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# A theoretical and experimental investigation of the role of mutual inhibition in shaping choice

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## Abstract

When studying value-based decision making, we typically focus on understanding how people choose one option from a set to the exclusion of other options in that set (e.g., choosing from a menu). Popular models of decision making likewise assume some form of competition between options to account for this element of *choice exclusivity*. Studying choices that relax this exclusivity property (e.g., choosing from a buffet) could provide a critical test of these models, as well as novel insights into the range of decision making we engage with in our daily lives. Here, we developed a novel task that compares exclusive (menu-like) choices to non-exclusive (buffet-like) choices, and used this task to test predicted computational mechanisms for choice exclusivity. Across two studies, we found that exclusive and non-exclusive choices were similarly accurate and similarly influenced by the relative values of the options (faster and more accurate the larger the value spread), but at the same time non-exclusive choices were overall much faster and demonstrated a greater speeding effect with higher overall (average) set values than exclusive choices. We show that these dissociable behavioral patterns are predicted by a sequential sampling model in which evidence accumulation is less competitive (more race-like) for non-exclusive relative to exclusive choices. We also demonstrate downstream influences of choice exclusivity on affective experiences, showing that participants experience exclusive choices as more conflicting than non-exclusive choices, particularly when choosing among higher value options. Our studies validate a novel paradigm for examining the impact of choice exclusivity on the dynamics and subjective experiences of decision making. In doing so, we lay the groundwork for new approaches to tease apart the processes that make our choices better from those that make our choices (unnecessarily) hard.

**Keywords:** value-based decision making, mutual inhibition, choice conflict, evidence accumulation models

# 1 Introduction

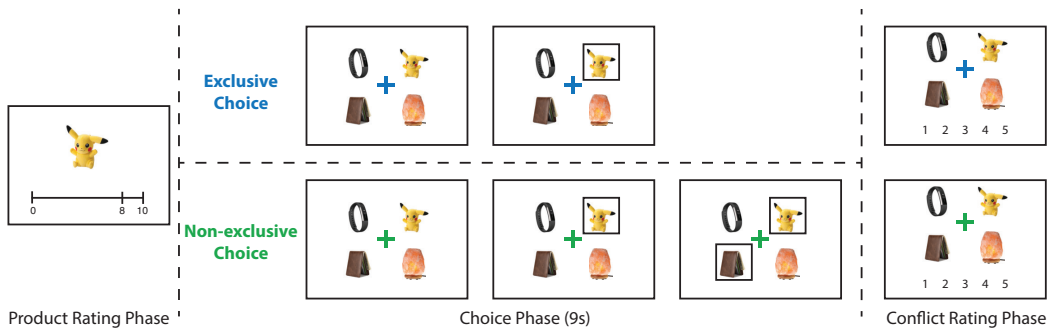
Previous studies on value-based decision making typically focus on types of choices where choosing one option precludes choosing any of the others (for example, choosing a dish from a restaurant menu). Most existing models of choice likewise assume some form of competition (e.g., mutual inhibition) between options to account for choice exclusivity [1, 2]. In contrast, fewer studies have explored the decision-making process in the choices where the mutual exclusivity between options is relaxed (for example, choosing food from a buffet).

In typical exclusive choices, people are faster, more consistent, and choices feel less costly when the relative value of the best option compared to the alternatives is greater. As the overall (average) value of their options increases, people are also faster but experience choices as more costly [3, 4]. These and other studies suggest that such patterns result from competition that occurs among options under consideration. However, to study this competitive process, past work has primarily focused on varying the inputs to the choice (i.e., the values of one’s options) rather than the nature of the competition between those options. Evidence accumulation models can generate distinct predictions regarding how choices among an identical option set should vary depending on the level of competition between those options, for instance when comparing the menu and buffet situations above. However, such predictions have yet to be tested, largely due to limitations of existing decision-making paradigms. As a result of this gap, little is known about how the dynamics of a value-based choice, and the experience of making this choice, change when the level of competition between the options is reduced.

To address these questions, we developed a novel task that compares exclusive (menu-like) choices to non-exclusive (buffet-like) choices, and used this task to explore the mechanism of choice competition. Across two studies (one in-lab, one online), we investigated how relaxing choice exclusivity modulates choice behavior and subjective experiences of choice conflict, and showed that the patterns of changes we observed (e.g., faster but similarly accurate responses during non-exclusive choice) can be accounted for by decreasing competition between options in a Leaky Competing Accumulator model (LCA)[5]. These findings provide novel insights into the range of choices we engage with in our daily lives.

# 2 Methods and Material

**Participants.** 17 participants (4 females, 13 males; age =  $20.5 \pm 0.5$  ys) participated in Study 1 (in-lab) , and 74 participants were recruited for Study 2, an online replication study on Prolific. Participants were excluded from our analysis based on the following criteria: (1) to ensure that participants’ product ratings prior to the choice task cover the full range of the liking scale, we excluded participants whose standard deviation of their product ratings was too low ( $SD_{value} < 1$ ) or too high ( $SD_{value} > 4$ ); (2) to ensure compliance with the task instructions, we calculated participants’ choice consistency within the easy trials (defined as trials with value difference greater than the within-participant median), and excluded participants whose mean accuracy in easy trials was less than 30% or whose proportion of choosing the worst product in easy trials was greater than 15%; (3) we also excluded participants with too low variance in their conflict ratings ( $SD_{conflict} < 0.5$ ). This resulted in a sample of 51 participants for Study 2 (25 females, 26 males; age =  $37.7 \pm 10.7$  ys) and no exclusions for Study 1. The qualitative patterns reported in this paper hold when we include all 74 Study 2 participants.



**Figure 1. Task paradigm.** In Phase 1, participants rated how much they would like to have each product. In Phase 2, participants saw sets of four products and were asked to choose the one they like best. On exclusive choice trials, the trial then ended. On non-exclusive choice trials, participants were allowed to select as many additional products as they liked. In Phase 3, participants saw the Phase 2 option sets again and rated the level of conflict they experienced when making their choices.

**Procedure.** Our experiment consisted of three phases (Figure 1). In Phase 1, participants viewed a series of products (in-person: 359, online: 200) and were instructed to rate how much they would like to have each one, by clicking on an analog liking scale from 0 (not at all) to 10 (a lot). In Phase 2, participants made choices (in-person: 160, online: 120) among sets of four products. On *exclusive* choice trials, participants were allowed to choose one product from the choice set. Once they clicked on this product, a box appeared around it and they proceeded to the next trial. On *non-exclusive* choice trials, participants were able to continue selecting as many options as they preferred after they chose the first one. The two choice conditions were intermixed, occurred with equal likelihood, and were cued by the color of the fixation cross in the middle of the screen (blue for exclusive choices and green for non-exclusive choices). In both conditions, participants were given up to 9s to complete each trial and, importantly, were instructed to always start by selecting their favorite option out of the set. In Phase 3, participants viewed each choice set again and rated the amount of conflict they felt when facing each set on a 5-point scale.

**Behavioral Data Analysis.** For the choice phase, we analyzed reaction time (RT) and choice consistency (whether the highest-rated option was selected) for the first choice in each condition with linear mixed effect regressions (R package lme4). All regressions include the overall (mean) value of the choice set, the value difference (quantified as the difference between the value of the highest-rated product and the mean value of the remaining products), and trial order, with random (subject-specific) intercept and slopes for each variable. When analyzing conflict ratings, our linear mixed effect regression included the same predictors, as well as an additional quadratic term for overall value[6].

**Simulation.** We applied the Leaky Competing Accumulator model (LCA; Figure 4A)[5] to simulate the influence of choice exclusivity on behavior. In the LCA model, leaky accumulators, one for each option, accumulate evidence until the first accumulator reaches a decision boundary (here implemented as collapsing, starting at  $a$  and linearly collapsing to 0 at the choice deadline) and induces a response. The first boundary-crossing time and the corresponding option are recorded as the response time and the choice. At each time step the accumulation process advances as

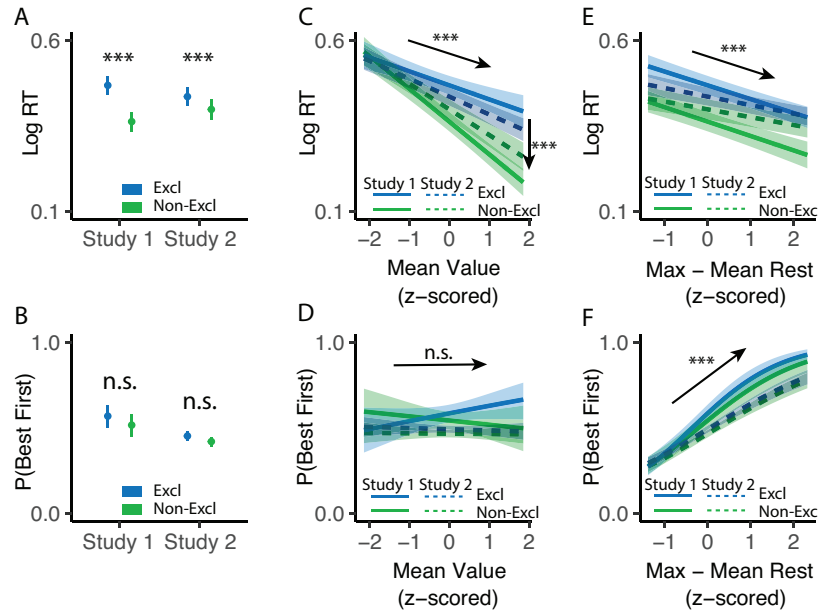
$$dy_i = (-ky_i - m \sum_{j \neq i} y_j + gV_i)dt + cdW$$

where  $g$  is the gain of input,  $k$  denotes the decay of the leaky accumulator,  $m$  represents the mutual inhibition from other accumulators,  $V_i$  is the option value, and  $cdW$  is the Gaussian random noise with mean 0 and variance  $c^2dt$ . We fixed all parameters ( $k, g, a, c$ ) except for mutual inhibition  $m$ . We simulated the distribution of response time and accuracy for different combinations of option values across a range of mutual inhibition levels. We then performed the same regressions on these simulated data as for the empirical data (e.g., regressing simulated RT and accuracy on overall value and value difference; Figure 4) to compare those findings qualitatively with those observed across our experimental conditions (Figure 2).

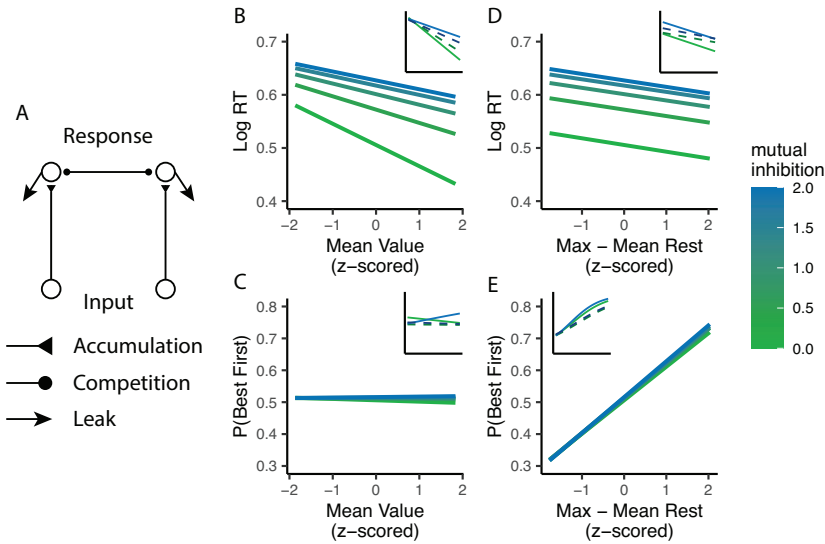
### 3 Results

**Behavioral Results.** Across both studies, we found that people responded faster for non-exclusive relative to exclusive choices (Study 1:  $F(1, 14.8) = 43.6, p < .001$ ; Study 2:  $F(1, 49.2) = 38.5, p < .001$ ; Figure 2A). This increase in response speed was not associated with a reliable decrease in choice accuracy (Study 1:  $Chisq(1) = 1.9, p = 0.17$ ; Study 2:  $Chisq(1) = 1.5, p = 0.23$ ; Figure 2B). Consistent with previous studies (e.g., [4]), participants in both conditions were faster to choose as the overall value of the choice set increased (Study 1:  $F(1, 12.0) = 97.2, p < .001$ ; Study 2:  $F(1, 32.6) = 196.1, p < .001$ ; Figure 2C). Importantly, though, overall value exerted a stronger influence on RT (i.e., demonstrated a steeper slope) for non-exclusive relative to exclusive choices (Study 1:  $F(1, 21.7) = 37.2, p < .001$ ; Study 2:  $F(1, 50.7) = 18.3, p < .001$ ; Figure 2C). Overall value did not influence choice accuracy in either study (Study 1:  $Chisq(1) = 0.8, p = 0.37$ ; Study 2:  $Chisq(1) = 0.3, p = 0.58$ ; Figure 2D). Also consistent with previous research, participants were faster (Study 1:  $F(1, 25.0) = 127.4, p < .001$ ; Study 2:  $F(1, 57.1) = 92.9, p < .001$ ; Figure 2E) and more accurate (Study 1:  $Chisq(1) = 117.9, p < .001$ ; Study 2:  $Chisq(1) = 273.8, p < .001$ ; Figure 2F) in making these initial choices the higher the relative value of the best option in the set. However, neither of these effects varied by choice condition (Figure 2E-F).

**Model Simulation.** Our simulations replicate the behavioral patterns we observed in Studies 1-2. Consistent with overall differences in choice behavior between exclusive and non-exclusive choice (Figure 2A-B), reducing mutual inhibition in the LCA reduces the median response time but does not influence the mean accuracy (Figure 3B-C). Lower mutual inhibition is also associated with a stronger effect of overall value on response time (Figure 3B), as we found empirically when choice exclusivity was relaxed experimentally (Figure 2C). Conversely, varying mutual inhibition does not modulate the correlation between value difference and response time (Figure 3D), and only weakly influences the influence of overall value and value difference on accuracy (Figures 3C and 3E), consistent with our findings across the relevant conditions (Figures 2E, 2D, and 2F). Taken together, our simulations suggest that our empirical findings can be accounted for by reduced competition during evidence accumulation. Compared to exclusive choices, non-exclusive choices seem to be associated with a less competitive and more independent (race-like) evidence accumulation process.



**Figure 2. Influence of choice exclusivity on speed and accuracy of first choices.** (A-B) Compared to exclusive choices (blue), people made faster and similarly accurate decisions in non-exclusive choices (green). (C-D) People were faster to choose when the overall value of a choice set was higher. This speeding effect was greater for non-exclusive relative to exclusive choices. Overall value did not significantly influence choice accuracy. (E-F) People chose faster and more accurately the greater the difference between the best option and the others. These effects did not differ across conditions. Error bars show 95% confidence intervals. n.s.:  $p > .05$ ; \*\*\*:  $p < .001$ .



**Figure 3. Comparison between simulation and empirical findings.** (A) Schematic of the LCA model used for simulations. (B) As mutual inhibition (competition) decreases, choices are faster overall, and demonstrate a stronger speeding influence of overall value. (C-E) Variability in mutual inhibition does not alter the relationship between reaction time and value difference (C), nor the relationships between accuracy and overall value (D) or value difference (E). Insets in Panels B-E show associated empirical findings from Figure 2.

**Choice Conflict.** Consistent with previous observations[6], we found that during exclusive choice people experience less conflict the greater the difference was between the best option and the others (Study 1:  $F(1, 17.6) = 22.1, p < .001$ ; Study 2:  $F(1, 37.3) = 4.2, p = 0.047$ ; Figure 4A), and that conflict has a U-shaped relationship with overall value, such that participants experience the most conflict when the options are generally very good (cf. approach-approach conflict)

and when the options are generally not good (cf. avoid-avoid conflict) (Study 1:  $F(2, 13.1) = 10.4, p = 0.002$ ; Study 2:  $F(2, 41.0) = 14.0, p < .001$ ; Figure 4B).

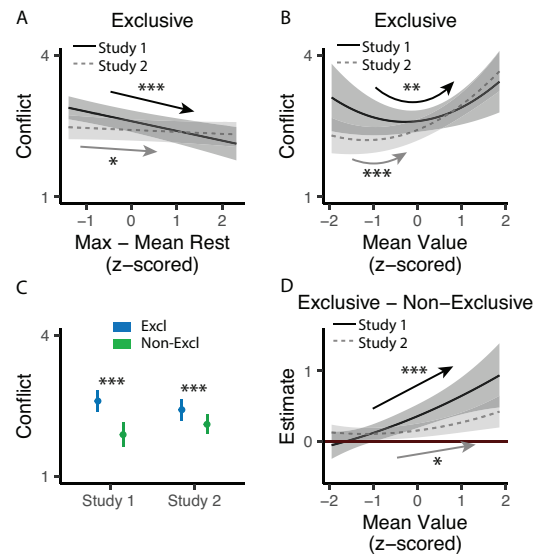
Examining these subjective experiences during non-exclusive choice, we first found that participants overall experienced significantly less conflict during these choices relative to when they were engaged in exclusive choice (Study 1:  $F(1, 16.6) = 17.5, p < .001$ ; Study 2:  $F(1, 49.1) = 13.5, p < .001$ ; Figure 4C). We also found that choice exclusivity also altered the influence of overall value on subjective experiences of conflict (Study 1:  $F(2, 12.6) = 17.2, p < .001$ ; Study 2:  $F(2, 61.8) = 4.2, p = 0.019$ ; Figure 4D). In particular, we found that participants no longer experienced the same increases in choice conflict when choosing between high-value items (perhaps because they could now select more than one) but they continued to experience similar levels of conflict when choosing between low-value items (perhaps because they are still being forced to choose at least one of them).

## 4 Conclusion and Future Work

In the current study, we developed a novel paradigm to extend research in value-based decision making to a greater variety of real-world forms of choice. The paradigm was validated in two independent populations. In both in-lab and online settings, we observed reliable main effects of choice exclusivity on the speed of decision making and the experienced conflict.

We found that when typical exclusivity constraints were relaxed (simply by allowing participants the option of later selecting more items from a choice set), participants chose faster and experienced less conflict doing so, but were no less accurate. This is particularly notable given that participants had identical goals when making their first choice in both conditions (i.e., to choose the best item in the set). We also found that the overall value of the option set had a larger speeding effect for non-exclusive relative to exclusive choices. Our model simulations show that these and other choice patterns during our task can be accounted for by varying the level of mutual inhibition across options as a person accumulates evidence for each of their options.

Future work will use this model to make quantitative comparisons to predicted patterns of behavior and choice conflict, and to compare it with alternative models, including those that attempt to account for choice exclusivity effects by varying other model parameters such as response threshold (though note that threshold differences alone would predict accuracy differences that we failed to observe).



**Figure 4. Experienced conflict in decision making.** When making exclusive choices, participants experienced (A) less conflict as value difference increased; and (B) more conflict when overall set value was especially low or especially high. Relative to exclusive choices, non-exclusive choices (C) engendered less conflict overall; and (D) attenuated experiences of conflict particularly for the highest-value choice sets. Error bars show 95% confidence intervals. \*:  $p < .05$ ; \*\*:  $p < .01$ ; \*\*\*:  $p < .001$ .

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