Journal Club

Editor's Note: These short, critical reviews of recent papers in the *Journal*, written exclusively by graduate students or postdoctoral fellows, are intended to summarize the important findings of the paper and provide additional insight and commentary. For more information on the format and purpose of the Journal Club, please see http://www.jneurosci.org/misc/ifa_features.shtml.

Uncovering the Neural Basis of Resisting Immediate Gratification while Pursuing Long-Term Goals

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Review of Diekhof and Gruber

Adaptive functioning in the world often requires that we resist the pull of immediate gratification and instead choose actions that serve long-term goals. On a sunny day, we must go to work and resist the allure of the beach; on the night before an exam, it is prudent to stay home and study rather than venture out to a party; and to maintain a New Year's resolution to eat healthier, the nefarious persuasion of dessert must be ignored.

While empirical studies have begun to elucidate the neural basis of decision making about immediate and delayed rewards (McClure et al., 2004), little is known about the neurobiological basis of the ability to resist immediate gratification while pursuing a long-term goal. A recent study (Diekhof and Gruber, 2010) published in *The Journal of Neuroscience* sought to directly shed light on this issue. Subjects performed a novel sequential forced-choice task while undergoing functional magnetic resonance imaging (fMRI). At the beginning of each trial, subjects were shown a cue showing three target colors. Subsequently, colors were presented sequentially and subjects had to "collect" the colors that belonged to the target set for that trial, and "reject" all other colors. This was the long-term goal. If successfully completed, subjects earned 4 points at the end of the trial (points corresponded to money that would be earned at the end of the study).

Importantly, before the fMRI task, subjects performed an operant behavioral task in which they learned to associate particular colors with an immediate reward. During the fMRI task, if a color that had been previously associated with reward in the operant behavioral task (i.e., a conditioned stimulus) appeared and was not part of the target color set, then subjects were free to collect the conditioned stimulus and receive a bonus point. This trial type allowed the authors to identify neural activity related to the selection of an immediate reward. In other trials, the conditioned stimulus was part of the target set. In this case, subjects had to select the conditioned stimulus once as part of the task goal, but then they had to reject it if it appeared again within the same trial. Thus, when a conditioned stimulus appeared for a second time within a trial, subjects had to resist the immediate reward (one bonus point) in favor of completing the task and obtaining a delayed, but larger reward at the end of the trial. Neural activation on these trials therefore revealed the circuitry involved in overriding the temptation of an immediate reward when it conflicts with a long-term goal.

The neuroimaging data revealed several important findings. First, consistent with prior work (McClure et al., 2004), robust neural activity was observed in the nucleus accumbens (NAcc) and the ventral tegmental area (VTA)—regions along the mesolimbic dopaminergic pathway—when subjects could freely collect a conditioned stimulus and obtain an immediate reward [Diekhof and Gruber (2010), their Fig. 2]. Interestingly, on trials in which subjects successfully resisted the immediate reward in service of a long-term goal, activation in these mesolimbic reward regions was attenuated. This potentially suggests that when an immediately available reward will interfere with a long-term goal, subcortical reward activity is actively suppressed.

The authors next conducted a psychophysiological interaction (PPI) analysis to examine whether the prefrontal cortex (PFC) exerts a regulatory influence over the VTA and NAcc reward activity. The PFC was a key area of interest based on theoretical and empirical work associating this region with goal-directed action and executive control (Miller and Cohen, 2001). Consistent with the idea that the PFC may exert a regulatory influence, this analysis revealed negative functional connectivity between the anterior PFC and the NAcc and VTA in the context of resisting an immediate reward [Diekhof and Gruber (2010), their Fig. 3*a*,*b*]. That is, stronger activity in the anterior PFC was associated with lower activation in these mesolimbic regions. The anterior PFC activation was in the vicinity of the rostrolateral prefrontal cortex (RLPFC), a region that supports some of the most complex cognitive capacities (Christoff and Gabrieli,

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2000). Importantly, the extent to which the RLPFC was negatively coupled with the NAcc positively correlated with subjects' ability to resist the immediate reward [Diekhof and Gruber (2010), their Fig. 3*c*], providing strong evidence that RLPFC–NAcc interactions may play a crucial role in determining whether an individual will successfully resist immediate gratification.

The intriguing findings of this study prompt several questions. First, it will be important to clarify the precise cognitive mechanism instantiated by the RLPFC that allows individuals to resist immediate gratification. There are several possibilities. First, when subjects confronted a conditioned stimulus that was part of the target set, they had to probe their memory and determine whether the stimulus had been previously selected during the trial. Given the role of RLPFC in controlled memory retrieval (Velanova et al., 2003), it could be that the extent to which subjects accurately recalled their choices of stimuli during each trial allowed them to effectively reject conditioned stimuli when presented for a second time. A related possibility is that RLPFC was supporting a multitasking function (Koechlin et al., 1999); during the task, subjects were required to maintain targets in mind while concurrently responding to the sequentially presented stimuli. Again, the effectiveness of this process could influence subjects' success at rejecting the conditioned stimuli. If either of these explanations is correct, then RLPFC may not contribute to resisting immediate gratification in general; rather, its role may be limited to situations in which memory retrieval or multitasking plays an essential role in resisting an immediate reward.

A third possibility based on RLPFC's noted role in establishing task sets (Sakai and Passingham, 2006) is that this region contributed to the establishment and maintenance of the targets, the future reward, or both in working memory; it could be that resisting immediate gratification is simply a matter of keeping attention on this information and away from the immediate reward. Finally, RLPFC may play a central role in the joint evaluation of two or more potential goals or decisions (Ramnani and Owen, 2004). This region may thus be recruited to compare the relative desirability of pursuing an immediate, versus a delayed reward based on integrating multiple pieces of information, including the magnitude of the rewards and the effort needed to obtain them. Supporting the idea that RLPFC may play a role in comparing the value of different actions, a recent study (Boorman et al., 2009) showed that RLPFC activity specifically encodes the relative probability that an unchosen, relative to a chosen, action will be rewarded. If this latter interpretation is correct, then it will be important for future investigations to determine whether RLPFC plays a general role in comparing the value of actions or whether it only becomes engaged when it is necessary to simulate a future action or reward during the comparison process.

An additional question pertains to the best way to characterize the ability to resist an immediate reward in favor of larger, delayed reward. This study was framed in terms of reason triumphing over desire. However, it can be argued that sometimes the most rational action is to interrupt a long-term goal and consume an immediately available reward, e.g., when individuals take a break from work (which ultimately brings about a future goal—a pay check) to have lunch (an immediate reward). Discerning what is rational or reasonable behavior is very context dependent and therefore has little intrinsic meaning. Therefore, it may be useful to discard terms such as reason and passion in favor of more explicit and informative terms. With respect to the present study, it could be characterized in terms of a competition between motivational information represented at different levels of abstraction. Whereas immediate rewards can be considered concrete (they are physically present and elicit strong physiological changes in the body), delayed rewards can be considered abstract (they are not physically present and may be less likely to promote immediate physiological changes). This characterization fits well with the finding from this study that RLPFC may promote the acquisition of delayed rewards and recent data showing that the RLPFC supports highly abstract representations (Christoff et al., 2009; Badre and D'Esposito, 2009). This characterization also leads naturally to the following question: when individuals are not instructed to pursue a long-term goal, but rather, are left to make their own decisions, how do genes, learning history, and present context contribute to individual differences in choices for concrete versus abstract rewards?

In summary, the findings of Diekhof and Gruber (2010) make an important step toward characterizing the neurobiological basis of a remarkable capacity—the ability to resist immediately available rewards in favor of obtaining a larger reward in the future. The data highlight anterior PFC–NAcc interactions as a key neural substrate. The next step will be to elucidate the precise cognitive mechanism supported by the anterior PFC that allows long-term goals to prevail over immediate rewards.

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