units) appeared below the shape in an arbitrary unit of measurement.

In the main experiment, in a given trial, 3 stimuli were presented with their positions randomly varied across trials.

Procedure

Participants were instructed to determine which of the three shapes required the least amount of extra colored sand to extend into a perfect square. In each trial, participants made their selection and proceeded to the next trial. During the practice session, participants were provided feedback after each selection to help familiarize them with the task.

Results and Discussion

A one-tailed t-test was performed to compare the RST values against the null value of 0.5. The mean RST ($M = 0.545$, $SD = 0.047$) was significantly higher than the null value of 0.5; $t(37) = 5.871$, $p < 0.001$. The effect size was large ($Cohen's\, d = 0.952$). Figure 5 shows two example trials and the overall distribution of the choice share in the two contexts. Figure 6 depicts a corresponding violin plot for the overall RST values. To our knowledge, this study is the first to demonstrate the positive AE for perceptual stimuli arranged in a triangle.

Re-analyzing results from Experiments 2 and 3

We reanalyzed the data from experiments 2 and 3 using a mixed ANOVA to examine the effects of stimuli type (rectangle vs star) and base pair of the triangular configuration (CD vs TD) on the RST. If no AE in rectangle stimuli and positive effect in the star stimuli were due to a breach of asymmetric dominance in the former and the presence of asymmetric dominance in the latter case, we would expect an interaction effect in the mixed-design analysis.

The main effect of *Stimulus Type* was significant, $F(1, 144) = 4.30$, $p = 0.040$. $\eta_p^2 = 0.026$. The main effect of *Base Pair* was significant, $F(1, 144) = 12.55$, $p = 0.001$. $\eta_p^2 = 0.075$, and the interaction effect of *Stimulus Type* $\times$ *Base Pair* was also significant, $F(1, 144) = 5.63$, $p = 0.019$. $\eta_p^2 = 0.034$. Table **??** summarizes the descriptive statistics for the different conditions, and Figure **??** shows the interaction plot.

As hypothesized, we observed an interaction effect indicating that the stimulus type modulated the effect of presentation configuration. Specifically, the effect of the base pair was more pronounced under rectangle stimuli compared to the star stimuli. In the rectangle condition, the base pair CD led to a negative effect, suggesting that the decoy(D) was dominated by the competitor(C). Similarly, the base pair TD led to a positive effect, suggesting that the decoy was dominated by the target(T). Thus, taking both conditions, we could conclude that triangular configuration geometry for display did not have an effect on star stimuli. The results were probably because there was an asymmetry in difficulty of choice between TD and CD pairs in star, whereas this asymmetry was reduced or missing in rectangular stimuli in the current display configuration. In the current experiment, we did not have any independent measure of difficulty. We conducted a preregistered experiment 4 to verify our claim related to the difficulty of comparisons.

Experiment 4

Introduction

To test whether the asymmetry of the decoy's dominance produced by the newly designed star stimuli was a result of asymmetry in difficulty and hence in accuracy for pair-wise comparisons CD vs. TD, we designed and preregistered another within-subject experiment involving pairs from both rectangle and star stimuli set in different trials, with respective task instructions. Note that in experiment 1, perceived difficulty was important for the pair with low perceived difficulty to be considered as the salient pair. Whereas in the current experiment, actual choice and accuracy would matter more, for a differential accuracy score would directly translate to asymmetric dominance of the decoy. Hence, it is not unreasonable to assume that accuracy would represent the true difficulty of the task. Our confirmatory hypothesis was related to the accuracy and reaction time. Nonetheless, we also collected perceived difficulty ratings of choice (exploratory) when alternatives were compared in pairs.

Method

Participants

Sixty-seven undergraduate students, aged 18–25 years, with normal or corrected-to-normal vision, participated in the experiment.

Apparatus and Stimuli

The experiment was designed using JavaScript and conducted on similar laboratory computers. Stimuli were presented in pairs, aligned horizontally, and consisted of two types of shapes: rectangles and star-like shapes.

The rectangles were created using the same procedure as in Experiment 1, with their dimensions (width and height) serving as the two attributes. The star-like shapes were constructed following the method used in Experiment 3. Each star-like shape had the width of the base rectangle and the height of the removed triangles as the two attributes. The vertical positions of the stimuli were jittered slightly across trials.

Procedure

The experimental conditions were defined by two independent variables: (1) Stimulus Type (rectangle vs. star), and (2) Comparison Pair (Target-Decoy [TD] vs. Competitor-Decoy [CD]). Each participant experienced all four combinations of these variables: (1) Rectangle, CD, (2) Rectangle, TD, (3) Star, CD, and (4) Star, TD.

The trials were presented using block randomization to ensure balanced exposure to all conditions. The experiment consisted of 12 blocks, each containing one trial per condition. Each condition was presented 12 times, resulting in 48 experimental trials. The Fisher-Yates algorithm was applied to randomize the order of conditions within each block, ensuring that the sequence of trials was unpredictable while maintaining balance.

Additionally, 12 catch trials were included as exclusion criteria and were randomly interspersed throughout the experiment. The catch trials were distributed across the trial sequence using the same randomization method, ensuring a unique and unbiased presentation for all participants.

For rectangle trials, participants were instructed to select the rectangle with the largest area. For trials with star-like shapes, they were instructed to choose the shape requiring the least amount of additional colored sand to extend it into a perfect square. These task instructions replicated the methods used in Experiments 1 and 3, respectively. In each trial, participants selected the alternative using left or right arrow keys. Following their decision, using number keys 1-7, they rated the difficulty of their choice on a 7-point Likert scale, where one represented "extremely easy" and seven represented "extremely difficult." On average, participants completed the experiment in approximately 25–30 minutes.

Results and Discussion

Out of a total of 67 participants, we excluded data from 6 participants because their performance was lower than 0.8 in the catch trials, where in each trial, there was clearly one best option out of the two. Additionally, we excluded a total of 119 individual trials (4.05%) that were either too fast (<100 ms) or too slow (>20,000 ms).

We performed repeated measures ANOVAs on accuracy, reaction time, and perceived difficulty ratings. The interaction effects of *Stimulus Type* (Star vs. Rectangle) $\times$ *Comparison Pair* (CD vs. TD) on all three were significant. ANOVA results are in Table 1. Interaction plots are shown in Figure 4. The main effects of the pair were significant for difficulty rating, accuracy, and RT. On average, the CD pair was rated as more difficult than the TD pair, and performance (both accuracy and RT) was better for the CD pair than the TD pair. Similarly, the main effects of stimulus type were also significant for accuracy and RT. Performance for rectangular stimuli (both RT and accuracy) was better compared to star stimuli. However, considering both the stimulus type and the comparison pair interaction, the pattern of results diverged between the stated difficulty and the revealed difficulty (as measured by accuracy), as well as RT.

Using accuracy as a proxy for true difficulty, the results support our hypothesis regarding the asymmetry of difficulty. In the post hoc analysis, the accuracy difference between the two pairs was significant for the star stimuli ($t(60) = 7.069$, $p < 0.001$, Cohen's $d = 0.905$, mean difference = 0.180, SD = 0.2). In contrast, the TD CD accuracy difference for rectangle stimuli, while still significant, was notably smaller ($t(60) = 5.118$, $p < 0.001$, Cohen's $d = 0.655$, mean difference = 0.085, SD = 0.130). These results suggest that the asymmetry in true difficulty was strong for star stimuli but less pronounced for rectangle stimuli. The interaction pattern between stimulus type and comparison pair for accuracy aligns with findings from the reanalysis of Experiments 2 and 3 (Figure **??**). This suggests that the presence of strong asymmetry in true difficulty between the CD and TD pairs may have translated into the presence of asymmetric dominance of the decoy in the case of star stimuli.

Surprisingly, for self-reported difficulty and RT, there was a difference between CD and TD only with rectangular stimuli. It is not clear why the less accurate star stimuli do not show a significant difference in RT and perceived difficulty between the CD and TD pairs.

General Discussion

This series of experiments sought to reconcile conflicting findings in the literature on the AE in perceptual tasks. While Trueblood et al. (2013) demonstrated a positive effect, later research reported reversed effects with perceptual stimuli, questioning the domain generality of the phenomenon. We hypothesized that such inconsistencies stem from an unexamined confound: pair-wise comparison difficulty. Across four experiments, we demonstrated that this difficulty is critical in modulating the AE.

In Experiments 1 and 2, we examined the role of spatial arrangement and salience in triangularly arranged rectangle stimuli. The results revealed that oblique arrangements increased difficulty, but the effect was primarily driven by the pair (TD or CD) horizontally positioned as the salient pair, underscoring the importance of the asymmetry in the dominance of the decoy.

Experiments 3 and 4 tested whether increasing CD comparison difficulty could restore a positive AE, even with triangular arrangements. Using novel star stimuli designed to increase this difficulty, we observed a robust positive AE, absent in the rectangle stimuli used in prior studies. The accuracy score as a proxy for the revealed difficulty obtained from pair-wise comparisons further validated that the asymmetry of comparison difficulty between CD and TD pairs was a likely cause of the asymmetry of the dominance of the decoy. Reanalysis of Experiments 2 and 3 provided further support for our hypothesis.

Our findings align well with previous research claiming the effect of attribute incommensurability on AE (Hayes et al., 2024; Walasek & Brown, 2023), though we are the first to show its presence in the perceptual domain.

Given our results, one might question why stimuli, with low competitor-decoy comparison difficulty, arranged linearly, did Trueblood et al. (2013) observe a standard

AE, later replicated by Spektor et al. (2018). Although this remains to be explored in future studies, first, we highlight that in the past, the authors in both of these studies have not controlled for the order of stimuli, which is a possible confound. Second, a linear arrangement of stimuli could have introduced other biases in eye movements (Spektor et al., 2022). Third, we propose that even when order is controlled, the matched orientation of the stimuli could make the target-decoy pairs consistently salient, regardless of their position in a trial, leading to overall positive effects. This assumption is reasonable. In fact, the Multi-attribute Linear Ballistic Accumulator (MLBA) model (Evans et al., 2019; Trueblood et al., 2014; Turner et al., 2018) makes a similar assumption to explain the same positive effect.

In summary, this brief report makes three contributions. First, we re-established the domain generality of the attraction effect by demonstrating a strong positive effect, even with perceptual stimuli in an alignment previously associated with negative effects. Second, we corroborated pairwise ordinal comparison accounts of the mechanism by which alternatives are compared in such tasks. Third, we identified a possible cognitive mechanism underlying the effect by showing that pair-wise comparison difficulty likely modulates the asymmetry in the dominance of the decoy and thereby controls the overall attraction effect.

Declarations

Funding

No funds, grants, or other support were received for conducting this study.

Conflicts of interest/Competing interests

The authors have no competing interests to declare that are relevant to the content of this article.

Ethics approval

All experiments were approved by the Institute Ethics Committee.

Consent to participate

Participants provided informed consent before participation and received compensation for their time.

Consent for publication

Not applicable.

Availability of data and materials

The data and materials for this study are openly available at OSF. Experiment 4 was preregistered, and the preregistration is available at OSF.

Code availability

The analysis code for this study is available at OSF.

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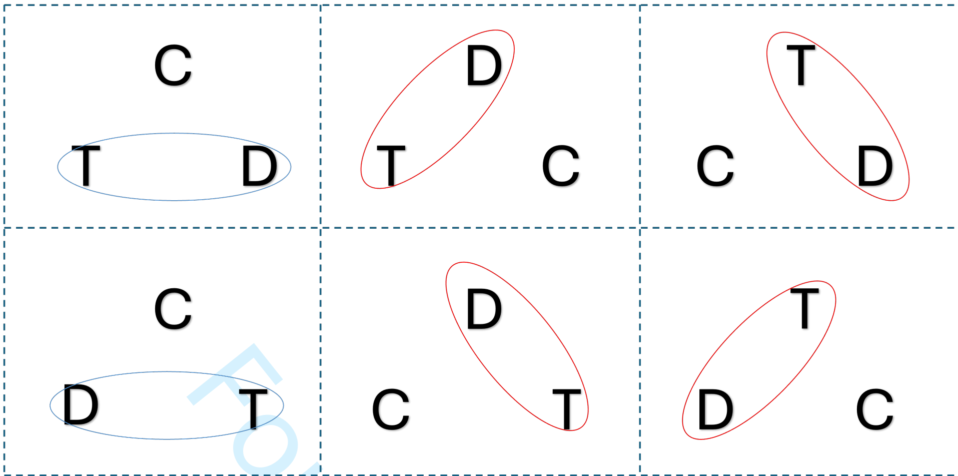
Factor	$F(1, 60)$	p	η^2
Accuracy			
stimulus_type	11.160	0.001	0.788
pair	75.767	<0.001	0.962
stimulus_type × pair	9.813	0.003	0.766
Reaction Time			
stimulus_type	26.725	<0.001	0.899
pair	9.422	0.003	0.758
stimulus_type × pair	4.494	0.038	0.600
Difficulty Rating			
stimulus_type	2.478	0.121	0.452
pair	22.623	<0.001	0.883
stimulus_type × pair	8.634	0.005	0.742

Table 1

Repeated Measures ANOVA results for Accuracy, Reaction Time, and Difficulty Rating.

Figure 1

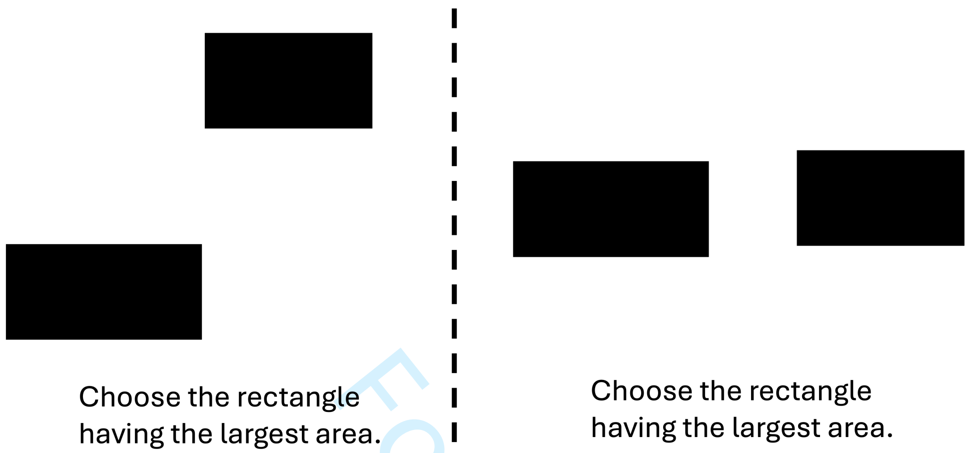
Six Possible Configurations of Stimuli in a Triangular Arrangement



Note. TD pairs appear in the oblique position two-thirds of the time, whereas in the horizontal position one-third of the time.

Figure 2

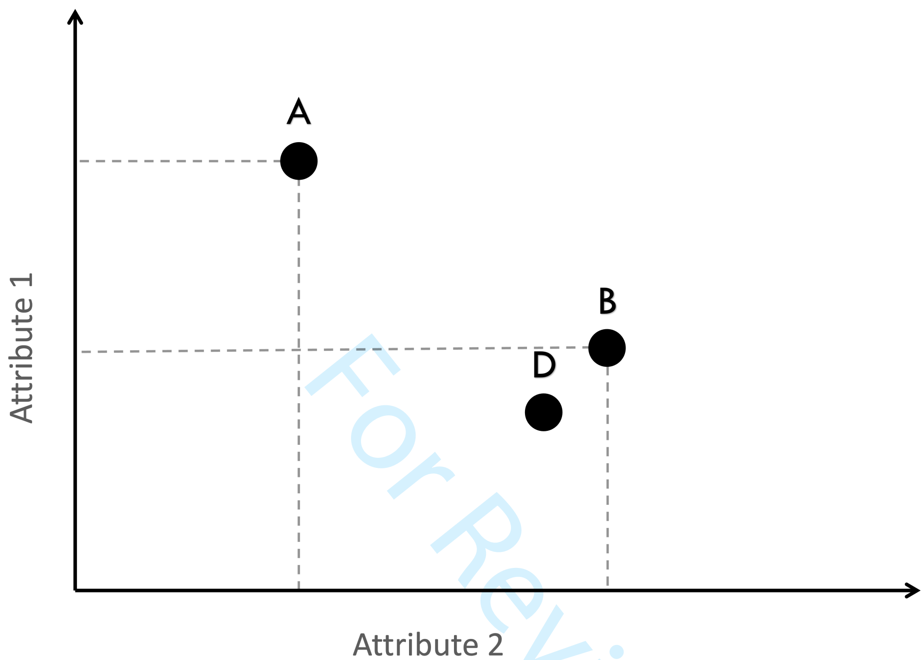
Example Trials in Experiment 1



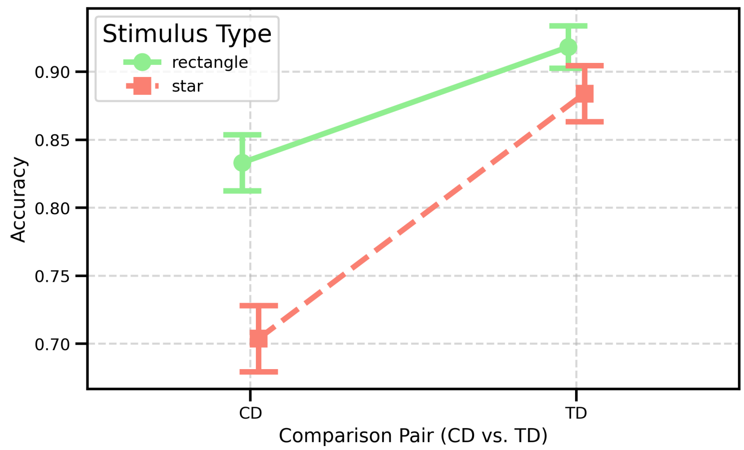
Note. Two example trials: stimuli pair in oblique and horizontal positions from left to right.

Figure 3

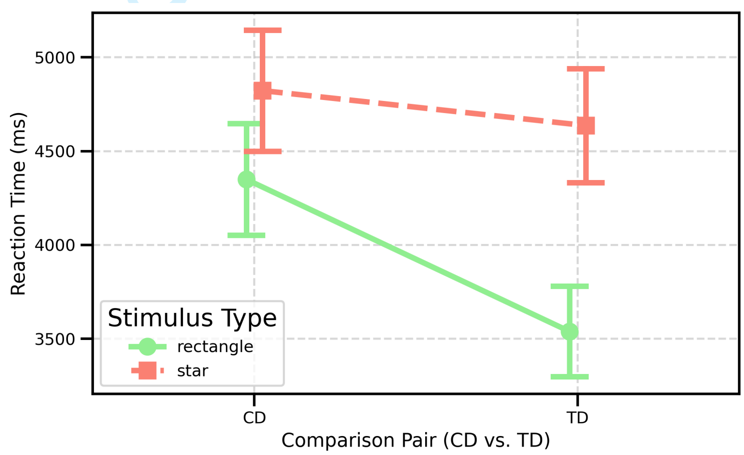
Asymmetric Dominance Effect.



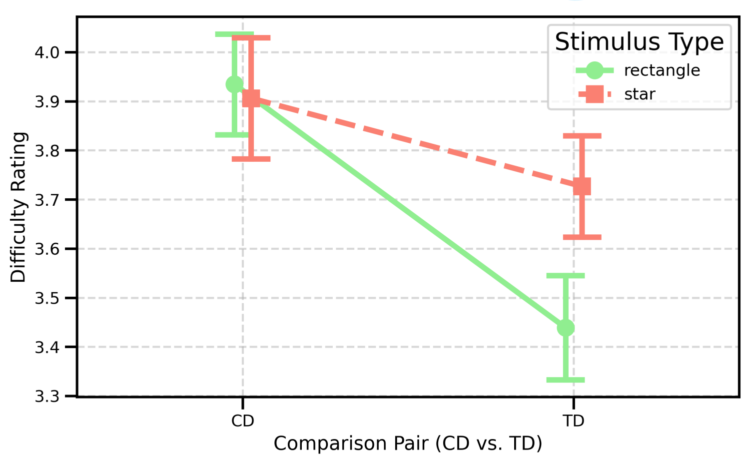
Note. Here B is the target, A is the competitor, and D is the decoy. The choice share of alternative B increases with the introduction of decoy D, which is dominated by B but not by A.



Accuracy



Reaction Time



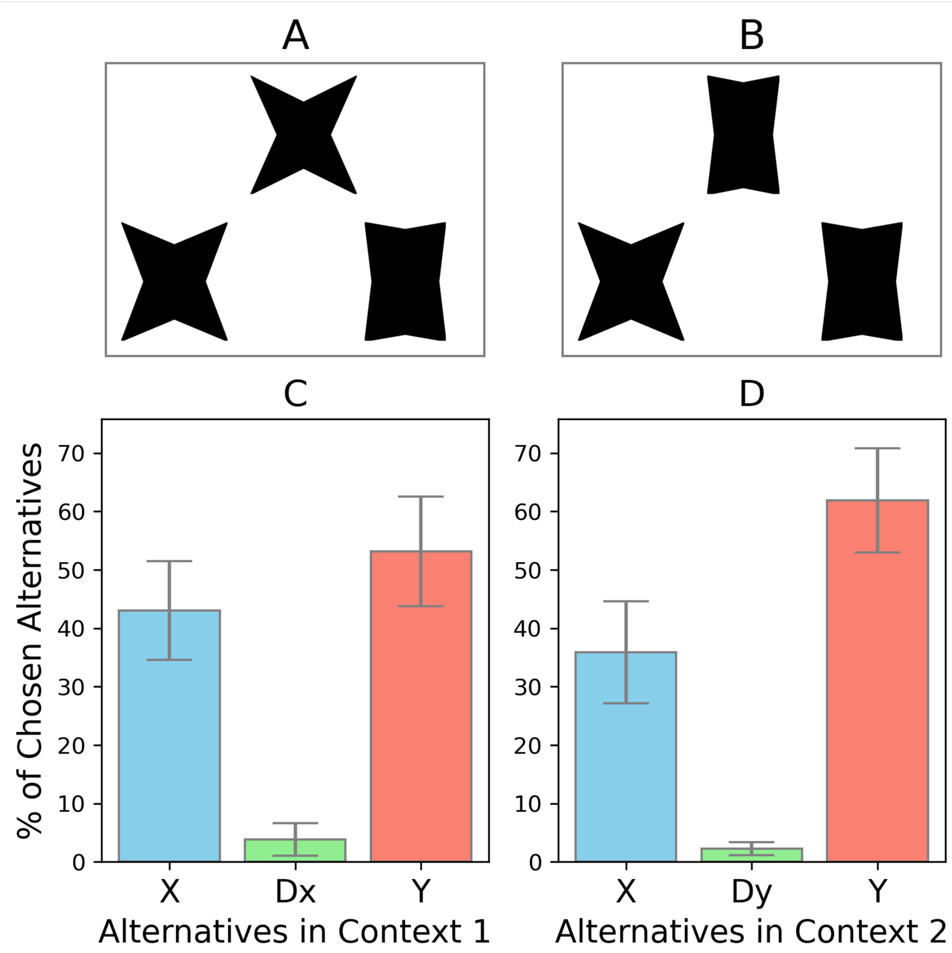
Difficulty Rating

Figure 4

Interaction Plots in Experiment 4

Figure 5

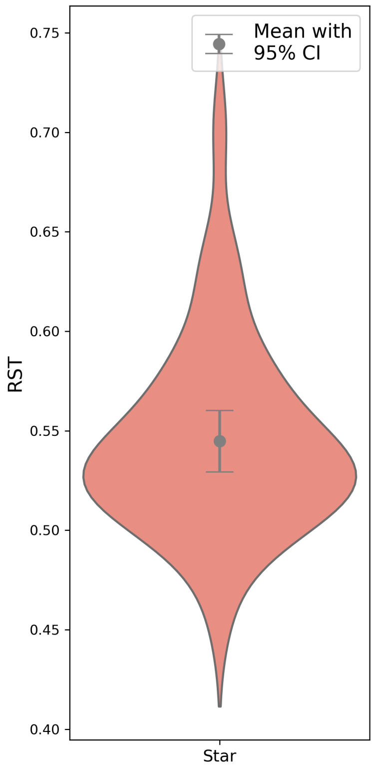
Example Trials, Choice Shares in Experiment 3



Note. Panel A shows a trial with the wider stimulus as the target, while panel B shows the narrower stimulus as the target. Panels C and D display choice shares for two contexts, with X and Y as core options and Dx and Dy as decoys favoring X and Y, respectively. Error bars are 95% confidence intervals.

Figure 6

RST in Experiment 3



Note. Error bars represent 95% confidence intervals.

Appendix

Derivation of the hypothesis in experiment 2

Throughout the paper, we have used relative share of the target (RST) as proposed by (Katsimpokis et al., 2022) to compute the strength of the context effect.

$$\text{RST} = 0.5\left(\frac{n_{t,C1}}{n_{t,C1}+n_{c,C1}} + \frac{n_{t,C2}}{n_{t,C2}+n_{c,C2}}\right).$$

where $n_{x,C\#}$ = choice frequency of x in the context C#, #:1,2, i.e., C1 and C2 represent the two contexts respectively and x: t (target), c (competitor).

Each subject provides three instances of RST: 2 values for TD_Oblique and 1 value for TD_Horizontal. Since there are more data points for TD_Oblique (2 data points per subject) than for TD_Horizontal (1 data point per subject), we compute the weighted average RST (RST_avg) for the subject, where the weights reflect the number of observations in each condition.

The weighted average RST for each subject is calculated as:

$$\text{RST}_{\text{avg}} = \frac{n_{\text{TD\_Oblique}} \cdot \mu_{\text{TD\_Oblique}} + n_{\text{TD\_Horizontal}} \cdot \mu_{\text{TD\_Horizontal}}}{n_{\text{TD\_Oblique}} + n_{\text{TD\_Horizontal}}}$$

Where:

- $n_{\text{TD\_Oblique}} = 2$ (the number of observations for TD_Oblique),
- $n_{\text{TD\_Horizontal}} = 1$ (the number of observations for TD_Horizontal).

Substituting the values for $n_{\text{TD\_Oblique}}$ and $n_{\text{TD\_Horizontal}}$:

$$\text{RST}_{\text{avg}} = \frac{2 \cdot \mu_{\text{TD\_Oblique}} + 1 \cdot \mu_{\text{TD\_Horizontal}}}{2+1} = \frac{2 \cdot \mu_{\text{TD\_Oblique}} + \mu_{\text{TD\_Horizontal}}}{3}$$

Now, to ensure that the weighted average RST for each subject is less than 0.5 (for the negative attraction effect to be replicated), we set the following condition:

$$\text{RST}_{\text{avg}} < 0.5$$

Substituting for RST_{avg} from the earlier equation:

$$\frac{2 \cdot \mu_{\text{TD\_Oblique}} + \mu_{\text{TD\_Horizontal}}}{3} < 0.5$$

Multiplying both sides of the inequality by 3 to eliminate the denominator:

$$2 \cdot \mu_{\text{TD\_Oblique}} + \mu_{\text{TD\_Horizontal}} < 1.5$$

This inequality represents the condition we are testing in the hypothesis: the weighted sum of TD_Oblique and TD_Horizontal RST values must be less than 1.5 for each subject. If this condition holds true for the data, we would expect the weighted sum of the two categories' means to be less than 1.5, indicating a potential relationship between the RST values from the two conditions.

LME Model Comparison in experiment 2

We compared three models to assess the best fit for explaining the dependent variable (average RST per subject):

1. **Full Model**: Includes both *TD_Position* (i.e., *TD_Oblique*, *TD_Horizontal*) and *BasePair* (i.e., *CD*, *DT*, *CT*).
2. **Reduced Model without *TD_Position***: Removes the *TD_Position* variable.
3. **Reduced Model without *BasePair***: Removes the *BasePair* variable.

The models can be mathematically described as follows, where RST_i represents the average RST for subject i:

- **Full Model**:

$$RST_i = \beta_0 + \beta_1 \cdot TD\_Position_i + \beta_2 \cdot BasePair_i + u_i + \epsilon_i$$

where:

- RST_i is the average response (average RST) for subject i,
- $TD\_Position_i$ represents the TD position (Oblique or Horizontal) for subject i,
- $BasePair_i$ represents the Salient Pair (CD, DT, CT) for subject i,
- u_i is the random intercept for subject i (accounting for repeated measurements within subjects),
- ϵ_i is the residual error term for subject i.

- **Reduced Model without *TD_Position***:

$$RST_i = \beta_0 + \beta_2 \cdot BasePair_i + u_i + \epsilon_i$$

where $TD\_Position_i$ is excluded from the model, and the response variable depends only on the *BasePair* variable.

- **Reduced Model without *BasePair***:

$$RST_i = \beta_0 + \beta_1 \cdot TD\_Position_i + u_i + \epsilon_i$$

where $BasePair_i$ is excluded from the model, and the RST depends only on the *TD_Position* variable.

The model comparison was performed based on two criteria: *AIC* (Akaike Information Criterion) and *BIC* (Bayesian Information Criterion). The results are summarized in the table below:

Interpretation

- AIC Comparison: The Reduced Model without *TD_Position* and the Reduced Model without *BasePair* show a notable difference in AIC values, indicating that the model without *BasePair* performs less well than the model without *TD_Position*.

- BIC Comparison: Similarly, the Reduced Model without *TD_Position* outperforms the Reduced Model without *BasePair* in terms of BIC, suggesting that excluding *BasePair* worsens the model fit.

Since the Full Model had perfect multicollinearity between *TD_Position* and *BasePair* (with high VIF values), it was excluded from the comparison. This redundancy between the variables renders the full model inappropriate for a meaningful comparison with the reduced models. The model comparison results suggest that *BasePair* plays a more crucial role in explaining average RST than *TD_Position*; in short, more than *where the TD pair is* (Oblique vs Horizontal), what matters most is *what the horizontal pair is* (TD vs CD vs CT).

References

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Model	**AIC**	**BIC**
Full Model	-121.252	-113.206
Reduced Model without *TD_Position*	-121.252	-113.206
Reduced Model without *BasePair*	-117.461	-112.097

Table 1

Model comparison based on AIC and BIC values.