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Brain network response underlying decisions about abstract reinforcers

Colleen Mills-Finnerty *, Catherine Hanson, Stephen Jose Hanson

Rutgers University, United States

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ABSTRACT

Decision making studies typically use tasks that involve concrete action-outcome contingencies, in which subjects do something and get something. No studies have addressed decision making involving abstract reinforcers, where there are no action-outcome contingencies and choices are entirely hypothetical. The present study examines these kinds of choices, as well as whether the same biases that exist for concrete reinforcer decisions, specifically framing effects, also apply during abstract reinforcer decisions. We use both General Linear Model as well as Bayes network connectivity analysis using the Independent Multi-sample Greedy Equivalence Search (IMaGES) algorithm to examine network response underlying choices for abstract reinforcers under positive and negative framing. We find for the first time that abstract reinforcer decisions activate the same network of brain regions as concrete reinforcer decisions, including the striatum, insula, anterior cingulate, and VMPFC, results that are further supported via comparison to a meta-analysis of decision making studies. Positive and negative framing activated different parts of this network, with stronger activation in VMPFC during negative framing and in DLPFC during positive, suggesting different decision making pathways depending on frame. These results were further clarified using connectivity analysis, which revealed stronger connections between anterior cingulate, insula, and accumbens during negative framing compared to positive. Taken together, these results suggest that not only do abstract reinforcer decisions rely on the same brain substrates as concrete reinforcers, but that the response underlying framing effects on abstract reinforcers also resemble those for concrete reinforcers, specifically increased limbic system connectivity during negative frames.

Introduction

The role of the corticostriatal circuit in motivation, reward seeking, and decision making has been well studied in the context of biologically relevant rewards. Several key dimensions typically define these choice scenarios. First, the *survival value* of stimuli used in studies ranges from the most pressing biological needs (food, shelter), to the means for acquiring those needs (money, social status), to choices more distant from survival such as choosing a vacation destination. Second, in many studies, the choices have *hedonic value*, in that the properties of the stimuli themselves activate hedonic drives (such as pictures of appetitive food invoking a salivary response). Third, in virtually all of these studies, there are clearly defined action-outcome contingencies in that the subject does something (e.g. presses a button to choose a gamble) and something happens (they win/lose). Thus, another dimension of the stimuli in these studies is that they involve *concrete reinforcers* — subjects expect and receive tangible experiences like winning money, food, viewing attractive faces, or listening to pleasant music. However, many of the decisions we make every day involve potential future states, not immediate outcomes — should we finish writing a paper now so that we have time to go for a bike ride later? What would be nicer, a bike ride or a hike? Daydreaming about or planning pleasurable experiences like hobbies involves an *abstract reinforcer*, in that it is hypothetical, not tangible. The brain response underlying these kinds of choices have not been addressed in the current literature.

Though most decisions involve evaluating multiple dimensions (such as weighing value of a gamble against the risk of losing), abstract reinforcer decisions involve a particularly high level of decision complexity, sophistication, and individual variation. Also, though these experiences do not involve tangible exchange of rewards, they nonetheless seem to be experienced as pleasurable — daydreaming of a tropical vacation provides some respite on a dreary winter day. It follows that such processes would rely on uniquely human brain architecture that allows for comprehension of concepts embedded in the idea of vacation planning, such as “traveling”, “the future” and “the self.” Regions of dorsolateral and ventromedial prefrontal cortex that have been linked to memory, sense of self, and mental simulation are obvious candidate areas to serve this function (D'Argembeau et al., 2008; Roy et al., 2012; Lin et al., 2012). As mentioned previously, existing studies have used contingencies ranging from extremely concrete and linked to biological needs (receiving preferred foods, losing or winning money); to increasingly abstract such as listening to dissonant vs. melodic music or viewing pictures of car logos of inexpensive vs. luxury brands (Koelsch et al., 2006; Blood and Zatorre, 2001; Menon and Levitin,

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* Corresponding author at: Rutgers Newark Psychology Department, 101 Warren Street, Newark, NJ 07102, United States.
E-mail address: cfinnerty@psychology.rutgers.edu (C. Mills-Finnerty).

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2005; Schaefer and Rotte, 2007); to increasingly reliant on mental simulation of potential futures, such as purchasing future vacation destinations from a fictional "travel store" (Chaudhry et al., 2009; Sharot et al., 2009). Many of these studies have found that VMPFC supports the assessment of disparate rewards by coding them into a "common neural currency" (Chib et al., 2009; Smith et al., 2010; Levy and Glimcher, 2012), and that the striatum tracks the reward value of options, seemingly regardless of stimulus domain (e.g. Bartra et al., 2013). However, no studies to our knowledge have examined rewards in the absence of any contingency, implied or actual. It remains unknown whether the corticostriatal system implicated in concrete decision contexts also plays a role in choices for abstract reinforcers. Given that the primary adaptive advantage of the reward system may have been primarily to motivate behavior towards survival needs, it is possible that it would not be active during choices for abstract reinforcers.

However, another possibility follows from evidence showing that areas of the human brain that might have originally evolved for one purpose get co-opted for other, potentially more complex processes. An analogous example is the motor system, which instead of remaining limited to the execution of motor tasks, also responds when watching others perform the same task — a social skill that has obvious implications for the *Homo sapien* first learning to start a fire. Perhaps the corticostriatal reward system has been similarly co-opted, such that making choices about needs that seem fairly distant from any survival value still rely on this system to support functions such as comparative evaluation, tracking reward value, and motivation of behavior. If this were the case, a feedback mechanism between subcortex and cortex would likely be needed in order to integrate the complex variables that would be necessary for such a process (e.g., knowledge of one's own preferences), which is feasible given the dense anatomical connectivity between these areas.

One way to test whether concrete and abstract reinforcer contexts rely on the same or different corticostriatal mechanisms is to investigate whether the decision making biases seen in concrete contexts also occur when subjects choose between abstract reinforcers. A substantial body of research has investigated neural correlates of biases during decisions for concrete reinforcers, including delay discounting, endowment effects, and framing effects (McClure et al., 2004; Knutson et al., 2008; De Martino et al., 2006). Framing research has shown that even when the actual outcomes are equivalent, whether a choice is framed as a gain or a loss will alter the behavioral response or decision made (e.g. Tversky and Kahneman, 1986; refer to Kuhberger, 1998 for meta-analysis). For example, in one neuroimaging study, a $0 lottery winning was perceived as aversive if the other options are winning $2 and $5, but appetitive if the other options are losing $2 and $5 (Breiter et al., 2001). The mechanisms of this bias are thought to be as follows: loss frames tend to encourage riskier decisions than gain frames, due to loss aversion, whereby offsetting a loss requires a gain twice as large. Under the threat of loss, riskier decisions become more appealing if they offer the chance at avoiding a loss altogether. This bias exists in a range of domains including gambling tasks, choices about health outcomes, consumer product decisions, and solving logic problems (Tversky and Kahneman, 1986; Biswas and Grau 2008; Rothman and Salovey, 1997; Kuhberger, 1998). In terms of brain response, areas implicated include the amygdala (De Martino et al., 2006), striatum, ventromedial prefrontal cortex (Tom et al., 2007; Foo et al., 2014), and dorsolateral prefrontal cortex (Gonzalez et al., 2005; Foo et al., 2014).

To our knowledge there have been no studies of framing effects on abstract reinforcer decisions. The present study addresses this topic using a task in which participants make hypothetical choices with no expectation of outcomes, no actual outcomes, and no concrete reward for choices. This is done using a simple "which do you like more/ which do you like less" decision prompt. We hypothesize that abstract reinforcers engage the same brain areas as concrete reinforcers, but the role these brain areas play will be different due to the different task demands for making decisions about abstract reinforcers. Specifically, as there are no explicit goals when choosing between abstract reinforcers, we expect that activation of the prefrontal cortex will track the perceived or subjective value of the options presented rather than tracking goals as in concrete decision making. The anterior cingulate, rather than predicting outcomes of choices, since there are no outcomes, will instead direct attention and integrate affective feedback to guide choice behavior. The insula, instead of predicting risk, will integrate affective components such as how salient or arousing choice options are. Finally, the striatum will not track reward outcomes via a prediction error algorithm requiring terms for expectations and outcomes, but will instead track the perceived reward value or attractiveness of the choice options in order to guide decisions.

We also test whether the behavioral biases due to framing in concrete reinforcer scenarios also occur during decisions — using abstract reinforcers. We expect that negative frames will involve longer reaction times than positive frames in terms of behavior, as has been found in studies using concrete reinforcers (e.g. Alós-Ferrer et al., 2012; Foo et al., 2014). This longer RT for negative framing is thought to be related to increased negative affect, akin to loss aversion, although unlike in monetary contexts where subjects must evaluate offers for potentially bad gambles, here they are choosing which of two exemplars in a preferred category they must reject. This is thought to also induce choice conflict, particularly when being forced to choose between exemplars when both are highly preferred. Choice conflict plus increased negative affect are proposed to account for the longer reaction time in the negative condition, which should be reflected in engagement of brain areas implicated in processing aversive content, such as the ACC and insula. Differences in brain response during positive and negative framing will be addressed by examining both the magnitude of activation using GLM analysis as well as patterns of connectivity between a network of regions associated with decision making and reward, including the VMPFC, dorsolateral prefrontal cortex (DLPFC), anterior cingulate (ACC), insula, caudate, and putamen.

Methods

Participants

Sixteen healthy adult participants (8 females, ages 19–60; mean age = 25.47, SD = 4.37 years) underwent functional MRI conducted at the Rutgers University Brain Imaging Center (RUBIC). Participants met standard MRI exclusion criteria (e.g.,. no metal implants, pregnancy, neurological disorders). One participant did not complete all experimental conditions and was excluded from the analysis. Three participants identified as white, 5 as Asian, 2 as black, 3 as Hispanic, 1 as Pacific Islander and 1 as other/multiracial. Participants were recruited from the Rutgers University Newark community through a department based subject recruitment system and word of mouth. Thirteen participants were undergraduates, 1 was a graduate student, and 1 was a staff member. Undergraduates were awarded course credit for participation. One participant reported taking medication, a low dose (5 mg) of the stimulant Adderall. Significantly higher doses of stimulants (20 mg) have been found to modulate brain activity during attentional tasks (Tomasi et al., 2011), but given the low attentional load of the present study and the low dose of the drug, this participant was included in the analysis after a review of their data showed reaction time within the range of the sample and patterns of brain activation consistent with the rest of the group. The same review process was applied to one left-handed participant who was ultimately also included in the analysis. All participants gave informed consent to participate. The study was approved by the Rutgers Institutional Review Board.

Procedure

An Abstract Reinforcer Task (ART) was developed through behavioral piloting with an independent group of subjects (n = 54) to determine an