Studying the Neural Basis of Outcome Anticipation in Goal-Directed Behavior: An Investigation of Self-Control, Instrumental Learning, and the Effects of Stress

by

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Summary

Adaptive, goal-directed decision-making requires anticipating the potential future consequences of our actions. That is because outcome anticipation enables us to align behavior with desired action outcomes. Outcome anticipation can occur at different time scales (e.g., immediate vs. long-term outcomes) and levels of abstraction (e.g., specific outcomes such as a light being turned on upon pressing a light switch vs. abstract outcomes such as having a higher chance at getting a desired job upon doing well in an exam) and is susceptible to situational influences, for example, to the experience of acute stress.

Let us consider, for instance, a dieter facing an unhealthy but tasty snack who needs to anticipate that giving in to this temptation might result in immediate pleasure while being detrimental to the long-term goal of losing weight. Past research has generated important insights into the neural and behavioral processes underlying the successful exertion of self-control in this kind of decision-making scenario, and there is evidence that acute stress significantly interferes with these processes. However, systematic replication studies and studies investigating the neural basis of stress effects on self-control are rare and limited to the domain of food choices. Outcome anticipation has also been studied in the context of instrumental contingency learning. Here, classical experimental paradigms have tested the degree to which participants show outcome-guided behavior when previously learned action outcomes are selectively devalued. Such outcome devaluation paradigms have been used to delineate the neural basis of a goal-directed system supporting behavior guided by anticipated action outcomes and a habitual system supporting stimulus-driven response behavior. Although there is some previous evidence that anticipatory outcome encoding in the brain determines goal-directed behavior during outcome devaluation, fMRI evidence linking this effect to specific brain areas is rare.

Using functional magnetic resonance imaging, this dissertation studied the neural basis of outcome anticipation in goal-directed behavior to address the aforementioned gaps in past research. Specifically, this thesis addresses the following research questions:

1) What are the neural mechanisms supporting outcome anticipation and, consequently, outcome-guided decision-making in goal-directed behavior?
   a) What are the neural mechanisms of anticipating short- and long-term action consequences during self-controlled decision-making?
   b) Can large-scale functional network connectivity at rest predict self-controlled behavior guided by anticipated long-term action outcomes?
   c) Are there brain regions that support outcome-guided goal-directed behavior via encoding anticipatory action outcomes during instrumental learning?
2) Does stress affect neural mechanisms of outcome anticipation and, consequently, outcome-guided decision-making in goal-directed behavior?
   a) Does acute or chronic stress affect self-controlled behavior guided by anticipated long-term action outcomes?
   b) Does acute or chronic stress alter the neural encoding of anticipated action consequences during self-controlled decision-making?

To address these questions, two neuroimaging projects summarized in three studies were conducted.

Study 1 combined neuroimaging with a stress induction protocol and the collection of biomarkers of acute and chronic stress to investigate neural mechanisms of self-control and their modulation by acute and chronic stress. Here, the previously reported role of the ventromedial prefrontal cortex in encoding decision values during self-controlled decision-making was replicated. However, contrary to our hypothesis, the encoding of anticipated action short- and long-term consequences in this region did not significantly predict self-control success. Furthermore, there was evidence for activation in the brain's cognitive control and conflict monitoring systems during self-control conflict. Finally, acute stress was associated with alterations in the neural encoding of anticipated short- but not long-term action outcomes, changes in functional connectivity between the ventromedial and dorsolateral prefrontal cortex, and in conflict-related neural activation. However, the neural effects of acute stress were not accompanied by behavioral changes in self-control performance.

In Study 2, resting-state functional connectivity data were analyzed to conceptually replicate the previous finding that a network interaction index indicating integration of the salience network with the central executive network and disintegration of the salience network with the default mode network at rest positively predicted self-control success. In two independent datasets, there was evidence for the exact opposite effect. This result highlights the potential role of the default mode network in self-control, as well as methodological challenges concerning the analysis of resting-state functional connectivity and the measurement of self-control.

In Study 3, neuroimaging was combined with an instrumental outcome devaluation task. Here, a region in the left dorsolateral prefrontal cortex was identified where the encoding strength of anticipated action outcomes during instrumental learning significantly predicted the degree to which participants successfully adjusted their response behavior to devalued action outcomes. Therefore, this result points out the specific mechanisms by which this region contributes to goal-directed behavior in outcome devaluation paradigms and provides a region of interest for future studies investigating the neural basis of impairments in goal-directed behavioral control.

Overall, the results presented here highlight the role of two brain areas, namely the ventromedial and dorsolateral prefrontal cortices, in outcome-based, goal-directed decision-making. These regions overlap with large-scale cortical resting-state brain networks whose connectivity at rest also seems to be relevant for goal-directed behavioral control. The insights and experimental paradigms from this work can be applied in future research to study impairments in goal-directed control, for instance, in clinical populations. Future research could also elaborate on the role of these brain regions by incorporating more multivariate approaches in research investigating self-control and by expanding existing experimental paradigms in the instrumental learning domain to be able to disentangle different types of associative contents potentially encoded in the dorsolateral prefrontal cortex. In addition, the field would benefit from combining laboratory measures with more ecologically valid research approaches. Finally, the research presented in this dissertation yielded critical contradictions to previous work, most strikingly in the domain of self-control. These require further systematic investigation and point out the importance of replication studies in the field.