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How costs affect preferences: experiments on state dependence, hedonic state and within-trial contrast in starlings

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We examined how starlings, *Sturnus vulgaris*, adjust preferences to retrospective sunk costs in either time or work. Ideal decision-makers disregard sunk costs, but under some circumstances animals, like humans, prefer normally costlier rewards when they do not have to pay the costs. We argue that a possible explanation is state-dependent valuation learning (SDVL). The argument is that subjective value (hedonic state or fitness) is a decelerated function of energetic state, and energetic costs displace the subject's state towards conditions where the function is steeper and the subjective value of rewards is enhanced. We compared SDVL with within-trial contrast (WTC). WTC says that experiencing a food reward brings subjects to a baseline, constant, hedonic state, so that being in a more negative prereward mood causes a bigger positive displacement. SDVL focuses on energetic costs, while WTC focuses on any emotional dimension. We carried out three experiments that differed in the salience and dimension of the cost (time or work) and found overvaluation of costlier outcomes when the retrospective cost involved work (locomotory activity) but not when it involved only delays. When work was used as a cost, the effects of cost on preference showed strong stochastic transitivity. Our findings are consistent with studies in which energetic state was altered by deprivation rather than cost, and may help to explain why studies of WTC have had unreliable outcomes.

We present a study linking decision-making mechanisms to their functional consequences, focusing on how previously experienced costs affect future preferences. The relation between consequences of actions and later preferences is crucial to both causal and normative (optimality) modelling, but it is widely known that empirical observations of how animals deal with costs often do not match theoretical predictions. Such discrepancies give salience to the mechanisms that assign (negative) value to each cost and combine them with gains, and raise issues about the selective history of value-assigning psychological mechanisms. We define costs as unfavourable changes in the state of any actor consequent on a given action, and gains as favourable state changes. From an evolutionary point of view, state ought to be seen as the set of values of variables that determine the expected future reproductive success of an organism (its Darwinian fitness), but given the obvious difficulties that using such a construct has, proxies such as the organism's energetic reserves, its health or its hedonic condition (assumed to reflect fitness) are used in designing and testing theoretical ideas. As we explain below, we discuss situations in which 'consequences' are identified with measurable modifications of energy reserves and we rely on the fact that fitness or hedonic changes do not need to be linear functions of these consequences. Most normative models use such definitions, and they make predictions by identifying the action that maximizes the difference (or sometimes the ratio) between gains and costs in either energy reserves or some other proxy for fitness.

Departures from normative expectations, often attributed to the actors' 'mishandling' of costs, are frequently observed among both human (e.g. Simonson & Tversky 1992; Tversky & Simonson 1993; Wedell & Pettibone 1996; Gigerenzer et al. 1999) and nonhuman decision-makers (e.g. Shafir 1994; Hurly & Oseen 1999; Wiegmann et al. 2000; Waite 2001; Bateson 2002; Bateson et al. 2002; Bateson 2003; Shafir et al. 2002; reviewed in Real 1996; Houston 1997). We experimentally examined how time (lost opportunity) or working costs affected preferences between food sources for starlings, *Sturnus vulgaris*, working for food in the laboratory. We focused on the claim that, in many situations, retrospective costs (namely those already incurred at the time of the choice) seem to enhance the subjective value that actors attribute to the consequences that follow, a property that is not compatible with maximizing either difference or ratio between gains and costs.

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Sunk Costs and State-dependent Valuation Learning

Our conceptual starting point is the frequently asserted idea that only prospective costs should determine decisions. The theoretical notion that optimizing or rational agents should ignore irrecoverable, previously incurred (sunk) costs is uncontroversial. A well-known biological application of this notion to reproductive decisions is the Concorde fallacy (Dawkins & Carlisle 1976), which points out that the value of an act of altruism towards a relative should only be dependent on the future contribution of the consequences of that action to the fitness of the actor, disregarding previous investment by the actor in the recipient. On a shorter timescale, however, sunk costs are frequently found to affect choices in both humans and nonhumans (e.g. Arkes & Blumer 1985; Arkes & Ayton 1999; Kacelnik & Marsh 2002; Navarro & Fantino 2005). This is often explained by suggesting that retrospective costs in nature can be good predictors of prospective ones; hence mechanisms sensitive to them are in fact adjusting the agent to deal with prospective costs (Sargent & Gross 1985). This explanation works well for reproductive or life history decisions that are often not subject to individual learning by repeated essays, but needs further elaboration to be applied to repeated, frequent choices, where reinforcement by consequences is involved in establishing the subjective value of each option.

To describe the problem in a functional and learning framework, we consider a subject repeatedly facing cycles (or chains) of events of differing types (see Fig. 1a). Such cycles are metaphors for foraging cycles in which a consumer first detects signs of a possible prey, then chases and consumes it, and finally experiences the associated consequences. 'State' R here is identified with energetic reserves. A chain of type i starts when a subject in state R_i^0 detects a stimulus S_i^1. Acting towards this stimulus (equivalent to the chase) leads, after some time or work costs C_i^1, to the onset of a second stimulus S_i^2 (equivalent to catching the prey). Acting towards S_i^2 causes a further cost (C_i^2; not shown in figure) and an outcome (O_i) that is a gain, or favourable change in state, of magnitude ΔR_i. We assume that the agent has an internal function $H(R)$, which is a proxy for fitness and can be usefully seen as hedonic state. H is an increasing, decelerated function of R. We can now compare two types of chains, each characterized by the subject's state R_i^0 at which S_i^1 is encountered, the costs C_i^1 and C_i^2 and the outcome O_i. We use this notation to discuss a case when only the initial cost C_i^1 differs between chain types, namely $C_A^1 > C_B^1$, with all other variables identical between chains. The overall net consequence of chain A will be a lower end state than that of B, because they differ only in initial cost ($R_A^0 - C_A^1 - C_A^2 + \Delta R_A < R_B^0 - C_B^1 - C_B^2 + \Delta R_B$). A maximizing agent given a choice between S_A^1 and S_B^1 should prefer the latter, because it signals entering a chain with better overall end state, but should not show any preferences between S_A^2 and S_B^2, because at the time of such choice the only differences are the already paid initial costs.

However, as Fig. 1a illustrates, because of the joint effect of the bigger cost and the concavity of the function H, psychological considerations lead to predicting a preference for S_A^2 over S_B^2. This is because the higher sunk cost in chain A means that the level of reserves at which S_A^2 is encountered is lower, and since the function H is decelerated with respect to R, the gain in H caused by the equally sized outcomes will be larger for A than for B. In the experience of the subject, S_A^2 is typically followed by a larger change in H than S_B^2 even though both cause the same change in R.

The idea that animals may attribute value to their options as a function of the experienced fitness or hedonic state change at the time of acting has been labelled state-dependent valuation learning (SDVL, viz. Pompilio et al. 2006). In the previous example the effects were due to amount of time or work preceding the critical choice

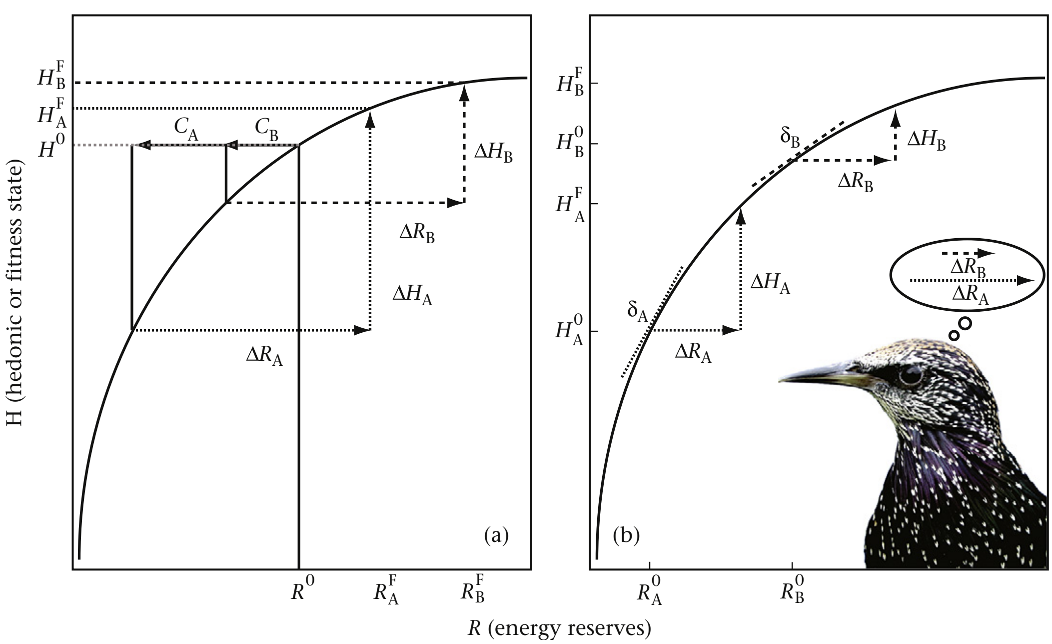

Figure 1. (a) State-dependent valuation learning when the cost of two options met within the same context differs. Hedonic or fitness state (H) is a decelerated function of energetic state (R). The consumer meets either of two possible options (A and B) in a given initial state R^0. Responding to option i leads to a cost (C_i) that displaces the energetic state leftwards. Once either cost is paid, the subject experiences the corresponding outcome as well as any further costs, and this displaces its state by a net amount (ΔR_i). Although in this example ΔR is identical between options ($\Delta R_A = \Delta R_B$), the different initial costs (here $C_A > C_B$) cause a differential gain in subjective value, so that $\Delta H_A > \Delta H_B$. If learning is driven by ΔH the subject will prefer A to B even if the final state is worse for that option ($H_A^F < H_A^F$). (b) State-dependent valuation learning when state is not dependent on cost. Here, the consumer experiences two options that deliver the same magnitude of food (ΔR) at a low (R_A^0) or high (R_B^0) initial energetic state, respectively. In contrast with (a), here the initial states differ between the options, for instance because each prey type occurs in a different context or season. The increase in subjective value (ΔH) is greater for the option encountered in the leaner of the two initial states. This leads to future preference for the option associated with a poorer initial state. The marginal rate of the value-versus-state function at each initial state is indicated by the slopes of the tangents δA and δB. The figure also shows (inset) that overvaluation could also occur if state or the experienced hedonic gain distorts the memory for the net energetic gain associated with each of the rewards.