Trends in Cognitive Sciences

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Spotlight

Perceptual Decision-Making: Picking the Low-Hanging Fruit?

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How do we decide what we perceive? Obviously, we base our decisions on sensory evidence. However, a new and surprising study by Hagura *et al.* shows that our perceptual decisions are also biased by the action costs that are associated with our decisions.

Perceptual decision-making is not solely determined by the characteristics of the sensory stimulus, but is influenced by several factors such as expectation [1], reward [2], and previous history [3], which may all facilitate perceptual decision-making under uncertainty. A factor that has been mostly neglected in laboratory settings is that, in everyday life, making perceptual decisions between several options entails actions which can differ dramatically in their associated motor cost. For instance, imagine standing in front of an apple tree and searching for the reddest-looking apple to pick. Naturally, picking apples higher up in the tree requires more physical effort than picking low-hanging apples. Therefore, your decision about whether to pick a high- or low-hanging apple has consequences for the subsequently accruing motor costs. Does this difference in expected motor costs influence your perceptual decision about the color of the apples? That is, do you judge the low-hanging fruit as more red? We know that motor costs can bias the choice behavior in perceptual decision-making tasks [4] to maximize the expected utility of the choice [5], but it is unclear whether motor costs can affect the perceptual decision itself.

Hagura *et al.* [6] shed light on this question. They asked participants to indicate the direction of motion (leftward or rightward) of a cloud of moving dots, by moving one of two robotic manipulanda with their left or right hand, respectively. Unknown to the participants, the resistance for moving one of the manipulanda was gradually increased, while the other remained unchanged. In line with a previous study [4], Hagura *et al.* found that participants subsequently showed a tendency to avoid decisions for the motion direction that was associated with the energetically more-costly motor response. Crucially, after the induction of asymmetric motor response costs for manual responses, participants showed a similar bias when indicating their decisions vocally. This transfer of the bias onto decisions reported with a different effector – for which motor response costs were not manipulated – suggests that the repeated exposure to motor response costs associated with a particular decision can bias future perceptual decisions themselves. Thus, the manual-to-vocal transfer effect provides first evidence that motor costs are not necessarily integrated with perceptual decisions at the motor output stage, but that recent experience of motor costs can change how sensory input is transformed into a perceptual decision.

The current results suggest that motor costs can bias perceptual decisions before they are transformed into an effector-specific response. However, the exact stage along the visual processing stream at which this bias occurs is unclear. Motor costs could target an early stage of visual processing, biasing the sensory representation of visual input, or occur at a later stage, targeting a general, effector-unspecific decision stage. Using a drift-diffusion model approach [7], the authors found that their data were best explained by a model in which the motor costs change the decision bound that is used to make the decision, rather than the evidence accumulation process itself. This suggests that motor costs target a later decision layer, rather than the sensory representation, and distinguishes it from other processes such as attentional biases which affect the accumulation rate of sensory evidence [8]. An intriguing outstanding question, related to this issue, is whether motor costs can alter the appearance of visual stimuli (Box 1).

Do motor costs influence decision-making in a similar manner to rewards? To a first approximation, it looks like they do. For example, similar changes of the decision bound have been reported when introducing asymmetric rewards associated with particular decisions [2]. It will be interesting to see how the costs of action are integrated with other costs or rewards during the unfolding perceptual decision. Related to this, in the current study specific decisions about stimulus features were tightly coupled with specific motor actions, establishing a stable relationship between decisions and subsequent motor costs over time. The repeated exposure to this relationship may have facilitated a leakage of motor costs into the decision process itself. In everyday life, however, motor costs that follow perceptual decisions often change on a much more rapid timescale because they depend on many factors that change on a

Box 1. Do Motor Costs Alter Perceptual Appearance?

The finding that motor costs bias perceptual decisions raises the intriguing possibility that motor costs may change how we perceive the world. However, biases in perceptual decisions do not always reflect biases in perceptual appearance. For example, when people are asked to name the color of the ink of the word blue, their responses are biased by the irrelevant word – the famous Stroop effect. By trying the experiment on oneself, one can easily discard the hypothesis that the word 'blue' changes the appearance of the ink color. Instead, the bias arises due to a response conflict. Biases in perception and decision are often difficult to disentangle [12]. Interestingly, when separating them experimentally, they can be opposite in nature [13].

moment-to-moment basis. This may prevent a strong *a priori* mapping of decisions about stimulus features to motor costs, and requires *ad hoc* evaluations of costs of action. It will be interesting to see whether motor costs that change rapidly on a moment-to-moment basis affect perceptual decisions in a similar way.

The influence of motor costs on perceptual decisions sets the current bias apart from other recently investigated contextual biases for which previous motor responses bias current motor responses independently of previous perceptual decisions [9], and carry-over effects between subsequent decisions that are independent of motor responses [10]. Thus, the new finding emphasizes the importance of jointly considering all levels, from sensory input to motor response, when studying perceptual decision-making under realistic and complex settings.

The current study presents an important addition to the literature, demonstrating a further important contextual factor – the cost of action – to consider when investigating perceptual decision-making. This changes the traditional view of perceptual decision-making: actions are not only the output but also influence earlier stages of processing, in line with theories of cortical function that underscore the importance of reciprocal pathways between perception, cognition, and action [11]. The current work will therefore have important implications for developing perceptual decision-making models in a naturalistic and ecologically valid context.

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