Reevaluating revaluation: evidence for value construction during decision making

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Abstract

The speed and accuracy of value-based decisions conform to regularities of bounded evidence accumulation. However, the source of the samples of evidence remains unknown. One possibility is that internal evidence is derived from memory. In particular, that episodic memory retrieval may play a role in value construction during the decision process. We reasoned that if memory contributes to constructing preference, choice options may undergo revaluation as a consequence of the decision. We tested this using an algorithm that supposes the chosen and unchosen items change value by $\pm\delta$. The revised values better accounted for behavior (choices and reaction time) compared to the original values. We also show that this revaluation is not simply due to statistical artifact and that revaluation is more likely a product of the decision process itself, rather than a post-decisional process.

Keywords: cognitive dissonance; value construction

Background

Some decisions take more time than others. A common explanation for why such decisions take more time is that a commitment to a choice depends on the accumulation of evidence to a threshold, and when the evidence is weaker, more samples of evidence are required to achieve this criterion. This simple observation holds across many kinds of decisions, whether they are based upon perception of the environment (e.g., Usher & McClelland, 2001) or from internal values and preferences (e.g., Milosavljevic, Malmaud, Huth, Koch, & Rangel, 2010). For decisions based on external evidence, it is clear why more time might provide more samples of evidence (Gold & Shadlen, 2007). But for decisions about internal values and preferences it is unclear why this framework still applies. For value-based decisions, it remains unknown what is the source of the evidence, and why it should take more time to decide when options are close in value compared to when one choice option is clearly more valuable than the other.

One possibility is that value-based decisions depend on internal evidence that is derived from memory (Shadlen & Shohamy, 2016). Decisions between options of similar value require more evidence, and therefore take more time. Consistent with this view, we have shown that reaction times correlate more positively with BOLD activity in the hippocampus during value-based compared to perceptual decisions, specifically within voxels that were independently identified to be important for memory retrieval (Bakkour, Zylberberg, Shadlen, & Shohamy, 2018). However, this finding raises the question of how memory helps resolve near value decisions, and what the consequences of such a process are for the construction of value next time the same option is encountered. In particular, a well-known phenomenon in cognitive psychology is “cognitive dissonance” (Festinger, 1962). By this account, making a decision between two similar options leads to a subsequent change in value due to post-decisional processes. By contrast, the idea that memory may help resolve near-value decisions raises another possibility: memory mechanisms may be recruited to consider new dimensions (e.g. saltiness) until a clear preference is achieved. This would suggest that the deliberative process during a decision may entail construction of value and revaluation of the foods under consideration, which itself would change the value of the items.

These two possibilities both suggest that making a decision should lead to revaluation, but they make different predictions about how revaluation occurs: 1) cognitive dissonance suggests that revaluation should manifest only on a subsequent trial from when the choice was made (i.e. post-decision), 2) a constructive memory-based account predicts that revaluation should manifest during the decision process on the current trial (i.e. pre-choice execution).

To test these predictions, we used a task that is closely related to the free choice paradigm. The typical free choice paradigm makes use of only a single decision to test for subsequent value change. In our task, items were presented several times during a choice phase, allowing us to capture dynamics of revaluation over the course of the experiment. Much cognitive dissonance research has recently come under critique after a statistical artifact that plagues the free choice paradigm was identified (Chen & Risen, 2010). Because pairs of choice options are formed based on the participants' own personal subjective values – and those values are thought to be noisy measures – any change in value due to choice is likely a reflection of noise reduction and thus artifactual. We used simulations and permutation tests to show better accounts of behavior after revaluation than would be expected by artifact alone, and to differentiate the predictions of a post-decision versus pre-choice execution account of revaluation.

Revaluation improves fits

Participants took part in an auction procedure (Becker, Degroot, & Marschak, 1964) and provided us with a measure of subjective value for each of 60 food items ($V_{BDM_{1..60}}$). These V_{BDM} values were used to pair items such that $\Delta V = V_{BDM_i} - V_{BDM_j}$ varied. Participants were asked to choose the item they preferred on every trial during a choice phase that lasted for 210 trials.

To test for revaluation, we took advantage of the fact that each of the 60 foods were presented several times, paired with different items. We reasoned that if the decision led to a change in value, then the next time that item appears, its V_{BDM} value might be updated $\pm\delta$. The value would be incremented by δ ($V_i' = V_{BDM_i} + \delta$) if the item was chosen and reduced by this amount if it was rejected (Figure 1A). Although we assume the process arises during the deliberation leading to a decision, we use only the outcome of the decision as an indicator of whether the revaluation was an increment or a decrement. In the algorithm, the new values can only affect subsequent preference decisions between these items and another. We fit δ for each participant to minimize the deviance of a logistic choice function to the data. For all participants, the fit to the revised values V' was significantly better (Figure 1B, mean ΔBIC = 64.1, Wilcoxon signed-rank test, p < 0.0001). The combined loglikelihood is reduced by greater than two orders of magnitude compared to the fits to the choices based on the original V_{BDM} values. Critically, such improvement is not guaranteed by the fitting procedure. However, our task is closely related to the free choice paradigm and our algorithm may be susceptible to a statistical artifact that may explain our findings. This artifact was first identified by Risen & Chen (2010) and later highlighted by Izuma & Murayama (2013).

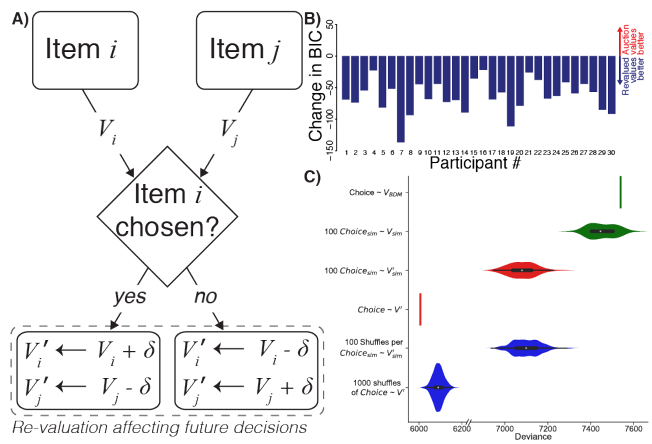

Figure 1: A) Schematic of the revaluation algorithm. B) Change in Bayesian information criterion for fits based on V_{BDM} vs. fits based on V' per participant. C) Deviance of the logistic fit to i. data based on V_{BDM} (green line), ii. 100 simulated datasets before revaluation (green violin), iii. the same 100 simulated datasets after revaluation (red violin), iv. data after revaluation (red line), v. 100 iterations of shuffled trial order for each of 100 simulated datasets after revaluation (top blue violin), vi. 1000 iterations of shuffled trial order for data (bottom blue violin).

Briefly, the argument is that the auction provides a noisy measure of the true latent value, which guide all choices. The participant's choices reveal (stochastically) their preferences, allowing us to better approximate the true latent values. We have simulated such artifactual revaluation and confirm that this could explain improvement in the deviance statistic of the logistic choice function (Figure 1C, ii compared to iii). Notice, (1) the improvement is much smaller than what we observe in data (Figure 1C, iii compared to i.), and (2) the degree of improvement does not depend on the order of the trials (Figure 1C, iii compared to v). Importantly, the deviance achieved in the real data in the order of the trials is more extreme than random permutations of the order (Figure 1C, iv compared to vi, permutation test, $p < 0.0001$). This is a sign that the values are actually changing as the experiment ensued from trial to trial.

Revaluation and cognitive dissonance

The permutation analysis above supports the idea that value is actually changing during the course of the experiment, but it does not differentiate between a revision of value to resolve the preference on the trial – that is, associated with deliberation on the trial – and a post-decision process whereby values change as a consequence of having made the decision and chosen the item, as in cognitive dissonance. Our revaluation algorithm actually models the latter cognitive dissonance scenario, because the updated value, V_i' only affects the next appearance of item i. But our hypothesis is that that values changed to affect the current decision. We adopt the shorthand $\Delta V_{post}'$ and $\Delta V_{pre}'$ to refer to the decision variable under the cognitive dissonance (post-decision) and deliberation accounts of revaluation (pre-choice execution), respectively.

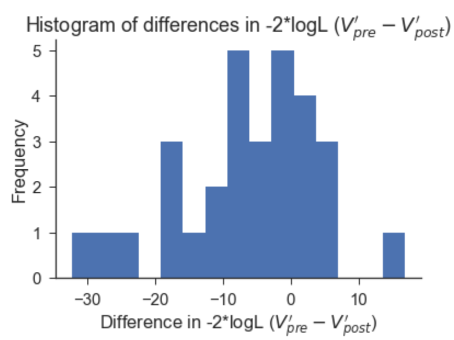

Figure 2: Histogram of differences in -2*logLikelihoods for fits based on $\Delta V_{pre}'$ and those for fits based on $\Delta V_{post}'$.

To compare these accounts, we compared the likelihoods of the reaction times rather than the deviance of the choice functions, as $\Delta V_{pre}'$ is always adjusted in a way that is favorable to the choice on that trial. We fit a bounded drift diffusion model using $\Delta V_{post}'$ and $\Delta V_{pre}'$ by maximizing the likelihood of each choice and RT. We then compared the likelihoods using the predicted RT that does not discriminate based on whether the choice is consistent with the sign of the $\Delta V'$. We find that $\Delta V_{pre}'$ better explains RT distributions than $\Delta V_{post}'$ (Figure 2, Wilcoxon signed-rank test, $p = 0.006$).

Taken together, these findings provide evidence in favor of the hypothesis that the deliberative process during decisions may involve value construction – perhaps involving episodic memory mechanisms well-suited for such a constructive process – offering an alternative to cognitive dissonance accounts of changes in value following choice, which are often thought to be post-decisional processes.

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