# **Re-evaluating the Numerical-Perceptual Distinction in the Attraction Effect**

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#### Abstract

A widely studied cognitive bias in decision-making is the 'attraction effect' or 'asymmetric dominance effect', where introducing a clearly inferior decoy option to a binary choice set increases the likelihood of choosing the dominating option (target) over the other (competitor). While there is a consensus in the literature that the attraction effect is robust with numerical stimuli, there have been inconsistent results with perceptual stimuli (Frederick et al., 2014). This numerical-perceptual distinction was further supported in some recent studies involving perceptual stimuli claiming to have produced a negative attraction effect (Spektor et al., 2018, 2022). We argue that this distinction does not exist and that people's choice behavior is better explained by inter-attribute relationships. In this study, we conducted two experiments where we showed positive attraction effects with combined perceptual-numerical stimuli (having both perceptual and numerical attributes) and both positive and null effects with numerical stimuli by manipulating the asymmetry in pair-wise comparison difficulty. In Experiment 1, we provided evidence for a strong attraction effect for perceptual-numerical stimuli by ensuring the tradeoff between the attributes are difficult. Next, in Experiment 2, we manipulated the competitor-decoy (CD) comparison difficulty while controlling for a confound-target-competitor (TC) comparison difficulty, a factor that has yet to be addressed by studies that have produced a positive attraction effect with perceptual stimuli. To achieve this manipulation, we leveraged findings from mathematical cognition and education research on fraction comparison, effectively activating or suppressing the standard attraction effect through our experimental design. Taken together, the results from both studies challenge the superficial distinction between stimulus types and support a universal cognitive mechanism underlying the ubiquitous attraction effect.

**Keywords:** attraction effect; context effect; asymmetric dominance; trade-off-difficulty; mathematical cognition; fraction comparison

#### **General Introduction**

Adding an alternative to a choice set should not increase the choice share of the original alternatives — an important principle in rational choice theory known as regularity (Luce, 1977). Huber et al. (1982) empirically demonstrated a violation of this assumption with the famous asymmetric dominance or attraction effect.

Beyond its theoretical significance, the attraction effect also serves as a practical behavioral nudge to influence consumer choices. Simply put, introducing a third option can sway decision-makers toward one of the original choices. While this effect has been observed across various domains and species over the past four decades, recent findings have questioned its domain generality.

Choices presented as symbolic digits have shown large context effects (Huber et al., 1982; Simonson, 1989). In contrast, Frederick et al. (2014) suggested that perceptual representations often elicit different effects than numeric representations, suggesting that the attraction effect may not be prevalent in choices that involve distinguishing between perceptual attributes. Huber et al. (2014), while advocating for the existence of the attraction effect highlighted the issue of over-generalization and blamed the lack of the effect in the perceptual domain on possible different processing. Brendl et al. (2023) argued that the quantitative-qualitative difference of the stimuli explained the numerical-perceptual difference. Spektor et al. (2021) highlighted this difference and ascribed it to the attribute concreteness in numerical stimuli, absent in perceptual ones. In contrast, however, research has found that people find numbers relatively intuitive to process. With more experience with numbers over the course of their lives, symbolic number processing is less associated with more deliberate thought in the prefrontal cortex and more automatic processing in the intraparietal sulcus (Ansari et al., 2005). This is because symbolic number processing is mapped to the approximate number system, which is associated with the processing of numeric magnitudes across modalities (Feigenson et al., 2004). Over development, people process symbolic numbers similarly to how we process perceptual dimensions, such as brightness and loudness. Similar to how those dimensions are perceived, the internal representation number is logarithmic in nature. Additionally, although initial studies in the perceptual domain demonstrated a positive attraction effect (Choplin & Hummel, 2005; Trueblood et al., 2013), subsequent findings of reversed effects in perceptual tasks (Spektor et al., 2018, 2022) posed a significant challenge to the claim of the effect's domain generality.

However, He and Sternthal (2023) proposed that the attraction effect occurs for both numerical and perceptual stimuli when ambiguity in choice prompts individuals to focus attention on the comparison of the target and applicable decoy to resolve the ambiguity. Likewise, Rath et al. (2024b) claimed that the previous multi-alternative, multi-attribute choice tasks employing perceptual stimuli (Spektor et al., 2018, 2022) failed to adhere to the boundary condition of asymmetric dominance while their task did. An asymmetrically dominated alternative is dominated by one item in the set but not by another (Huber et al., 1982). Figure 1 displays one such configuration of items in the attribute space. Rath et al. (2024b) satisfied the proposal requisite precondition for the effect by introducing a novel stimulus to increase the competitor-decoy (CD) comparison difficulty. CD comparisons were made more difficult by increasing the interattribute trade-off difficulty. When attributes are difficult to trade off, CD comparisons involving two extreme attribute values become difficult, whereas target-decoy (TD) comparisons remain easy. Rath et al. (2024b) showed that this asymmetry in difficulty translated to the asymmetry of the dominance of the decoy by the target and the competitor to produce a positive attraction effect. Conversely, with easy-to-trade-off attributes, it is likely that comparisons between alternatives are no longer along different attribute dimensions but along a common currency, leading to no context effects.

Figure 2 depicts one sample stimulus from each of these studies. The two attributes of interest in the first one were the height and width of rectangles, and the task was to choose the rectangle with the largest area. The second one had fill lengths in a horizontal and a vertical bar as two attributes, and the task was to choose the alternative with the largest sum. The stimuli in Rath et al. (2024a) had the maximum width and length of the indentations in a star-like shape as two varying attributes, and the task was to choose the shape that required the least amount of extra material to make it a perfect square. Unlike the previous two, the relation of the attributes to the task was not straightforward here.



Figure 1: Asymmetric Dominance Effect.

Given the existing literature, researchers have observed a strong positive effect in perceptual tasks with asymmetric dominance and a null effect in its absence. To blur the distinction between numerical and perceptual stimuli, we conducted two experiments: one with combined perceptual-numerical stimuli that ensured asymmetric dominance of the decoy and another with numerical stimuli, both with and without asymmetric dominance. For the second experiment with numerical stimuli, we relied on the findings from mathematical education and cognition research on how people understand fractions (Obersteiner et al., 2020, 2022).



Figure 2: Sample Stimulus adapted from three experiments Trueblood et al. (2013), Spektor et al. (2022), and Rath et al. (2024b) in left to right order.

### **Experiment 1**

**Introduction** Real-life decisions often involve difficult-totrade-off attributes (Bhatia & Walasek, 2024). The choice between two alternatives becomes challenging when trading off their prominent attributes is difficult. A trade-off is defined as a kind of compromise that involves giving up something in return for gaining something else. In economics, a trade-off is often referred to as an "opportunity cost." For example, one might take a day off work to attend a concert, gaining the opportunity to see their favorite band while losing a day's wages as the cost of that opportunity (Vocabulary.com, 2024).

Although Huber et al. (2014) did not explicitly introduce **attribute-trade-off-difficulty** as a boundary condition, they indirectly hinted at it: "...for the attraction effect to occur, the decision maker should also be unsure whether a ten-point difference in restaurant ratings is worth a \$10 price difference." This suggests that the difficulty of comparing attributes plays a critical role in the attraction effect.

Walasek and Brown (2023) further emphasized the importance of attribute incommensurability in multi-attribute, multi-alternative choices. They provided a compelling example to illustrate this concept. Imagine comparing two candidates for an assistant professor position at a research-focused university. Assume that the candidates are evaluated based on two distinct attributes: research value, measured by citation counts (e.g., h-indices), and teaching value, measured by student ratings. If only one attribute mattered, the decision would be straightforward: choose the best teacher or the best researcher. However, if the university's guidelines require both teaching and research to be considered, the decision becomes complex. If teaching ratings reflect only teaching value and h-indices reflect only research value, how does one trade off these two different scores against each other? Walasek and Brown (2023) described such attributes as incommensurate. Similarly, Hayes et al. (2024) demonstrated how manipulating attribute commensurability influences the size of the attraction effect in preferential choice domains. These studies further underscore the significance of attribute comparability in the context effect.

Chang (2013) summarized five distinct ways the term *incommensurability* has been used in the literature, none of which allow for a trade-off between incommensurate attribute values. Attributes can be incommensurate for one or more of the following reasons:

- Non-compatibility: Attributes cannot be compared directly.
- No super-value: There is no overarching metric to unify the attributes.
- **Trumping/discontinuity/threshold lexical superiority**: One attribute dominates the other(s) beyond a certain threshold.
- Nonsubstitutability/non-compensability: Attributes cannot substitute or compensate for one another.
- No common currency: Attributes lack a shared unit of measurement.

However, even when attributes are technically commensurate according to these definitions, trade-offs between them can still be challenging due to *representational noise*, which makes it difficult to assess the absolute values of the options' attribute values (Simonson, 2008). For instance, Rath et al. (2024b) used a stimulus where two attributes were presented in the same units (distance), but participants found it difficult to determine how much of a change in one attribute could compensate for a change in the other. This demonstrates that trade-off difficulty can arise even when attributes are nominally commensurate.

In this experiment, we use a **combined perceptualnumerical stimuli set** to explore how trade-off difficulty can manifest even when attributes share a super-value. Specifically, we use the area of alloy pieces represented by filled circles as the perceptual attribute and their price in integer values as the numerical attribute, where the price per unit area serves as the super-value. This design allows us to test the role of attribute-trade-off difficulty in producing the attraction effect in combined perceptual-numerical stimuli set.

The definitions of (in)commensurability provided by Chang (2013) treat incommensurability as a binary variable. However, we argue that trade-off difficulty exists on a **continuous scale**, reflecting the phenomenological challenge of comparing attributes. Therefore, we prefer the term **attribute-trade-off-difficulty** over *attribute commensurability*, as it better captures the gradational nature of this construct.

Most models of choice propose that in a multi-alternative comparison, alternatives are compared pair-wise (Evans et al., 2021; Kornienko, 2013; Noguchi & Stewart, 2018; Ronayne & Brown, 2017; Russo & Dosher, 1983; Trueblood et al., 2014; Wollschläger & Diederich, 2012). Building on this assumption, we hypothesized that an increased inter-attribute trade-off difficulty in our stimuli would lead to asymmetry in the difficulty of choice in different pairs, ultimately leading to the asymmetric-dominance effect.

**Methods** Thirty-six participants (Mean age = 21.11 years, SD = 3.42; 27 male, 9 female) with normal or corrected-tonormal vision gave informed consent and took part in the experiment. After the exclusion of 6 participants due to their low scores (< 0.8) in the catch trials, the analysis was done on data from 30 subjects.

The experiment was designed using JavaScript and conducted on laboratory computers with screen resolutions of  $1920 px \times 1080 px$ . In each trial, the stimuli consisted of three different black-filled circles 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. Figure 3 shows an example trial. Participants were informed that the circular discs were some special alloys whose prices were displayed in white at the center of the disc in arbitrary units. In each trial, the participants were asked to choose the disc with the lowest price per unit area. The two attributes that formed that attribute space were the area of the disc to be evaluated solely based on perception and the price of the disc displayed at its center.



Figure 3: Example Trial in Experiment 1

Following Trueblood et al. (2013), one set of circles was created using a bivariate normal distribution with a mean area of 28000 pixels and a mean price of 28. The variance for the area and the price were 28000 pixels and 28, respectively, and there was no correlation between the variances, allowing for variability in the task. A second set of circles were matched in price per unit area but were twice the area of the first set. One of these sets was considered the target, while the other was the competitor.

The third set (i.e., decoy circles) was created such that, in the attribute space, it was placed close to the smaller circle for half the trials and close to the larger one for the remaining half, effectively creating two sets of contexts. We included all three types of decoys: range, frequency, and range-frequency decoys (Huber et al., 1982). Participants completed 36 trials in each of the contexts. Additionally, 12 catch trials were included as exclusion criteria, in which one circle in each trial clearly had the lowest price per unit area. The presentation order of all 84 trials was randomized. Participants were instructed to respond as fast and as accurately as possible using the left, up, and right keys.

**Results and Discussion** A one-tailed t-test was performed to compare the RST<sup>1</sup> values against the null value of 0.5. The mean RST (M = 0.591, SD = 0.109) was significantly higher than the null value of 0.5; t(29) = 4.593, p < 0.001. The effect size was large (*Cohen's d* = 0.839). A Bayesian one-sample t-test further supported this result, yielding a Bayes factor of BF<sub>10</sub> = 273.75 (using a Cauchy prior with r = 0.4), indicating strong evidence in favor of the alternative hypothesis ( $H_1$  : RST > 0.5). Figure 4 depicts the violin plot for the overall RST values.

The results provide further evidence that perceptual stimuli are just as effective as numerical stimuli in producing the standard attraction effect. More importantly, they show that increasing the inter-attribute trade-off difficulty produces the asymmetric dominance of the decoy and, hence, the asymmetric-dominance effect. This experiment could be treated as a conceptual replication of (Rath et al., 2024b) while violating yet another definition of incommensurability.



Figure 4: RST Distribution in Experiment 1

## **Experiment 2**

**Introduction** We assume that, compared to stimuli used in previous studies that failed to produce a positive attraction effect in the triangular arrangement, our stimuli introduced greater competitor-decoy (CD) comparison difficulty due to increased attribute-trade-off difficulty, leading to asymmetric dominance of the decoys. Both Rath et al. (2024b) and the current study followed a similar approach to increase CD

comparison difficulty and report positive effects. However, when attribute-trade-off difficulty is increased by the choice of attributes, target-competitor (TC) comparisons also become more difficult, for the same reason that CD comparisons become challenging. This introduced a potential confound in both studies.

Thus, we cannot definitively claim that the positive effect observed in our study is due to the restoration of asymmetric dominance, nor can we attribute the negative effect in previous studies solely to its absence. When TC comparisons are easy, decision-makers can form a clear prior preference between the target and the competitor. This, in turn, diminishes the effect of an added undesired decoy (Huber et al., 2014; Rath et al., 2024a). We have not yet identified perceptual stimuli where CD comparison difficulty can be made independent of TC comparison difficulty. In Experiment 2, we used fractions, which offered us greater flexibility to control for this confound.

People's ability to process numbers very quickly is advantageous in many aspects of decision-making and information processing (Feigenson et al., 2004; Moyer & Landauer, 1967). However, it can interfere with understanding one abstraction that mathematics has built using numbers - fractions. People find fractions difficult to understand and reason about (Behr et al., 1984; Lortie-Forgues et al., 2015). One reason for this is because the symbolic numbers present in fractions are not sufficient to determine their magnitude. A small fraction can consist of larger numbers, for example,  $\frac{1283}{11823}$  and a larger fraction can include smaller numbers, for example,  $\frac{1}{3}$ . In this example, both the numerator and the denominator in the larger fraction contain clearly larger numbers, and it is often the choice students make when asked to pick the larger fraction. This is called the natural number bias, the automatic processing of symbolic number can interfere with how people judge the magnitude of fractions (Alibali & Sidney, 2015; Ni & Zhou, 2005; Reinhold et al., 2023). To properly compare fractions, one should suppress the urge to solely compare the magnitudes of the number, and integrate these magnitude representations with the rules of fractions. Studies have since also found the existence of a re*verse natural number bias*, where people judge the fractions with smaller numbers as the larger fractions, a likely overcorrection to the natural number bias (Barraza et al., 2017; DeWolf & Vosniadou, 2011; DeWolf & Vosniadou, 2015; Obersteiner et al., 2020). However, evidence also suggests that people are also able to perceive the holistic magnitude of a fraction, as the strength of the natural number bias decreases the greater the distance between two fractions being compared (Barraza et al., 2017; Park et al., 2021).

People's perceptions of the magnitudes of fractions are also determined by the strategies they know, by the strategies they use, and by the properties of the fractions themselves, and how the properties of the fractions interact with their strategies (Fazio et al., 2016; Obersteiner et al., 2022; Reinhold et al., 2023; Siegler et al., 2013). When asked to report

<sup>&</sup>lt;sup>1</sup>Throughout the paper, we used the Relative Share of Target equal weight (Katsimpokis et al., 2022) as the metric for the attraction effect.

how they compare fractions, people report a variety of strategies that range from componential, focusing on values and magnitudes of the numerators and denominators, to holistic, which involve determining the magnitude of the fraction itself (Obersteiner et al., 2022). Sometimes, these strategies are valid, for example, a componential strategy when people compare the multiplicative relationship between numerators of the fractions and compare it to the denominators to make a judgement. However, people also use heuristics that are not valid for all fractions. One example is a frequently reported holistic strategy called benchmarking, where they find a familiar fraction (benchmark) close to the fraction they need to compare, and compare the other fraction (or a benchmark close the other fraction) to this benchmark (DeWolf & Vosniadou, 2011; Liu, 2018; Obersteiner et al., 2020). Errors in finding the nearest benchmark can invalidate this strategy. People also often compare the differences between the numerator and denominator of each fraction and compare them to determine which of the two fractions is greater (Gómez & Dartnell, 2019; Obersteiner et al., 2022). This componential strategy, called gap comparison, fails, for example, when  $\frac{31}{71}$ is compared to  $\frac{13}{23}$ . This rich complexity in how people process fractions allows us to manipulate the difficulties of pairwise comparisons. For example, comparisons with higher ratio distances are easier, comparisons with common components are easier, comparisons with divisible numerators and denominators are easier, etc.

This experiment serves three main purposes. First, to blur the numerical-perceptual distinction, we aimed to test whether the attraction effect could be activated or deactivated through a separate manipulation. Second, we sought to control for the confound introduced in Experiment 1, and the use of fractions provided greater flexibility in this regard. Third, we employed a within-subjects design to control for individual differences.

In this design, participants experience both CD comparison difficulty ( $Diff_CD$ ): high and low conditions, effectively controlling for TC comparison difficulty. TD comparison was easy in both conditions. We hypothesize that in the  $Diff_CD$ : High condition, we will observe a positive attraction effect, whereas in the  $Diff_CD$ : Low condition, we expect a null effect. We also predict a significant difference in RST values between these two conditions.

**Methods** Fifty-five participants (Mean age = 21.63 years, SD = 3.33; 39 male, 16 female) with normal or corrected-to-normal vision gave informed consent and took part in the experiment. None was excluded in the final analysis.

The experiment was designed using JavaScript and conducted on similar laboratory computers as in Experiment 1. Figure 5 shows an example trial.

To determine which fraction triplets to present to participants, we first needed to operationalize how easy it is to perceive the holistic magnitude of a fraction, i.e., the super-value of a fraction. This was determined as the geometric mean of a series of conditions, where the presence of a condition was represented as 1.05 and the absence as 0.05 instead of 1 and 0 to prevent the geometric mean from evaluating to 0 in the absence of any condition. The conditions were: (1) when the number of common factors between the numerator and denominator is greater than or equal to 4, (2) when the ratio represented by the fraction is  $\pm 0.15$  of a whole number, (3) when the numerator is perfectly divisible by the denominator, and (4) when the denominator was divisible by 5.

We also defined the ease of comparing two fractions to each other. Similarly, this was the geometric mean of a series of conditions with a 0.05 offset. The conditions were: (1) the fraction sharing a common component (this factor was weighted 4 times more than the others), (2) the comparison being gap congruent (the item with the larger numerator and denominator difference being the correct answer) and the ratio between the gaps of the two fractions being greater than or equal to 1.5, (3) the ratio between the numerators being less than or equal to 5.05 (this includes the most well-known portion of the multiplication table) and ratio between the numerators being  $\pm 0.15$  of a whole number, (4) the same for the denominator, and (5) the ratio between the holistic magnitudes of the fraction being greater than 2 (very distant) or close to  $1 \pm 0.15$  (very close). These scores, informed by research on how people use strategies to compare fractions, helped determine the items present in the two conditions.

We ensured that all stimuli in each condition fell between ease ranges, which greatly reduced the potential of confounds playing a role in the effect we observed. To determine the triplets, we first started with a set of all fractions with numerators and denominators with whole numbers greater than 1 and less than 100, where the numerator was not equal to the denominator. Using this set of fractions, we randomly sampled potential trials and assessed them through our criteria until we generated 30 items. For items in the CD comparison difficulty: low condition, we ensured that the decoys were similarly easy to compare with the target and the competitor, i.e., the ratio between the ease scores for target-decoy and competitor-decoy comparisons were constrained to be less than 2 and we set a minimum ease value for these comparisons (0.4). For the CD comparison difficulty: high condition, the ratio between the ease scores were constrained to be greater than 4, that is, the decoy was significantly easier to compare with the target fraction than the competitor fraction. All target and competitor ratios were constrained to be between 2 and 5.5. However, the ratios themselves were constrained to not be  $\pm 0.15$  of a whole number ratio.

**Results and Discussion** We conducted two two-tailed onesample t-tests on RST values from both blocks (Diff\_CD: High, Diff\_CD: Low) against the null value of 0.5. For Diff\_CD: Low, RST(M = 0.507, SD = 0.081) was not significantly different from 0.5, t(54) = 0.597, p =0.553, Cohen's d = 0.080. Figure 6 shows two violin plots for the two block conditions. The Bayesian one-sample t-test supported this result, with a Bayes factor of BF<sub>10</sub> = 0.176 (using a Cauchy prior with r = 0.7), indicating strong evi-





Figure 5: Example Trial for Block H in Experiment 2

dence for the null hypothesis ( $H_0$  : RST = 0.5). For Diff\_CD: High, RST(M = 0.545, SD = 0.095) was significantly different from 0.5, t(54) = 3.468, p = 0.001, Cohen's d = 0.468. The Bayesian test yielded a Bayes factor of BF<sub>10</sub> = 26.808 (using a Cauchy prior with r = 0.7), indicating strong evidence for the alternative hypothesis ( $H_1$  : RST  $\neq 0.5$ ). We next conducted a paired t-test between the RST values from the two conditions. The RST difference (M = 0.038, SD =0.093) was significantly different from 0, t(54) = 3.010, p =0.004, Cohen's d = 0.410.

To test for order effects, we performed a Monte Carlo permutation test. We randomly shuffled the block order assignments while keeping the within-subject block structure intact and repeated this process over 10,000 permutations to generate a null distribution of the test statistic. The p-value, calculated by comparing the observed statistic to the null distribution, was 0.158, indicating no significant order effect on RST values.

Note that our primary goal, even in the Diff\_CD: High block, was not to show how fractions can produce context effects. To ensure all constraints for the manipulation were met, we had to relax the ease scores in TC comparisons a bit, which could have allowed relatively easy comparisons for a few participants, reducing the overall effect. We believe a much stronger positive attraction effect could be produced using fractions if we solely aim for it and design the stimuli set accordingly.

## **General Discussion**

Aiming to explore context effects in both numerical and perceptual settings, we initiated two experiments based on the intuition that there is no fundamental distinction between the



Figure 6: RST Distributions for two blocks in Experiment 2

two and that the attraction effect is ubiquitous across domains. In Experiment 1, we successfully produced a strong positive effect using stimuli that incorporated both perceptual and numerical attributes, where inter-attribute trade-offs were difficult. In Experiment 2, a within-subject design, we extended this to numerical stimuli using fractions. We demonstrated that the standard attraction effect could be toggled on and off by manipulating the asymmetry between targetdecoy and competitor-decoy comparisons while controlling for a confound-the target-competitor comparison. Experiment 1 highlighted the role of inter-attribute trade-off difficulty, a concept distinct from traditional definitions of incommensurability, which typically treat commensurability as a binary variable-either allowing or disallowing trade-offs entirely. In contrast, we operationalized inter-attribute tradeoff difficulty as a continuous variable, capturing gradations in how difficult it is to compare attributes. Experiment 2 not only blurred the distinction between numerical and perceptual domains but also leveraged findings from education and mathematical cognition research on fractions to manipulate the attraction effect. Together, these experiments deepen our understanding of context effects by revealing a key cognitive mechanism behind the phenomenon, reinforcing that superficial distinctions between numerical and perceptual contexts are less consequential than previously thought. A direct application of these findings lies in consumer marketing, where tailored packaging and labeling can harness decoy effects to influence consumer choices. Ultimately, our results support the idea that higher inter-attribute trade-off difficulty facilitates the attraction effect—both by increasing the difficulty of choice between targets and competitors and by introducing asymmetries in pairwise comparisons between target-decoy and competitor-decoy pairs, corroborating the pairwise comparison argument in choice models.

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