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Neuron
Previews

Wait for the Second Marshmallow? Future-Oriented Thinking and Delayed Reward Discounting in the Brain

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DOI 10.1016/j.neuron.2010.04.001

Humans tend to discount the value of delayed rewards. Peters and Büchel show in this issue of *Neuron* that the ability to appraise the value of such future rewards improves when future-oriented cognitive processes in the brain are recruited using personally relevant information. These results provide the platform for exciting new questions.

Our brains are equipped with the ability to mentally project us to the future so that we can explore potential actions and outcomes in advance. As Karl Popper famously said, we should "…let our false theories die in our stead" (Popper, 1963). Future-oriented thinking is indeed a basic operation of our proactive brain (Bar et al., 2007), and mental simulation serves the basis for many cognitive processes (e.g., Bar, 2009; Barsalou, 2009; Hassabis and Maguire, 2009; Buckner and Carroll, 2007; Moulton and Kosslyn, 2009; Schacter and Addis, 2009). One domain where future-oriented simulations could be particularly beneficial is in assessing the value of future rewards.

In a famous experiment from the late 1960s, Walter Mischel and colleagues asked four-year-old children to choose between one marshmallow immediately or, if they could wait, two marshmallows twenty minutes later (see an illuminating popular coverage in Lehrer, 2009). The vast majority of the children opted for the immediate gratification of a single marshmallow. These experiments are traditionally taken as studies of self-control and impulsivity, and the dominant neural explanation to this impulsive decision making in children focuses on their yet immature prefrontal cortex. How exactly does the prefrontal cortex regulate impulsive behavior? The ingenious paper by Peters and Büchel (2010) in this issue of *Neuron* provides a convincing account. They studied the mechanisms required for an accurate evaluation of future rewards using the phenomenon of *delay discounting*: the tendency to discount the value of a potential reward as a function of temporal distance to its delivery in the future. Their study resulted in two main findings, both of which are highly important. First, the neural mechanisms mediating future-oriented mental processes need to be engaged during decision making for decisions to be more accurate. Second, using personally relevant (i.e., episodic) information when imagining the specific reward at the specific point in the future recruits this necessary network more effectively and results in reduced delay discounting. Therefore, appreciating the value of future rewards and the benefit of acting to obtain them relies on our ability to imagine the relevant future. When the prefrontal cortex is sufficiently developed and properly employed and interacts with other regions, we can exert a more experience-based, consequence-oriented influence on our decision-making process.

On each trial, participants in this fMRI experiment were given a choice of reward magnitude (e.g., 20, 26, or 35 €) and a reward delivery time (e.g., immediately, in 30 days, or in 45 days). In half of these trials, the reward option was presented along with an "episodic cue" derived from a previous individual interview. The prescan interview is a critical and original aspect of the design, which yielded information about participants' own future events planned for the time that coincided with the future reward delivery. In addition, after each scan the participants were asked to report the frequency and vividness of the associations evoked by each episodic cue during the experiment. The behavioral results showed that when decision-making network recruits future-thinking network, the result is reduced discounting of value. Furthermore, the effect of episodic cues on reducing reward discounting was stronger for future episodes that were imagined more vividly.

As to the neural findings, the critical aspect was that the recruitment of areas previously implicated in future-oriented mental processes was correlated with improved decision making related to future rewards. A great deal is already known about the regions involved in typical decision making, valuation, and cognitive control, which include the anterior cingulate cortex (ACC), the medial and lateral prefrontal cortex (PFC), and the posterior cingulate cortex (PCC) (Ballard and Knutson, 2009; Kable and Glimcher, 2007; McClure et al., 2004). Similarly, a great deal is known about the network involved in future-oriented processes, which includes the ventromedial PFC (vmPFC), hippocampal formation, and the medial parietal cortex (MPC) (Bar, 2009; Buckner and Carroll, 2007; Hassabis and Maguire, 2009; Schacter and Addis, 2009). It is the characterization of these networks' relative recruitment and their interaction in the service of better evaluation of a delayed reward that is novel and important. The functional coupling of prefrontal and hippocampal activations provides the neural basis for the authors' conclusion that delay discounting is inversely related to the extent of interaction with future-oriented processing. The additional coupling of the prefrontal cortex with the amygdala, on the other hand, reminds us that decisions are naturally also dependent on the emotional and arousal levels that a potential reward elicits.

Interestingly, the regions suggested by predominant accounts (Ballard and Knutson, 2009; Kable and Glimcher, 2007; McClure et al., 2004) to represent and process reward value—the medial prefrontal cortex (mPFC), hippocampal formation, and the PCC—overlap with the network involved in future-oriented processing. This striking overlap raises the question of which of the activations attributed by these previous studies to decision making are exclusive to decision making proper, and which are a manifestation of the future-related component recruited for making those decisions. The paper by Peters and Büchel (2010) underscores the need to refine this distinction. This interdependence is reminiscent of another overlap: between memory systems and the network involved in foresight, primarily in the hippocampus (Bar, 2009; Hassabis and Maguire, 2009; Schacter and Addis, 2009). Is the hippocampus directly involved in future-oriented processes, or is it instead active in such processes because foresight relies on memory? The conclusion may be that none of these networks—decision making, predictions, and memory—is truly independent and their function cannot be distinguished from each other's: memory provides the basis for predictions, and predictions provide the basis for decision making.

It is important to note that delay discounting is only one of many types of distortions of future-related decision making, which are diverse and have fundamental impact on our lives. For example, people show consistent inaccuracies in their ability to estimate how much happiness a certain event would bring (Gilbert, 2006). Can enhanced imagery improve judgments about predicted happiness as well? Supportive of this possibility is a demonstration from studies of affective forecasting, where encouraging participants to use more elaborated thinking (i.e., to think about additional activities expected to occur at the specific time in the future) improves the quality of their predictions (Wilson et al., 2000). In another example, the *planning fallacy* (Buehler et al., 1994), subjects have been shown to underestimate how long a certain task will take them to complete in the future (which might be why we find ourselves so often too close to deadlines). One of the explanations provided for this estimation distortion is that subjects focused too much on the future task itself and not enough on past experience with similar tasks. This is in perfect agreement with the idea that to predict accurately one needs to activate relevant memories.

The findings of Peters and Büchel (2010) provide the cognitive neuroscience platform for a host of exciting new questions and implications, and I will raise a few of them here. First, that enhanced imagery improved evaluation of future rewards has an immediate clinical potential: can various patient (and healthy) populations with impulsive behavior benefit from deliberately activating rich, vivid, episodic associations before making decisions regarding future rewards? Second, is it the personal relevance of the episodic cue that reduces discounting, or is it merely the fact that episodic information elicits richer associations and imagery, and it is this increased detail that improves valuation? If it is the latter, one would expect that even personally irrelevant imagery, if it is possible, will elicit the same benefit in future-related decision making. Third, future-oriented thinking relies on memory and experience, and the natural lack of experience in young children significantly reduces their ability to imagine future events and consequences. Is it the case that increased experience boosts the ability to imagine the future thereby driving the development of the prefrontal cortex? Or, instead, that a more developed prefrontal cortex results in an improved ability for future-oriented thinking and the corresponding guidance of behavior? The answer might be that foresight and the structural development of the PFC bootstrap each other, but how they interact to achieve this over the years is important to understand. This question is similarly interesting in the context of aging, where experience is ample but the integrity of the prefrontal cortex and the hippocampus is gradually compromised. If aging leads to increased delay discounting, is it because of a diminished cognitive ability to engage future-related processes, or because of a vanishing memory that could otherwise provide the basis for such mental projections? Fourth, the ability to properly evaluate a delayed reward may not necessarily guarantee willingness to wait for this reward. Evaluating and deferring gratification might originate from the operation of two different, although tightly interacting, mechanisms. It is important to learn more about how these two interact. Fifth, what are the computational operations performed by the brain to transform a present value, or a past value in memory, into a future value? This question is relevant more globally to any type of future-oriented thought; how is a memory converted to anticipation?

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