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Similarity and decision time in preferential choice

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Abstract

Choice option similarity is a key contextual variable in multiattribute choice. Based on theories of preference accumulation, we predicted that decision times would be longer when the available choice options were similar compared with when they were dissimilar, controlling for the relative desirabilities of the options. We tested for the relationship between similarity and decision time in an experiment involving incentivised binary choices between items of equivalent desirability and found that our predictions were confirmed. Our results show how the effects of contextual factors on key decision variables can be accurately predicted by existing computational theories of decision-making.

Keywords

Decision time; choice; sequential sampling; similarity

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Introduction

Models of preference accumulation provide a rigorous framework with which to study multiattribute choice processes. These models assume that decision makers sequentially and stochastically attend to the attributes of the available options during the decision. The relative values of these options on the attribute attended to at a given time period are used to update preferences. This continues until the preference for one of the options crosses a threshold. That option is then chosen by the decision maker, and the time taken to reach the threshold is assumed to be proportional to the overall decision time (see Busemeyer & Rieskamp, 2014 for a recent overview and discussion).

Preference accumulation models possess desirable statistical and neurobiological interpretations (e.g., Gold & Shadlen, 2007), and variants of these models are used to describe decision-making in low-level domains (e.g., Ratcliff & Smith, 2004). Importantly, preference accumulation models are able to account for a range of contextual determinants of choice probability in multiattribute choice tasks, including decoy effects, reference point effects, attention, and choice deferral effects (Bhatia, 2013; Bhatia & Mullett, 2016; Diederich, 1997; Krajbich, Armel, & Rangel, 2010; Roe, Busemeyer, & Townsend, 2001; Trueblood, Brown, & Heathcote, 2014; Usher & McClelland, 2004). They are also able to describe the relationship between decision time and various features of the choice task. For example, the accumulation of relative option values leads to longer decision times when the available choice options are comparable in terms of their desirability. As choices with equally desirable options are more difficult, preference accumulation models naturally predict that harder decisions are slower.

Preference accumulation models also make another, somewhat less intuitive, prediction: decision times are longer when the choice involves options that are highly similar compared with options that are highly dissimilar, even when the desirabilities of the options are held constant. The sequential sampling assumption underlying most preference accumulation models (see, for example, Diederich, 1997 or Roe et al., 2001) imposes dynamic dependencies between the preferences of options based on the similarities in their attributes. For this reason, choices between options that share few attributes (or have very different amounts of the various attributes) involve very large

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fluctuations in relative preferences if the attributes are sampled one after the other. This is in contrast to choices between options that share many attributes (or have very similar amounts of the various attributes) and are thus associated with much smaller fluctuations in relative preference. Keeping the decision threshold and the relative desirabilities of the options fixed, smaller fluctuations in relative preferences obtained with choice options that are similar lead to longer threshold crossing times and thus slower choices.

As an example, consider a choice between a tasty but unhealthy chocolate bar and a healthy but bland nutrition drink (highly dissimilar snack items). At a given time step, decision makers may consider the tastiness of the choice options. If so, their preference for the chocolate bar over the nutrition drink would experience a large increase, leading to a high likelihood that the decision threshold favouring chocolate is crossed. Alternatively, decision makers may consider the healthiness of the choice options. If so, their relative preference for the chocolate bar over the nutrition drink would experience a large decrease, leading to a high likelihood that the decision threshold favouring the nutrition drink is crossed. In either case, a large probability of crossing the decision threshold at each time step generates quick decision times. Now consider replacing the nutrition drink with a second type of chocolate bar that is tasty and unhealthy but, overall, equally desirable as the nutrition drink. In this setting, the relative and absolute desirabilities of the options are held constant, but the similarity of the options is changed. In such a choice, attending to either tastiness or healthiness would generate a small fluctuation in the relative preference for the chocolate bars. This would lead to a relatively low likelihood of a decision threshold being crossed, and correspondingly, generate longer decision times.

The dynamic dependencies in the relative preferences of choice options, generated by the sequential attribute sampling mechanism, have important theoretical implications. They allow preference accumulation models to account for violations of the proportionality and strong stochastic transitivity axioms in multiattribute choice generated by varying choice option similarity (Roe et al., 2001). When combined with other psychological mechanisms, they are also able to predict numerous similarity-based moderators of context effects (Bhatia, 2013; Bhatia & Mullett, 2016; Diederich, 1997, 2003; Roe et al., 2001). In related domains, such as risky choice, this mechanism allows preference accumulation models to generate violations of stochastic dominance and to display sensitivity to the covariance in the payoffs of the available options (Andraszewicz, Rieskamp, & Scheibehenne, 2015; Busemeyer & Townsend, 1993; Diederich & Busemeyer, 1999).

Despite the key theoretical role of the sequential sampling assumption in preference accumulation models, the relationship between decision time and similarity predicted by this mechanism has not, to our knowledge, been previously tested. Our goal, in this article, is to perform such a test. For this purpose, we conducted an experiment offering participants incentivised binary choices between everyday snack items. Some of the choices in our experiment involved items that were highly similar (were from the same product categories), whereas others involved choices between items that were highly dissimilar (were from different product categories). Participants also provided desirability ratings for each of the options prior to making their choices, and we tailored the choice problems for each participant to ensure that there were minimal differences in the desirabilities of the options across the choice problems. Thus, we were able to test for the effect of similarity on decision time, keeping the difficulty of the choice problems constant.

Methods

In total, 41 participants, recruited from an experimental subject pool at The University of Warwick, performed this experiment for monetary compensation in an experimental laboratory. The experiment was performed on a computer interface using the MATLAB Psychtoolbox program.

Our design was based on the experiments of Krajbich et al. (2010). As in their protocol, there were two parts: in the first part, each participant rated the desirability of 50 snack items on a scale of 1-9. The snack items used in this experiment were taken from five different categories: crisps, fruit candy, sweet carbonated drinks, health and sports drinks, and chocolate candy, and there were 10 unique snack items in each category. Based on the desirability ratings in the first part of the experiment, we generated 100 snack item choice pairs. These choice pairs were constructed so that 66 of the choices involved items from different categories, and the remaining choices involved items from the same category. In addition, the pairs were restricted so that each snack item was not seen in more than six choices. Finally, we constrained the desirability differences in each pair to be less than or equal to three rating points.

The 100 choice pairs constructed based on each participant's desirability ratings were then administered to the participant in the second part of the experiment. The items in each pair were presented to the participants in a random order, with one choice pair on each trial. The position of the items in the choice pair (left or right) was randomised, and participants indicated their preferences for the items with keyboard presses. These choices were incentivised so that at the end of the experiment, one choice was selected at random and participants received their selected snack item in that choice.

For the purposes of the experiment, we used category membership to proxy similarity and generate trials with varying levels of similarity. To ensure that category membership was in fact correlated with similarity, we ran a second (online) study, in which we asked 300 participants from a similar participant pool (current UK university students recruited using the prolific academic platform) to rate the similarity between each pair of items in our experiment on a scale of 1 (*dissimilar*) to 9 (*similar*). Each participant made 100 similarity ratings (with the specific pair of items chosen at random). This generated an average of 24.64 similarity ratings for each of the trials used in our main experiment.

Results

Overall, our main dataset consists of 4,100 choices and decision times, across 41 participants. For each choice, we have a binary measure of category overlap between the available options (1 if both options belong to the same category and 0 otherwise), as well as a continuous measure of option similarity, generated by participants in our second study. We find that these two variables are positively associated with options from the same category having an average similarity rating of 6.40 (standard deviation [*SD*] = 0.99) and options from different categories having an average similarity rating of 2.87 (SD = 1.17) on a scale of 1–9. A regression of similarity on category overlap finds that these differences are highly significant, $\beta = 3.53$, $z = 95.52$, $p < .001$, confidence interval (CI) = [3.46, 3.61].

We also have participant ratings of the component options and thus a measure of the relative desirabilities of the options. Although we tailored choice problems for each participant to ensure minimal differences in desirability in any given problem (and thus an equal level of difficulty across all problems), there are still a total of 3,171 choices for which the available options have slightly different ratings (difference of between 1 and 3 points on the rating scale). We found that participants chose the option that they rated higher in 81% of these choices. This is statistically different to 50% (the random choice probability) when evaluated using a binomial test ($p < .001$), suggesting that participant ratings of the choice options provide a good measure of the underlying desirabilities (and thus choice probabilities) of the options.

Our main variable of interest is decision time, and we found that the mean decision time was 2,185 ms (SD = 2,133). We log-transformed decision time to control for outliers and non-normality and used regression analysis to test for the effect of option similarity on this variable. Our first regression examined choices between options without any desirability differences (i.e., options that were given the same rating in the first experimental task). This regression controlled for participant heterogeneity in decision time with random intercepts. It also permitted fixed effects in the intercept for each category, thereby allowing different categories to have different effects on decision time. These fixed effects allowed for an additive change to the intercept based on whether or not a given category was present in the choice set. This regression found a strong positive effect of the average similarity rating of a pair of options on the decision time for choosing between those options ($\beta = 0.04$, $z = 2.70$, $p < .01$, 95% CI = [0.01, 0.08]). This indicates that decision times are longer in choices between equally desirable options that are highly similar compared with equally desirable options that are highly dissimilar.

Our second regression attempted to test for the effect of similarity on decision time for all of our data simultaneously. As above, it controlled for participant and category heterogeneity with random and fixed effects, respectively; however, it also controlled for the difference in the desirability of the underlying options (decision difficulty). This was quantified by the absolute value of the difference in the participant's desirability ratings for the two options in each choice problem. The regression revealed a strong positive effect of similarity on decision time ($\beta = 0.02$, $z = 3.01$, $p < .005$, 95% CI = [0.01, 0.04]), controlling for differences in desirability. Unsurprisingly, the absolute difference in the desirability ratings was negatively associated with decision time ($\beta = -0.09$, $z = -11.48$, $p < .001$, 95% CI = [–0.10, –0.07]), indicating that decision times were shorter when one of the options was much more desirable than the other.

All of the above results also hold if we replace the similarity rating with the binary category membership variable ($p < .001$ for all regressions). In addition, these results hold if we include both the binary category membership variable as well as the similarity rating variable simultaneously ($p < .01$ for similarity rating and $p < .05$ for the category membership variables), suggesting that similarity does matter beyond category overlap. Our findings are also unchanged if we implement category fixed effects based on the categories of the chosen items rather than the categories available in the choice set ($p < .001$ for all regressions). In addition, our results are robust to alternate ways of controlling for decision time outliers and emerge when decision time is left untransformed with decisions taking longer than the 90th or 95th percentile decision removed. They also emerge when no outliers are removed ($p < .05$ for all tests). Figure 1 (left panel) presents a scatter plot of mean log decision times for participants in trials in which both options were rated as being similar or dissimilar (average similarity rating greater than or less than median similarity rating in the experiment). Figure 1 (right panel) presents an analogous scatter plot based on category overlap. As can be seen, most points lie to the right side of the 45° line, indicating that participants took longer in choices with items that were rated as being highly similar or were from the same category.

Discussion

Preference accumulation with sequential attribute sampling is a key feature of decision-making and a core

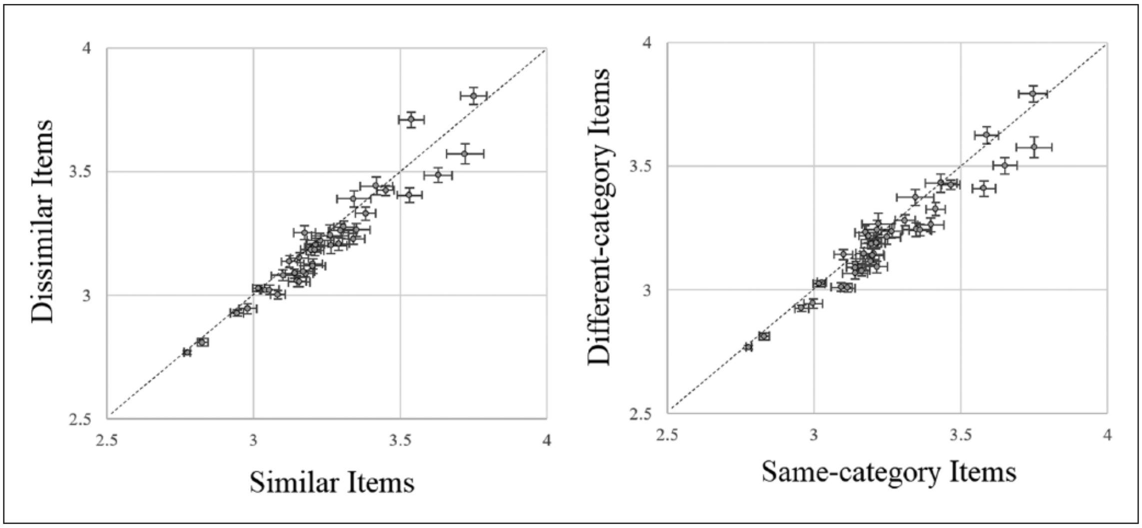

Figure 1. Scatter plot of average log decision times for our 41 participants for trials in which both items were rated as being similar (left panel) or were from the same category (right panel) versus trials in which items were rated as being dissimilar or were from different categories. Each point corresponds to a single participant, and error bars indicate ±1 *SE* for average log decision times for the corresponding participant. Overall, 82.5% (76%) of participants had longer decision times when options were rated as being similar (were from the same category), corresponding to points on the right side of the diagonal.

component of many cognitive theories of multiattribute choice (Bhatia, 2013; Diederich, 1997; Roe et al., 2001; Usher & McClelland, 2004). It induces correlations between the preferences of choice options, which have previously been used to explain a large number of behavioural findings, including changes in choice probability induced by the addition of irrelevant decoys, and the possibility of choice deferral (Bhatia, 2013; Bhatia & Mullett, 2016; Roe et al., 2001). In related domains, such as risky choice, preference correlations generated by sequential sampling have been shown to account for the effects of decision conflict, dominance, and payoff correlation (Andraszewicz et al., 2015; Busemeyer & Townsend, 1993; Diederich & Busemeyer, 1999).

Sequential attribute sampling also makes a clear prediction regarding the relationship between category overlap and choice option similarity: choices between options that are highly similar (which share many of their attributes) should involve highly correlated preferences, and thus slower decisions times, compared with choices between options that are highly dissimilar. This difference should emerge even when option desirability is controlled for. The goal of this article was to test this relationship using an adaptive design to minimise the differences in desirability between the available choice options. In our experiment, choices between similar choice options were associated with longer decision times compared with choices between dissimilar choice options.

Choice option similarity has been well studied, with considerable prior work on how decision makers judge the similarities between options and how this affects their decisions. Decision time is of course also extremely well studied, as it has important cognitive properties and key implications for practical applications of decision-making research (see Busemeyer & Rieskamp, 2014). By examining the effect of similarity on decision time, the results of this article not only showcase the predictive power of an important class of computational decision-making models but also rigorously demonstrate the relationship between two important decision variables.

There has been some prior work showing that settings with higher decision conflict are associated with longer decision times. The definition of conflict adopted in this work varies, and high conflict can refer to settings with small differences in option desirability (e.g., Berlyne, 1957) or settings involving approach-avoidance motivations (e.g., Lewin, 1951). Both of these effects of conflict are consistent with the predictions of preference accumulation theories. Some prior work has also defined conflict in terms of attribute trade-offs across alternatives (e.g., Chatterjee & Heath, 1996; Scholten, 2002; Tversky & Shafir, 1992). To our knowledge, this work has not examined the effect of trade-off size on decision time in forced choice tasks, although it has investigated closely related decision variables such as choice deferral and subjective measures of desirability. Overall, the effect of attribute trade-offs on these variables is mixed, although there are many settings in which higher trade-offs across attributes reduce conflict and decision difficulty (see Scholten & Sherman, 2006 for a discussion). Future work should attempt to replicate our results in settings with explicitly quantified attributes (rather than naturalistic objects such as snack items) to more rigorously establish the relationship between attribute similarity and decision time.

It would also be useful, in future work, to understand the effects of task-dependent determinants of similarity on choice probability and decision time. Similarity may, for example, be assessed differently in a choice setting (as in our main study) relative to a simple similarity rating setting (as in our online supplementary study). Likewise, different individuals may assess similarity differently based on differences in situational context (e.g., levels of thirst) or stable traits (e.g., taste and knowledge of different types of chocolates). Although our tests were unable to control for such factors, these limitations could be mitigated in future work by eliciting similarity ratings and choices as part of the same task.

Finally note that it is possible that the positive relationship between similarity and decision time, observed in this article, is a product of mechanisms other than sequential attribute sampling. Indeed, a number of preference accumulation models allow for choice option similarity to influence evaluative and comparison processes in addition to influencing preference correlations during the accumulation process. Cognitive theories of multiattribute choice that do not rely on an accumulation-based framework can also incorporate varying decision strategies as a function of choice options similarity (Payne, Bettman, & Johnson, 1988). Isolating the predictions of these various mechanisms, to better understand the relationship between similarity and decision time, is an important topic for future work.

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