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Neural congruence between intertemporal and interpersonal self-control: Evidence from delay and social discounting

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ABSTRACT

Behavioral studies using delay and social discounting as indices of self-control and altruism, respectively, have revealed functional similarities between farsighted and social decisions. However, neural evidence for this functional link is lacking. Twenty-five young adults completed a delay and social discounting task during fMRI scanning. A spatiotemporal partial least squares analysis revealed that both forms of discounting were well characterized by a pattern of brain activity in areas comprising frontoparietal control, default, and mesolimbic reward networks. Both forms of discounting appear to draw on common neurocognitive mechanisms, regardless of whether choices involve intertemporal or interpersonal outcomes. We also observed neural profiles differentiating between high and low discounters. High discounters were well characterized by increased medial temporal lobe and limbic activity. In contrast, low discount rates were associated with activity in the medial prefrontal cortex and right temporoparietal junction. This pattern may reflect biological mechanisms underlying behavioral heterogeneity in discount rates.

1. Introduction

Delay discounting (DD) is the tendency to subjectively devalue future rewards in favor of immediate gratification and is a commonly used measure of behavioral self-control (Green and Myerson, 2004). There is substantial variability in discount rates (Odum, 2011; Peters & Buchel, 2011) and individual differences are predictive of a broad range of behaviors, including general intelligence (Shamosh et al., 2008), purpose in life (Burrow & Spreng, 2016) and physical health (Moffitt et al., 2011). Moreover, excessive rates of DD are characteristic of several maladaptive and pathological behaviors (Bickel et al., 2012a, b). Much like the intertemporal choices in DD, social reciprocity can be characterized as a conflict between the immediate sacrifices of generosity and the long-term benefits of social cooperation (Axelrod and Hamilton, 1981; Boyer, 2008; Rachlin, 2002). For example, in an iterative Prisoner's Dilemma game, cooperation among agents promotes greater *long-term* payoffs but requires an agent to forgo the best *immediate* outcome. In order to maximize outcomes for oneself an agent must override the impulse to defect in order to build and sustain a cooperative relationship with an opponent, which will ultimately benefit the self. Discounting of future outcomes has consistently been found to correlate with the number of defections an agent makes against a tit-for-tat strategy (Harris and Madden, 2002; Stephens et al., 2002; Yi et al., 2005). Reciprocal altruism may therefore reflect a specific form of self-control (Rachlin, 2002).

Altruism can be measured via social discounting (SD), the tendency to subjectively devalue altruistic outcomes for others as a function of the perceived social distance separating oneself from a beneficiary (Jones and Rachlin, 2006; Rachlin and Jones, 2007; Safin et al., 2013). Emerging behavioral evidence highlights similarities between DD and SD. Both forms of discounting are well characterized as a hyperbolic function of increasing temporal and social distance (Jones and Rachlin, 2006, 2009; Rachlin and Jones, 2007) and may rely on shared psychological processes (Charlton et al., 2013; Locey et al., 2011; Yi et al., 2012; Yi et al., 2011). However, despite behavioral evidence for the effect of social distance on altruistic preferences, the neural basis of this effect has not been the focus of extensive investigation. Moreover, the degree to which these two forms of discounting draw on common and/or dissociable neural mechanisms remains unknown.

Despite the extensive functional overlap between DD and SD, dissociations between these two forms of discounting have been reported. For

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example, reward magnitudes differentially modulate discounting behavior, with participants generally becoming *more* self-controlled (DD) but *less* altruistic (SD) as potential reward amounts increase (Rachlin and Jones, 2007; Yi et al., 2012). Jones and Rachlin (2009) observed that, despite significant correlations between DD and SD, charitable contributions on a public-goods task positively covaried with altruistic preferences but not intertemporal self-control. Moreover, choices directly benefiting others tend to be more risk-adverse than decisions that only involve oneself, particularly when choices involve potential losses (for review, see Atanasov, 2016). Taken together, these behavioral findings suggest some qualitative differences between DD and SD.

DD is relatively well-characterized within the neuroimaging literature. Despite a diverse array of experimental paradigms and reward modalities, common patterns of cortical and subcortical activity have been reported in regions comprising default, frontoparietal control, and mesolimbic reward networks (Carter et al., 2010). One hypothesis is that DD emerges from the relative contributions of these functionally specialized systems (Bechara et al., 2005; McClure and Bickel, 2014; McClure et al., 2004). For example, the ventromedial prefrontal cortex (VMPFC) has been identified as a key region involved with representing and tracking subjective valuation signals which are modulated by competing neurobehavioral systems (Jimura et al., 2013; Kable and Glimcher, 2007; Montague et al., 2006). Activity in the default and frontoparietal control networks (particularly in the prefrontal cortex) is associated with more far-sighted decisions and higher rates of self-control (Benoit et al., 2011; Jimura et al., 2013; McClure et al., 2004; Peters and Buchel, 2010). The default network has been implicated in a number of diverse autobiographical processes, including the ability to vividly imagine or anticipate future events and outcomes (Andrews-Hanna et al., 2014a, b; Spreng et al., 2015), and is observed to flexibly couple with the frontoparietal control network during complex goal-directed planning (Gerlach et al., 2011; Spreng et al., 2010). Upregulation of the default network may reflect the ability to vividly anticipate future outcomes and therefore lead to increasing valuation signals in the VMPFC for time-delayed options (Benoit et al., 2011; Boyer, 2008; Hakimi and Hare, 2015; Peters and Buchel, 2010).

To date there has been only a single neuroimaging study investigating the neural basis of SD (Strombach et al., 2015). Similar to the extant literature on DD, SD was observed to result from a balance between selfish and generous motives encoded within valuation and default network regions, respectively. The VMPFC, in tracking the subjective value of rewards across time, may serve an analogous function within interpersonal contexts by tracking the long-term benefits of social cooperation (Montague et al., 2006; Rilling and Sanfey, 2011). Strombach and colleagues (2015) found modulations in VMPFC activity in response to subjective valuation signals associated with both selfish and generous choice options. Moreover, a psychophysiological interaction analysis revealed choice-dependent functional connectivity between the VMPFC and right temporoparietal junction (TPJ) during generous, but not selfish, choices. The TPJ is a node within the default network often observed in response to tasks involving social cognition (Andrews-Hanna et al., 2010; Andrews-Hanna et al., 2014a, b; Spreng et al., 2009). Thus, the existing evidence for the neural basis of SD indicates that, during prosocial choices, valuation signals in the VMPFC are modulated by superordinate prosocial preferences encoded in the TPJ (Strombach et al., 2015).

Despite behavioral evidence for similarities and dissociations between DD and SD, the neural basis of decisions regarding temporally and socially distal outcomes remains poorly understood. Behavioral similarities may suggest an underlying neural correspondence that, if identified, might reflect a "domain agnostic" network for deliberative decisions requiring intertemporal and interpersonal self-control. Alternatively, neural data may dissociate patterns of activity associated with discounting specificity. In the current study we used functional magnetic resonance imaging (fMRI) to scan participants as they completed both DD and SD tasks (see Bickel et al., 2009). FMRI data were analyzed using spatiotemporal partial least squares (PLS) in order to identify patterns of brain activity distinguishing between DD, SD, and control trials as well as patterns of brain activity covarying with behavioral measures of discounting.

2. Materials and methods

2.1. Participants

Twenty-six members of the Virginia Tech community (19 females, mean age = 24) were recruited to participate. All participants were right handed. One female participant was excluded from fMRI data analysis due to technological failures in stimulus presentation timing and syncing for a final N of 25.

2.2. Procedure

We incorporated the same task design and stimuli as a previous study investigating commonalities in the neural profiles underlying DD for real and hypothetical outcomes (Bickel et al., 2009) but extended the design to a SD task. Participants completed DD and SD trials for hypothetical monetary rewards during fMRI scanning. During DD trials, participants chose between receiving a variable outcome of less than $100 immediately or $100 in 1 week, 1 month, or 6 months. Immediate reward alternatives and presentation order were the same as those used in Bickel et al. (2009).

During SD trials, participants chose whether to forgo receiving a moderate outcome for themselves in lieu of allocating $100 to acquaintances at varying social distances. Before scanning, participants were prompted to imagine generating a list of the 100 people closest to them in the world where number 1 was their closest friend or relative and number 100 was a distant acquaintance (Jones and Rachlin, 2006; Rachlin and Jones, 2007). They were then asked to provide the first name and last initial of the persons occupying spots 1, 2, and 8 on this list. Using normative SD rates from prior studies (Jones and Rachlin, 2006; Rachlin and Jones, 2007), we selected social distances that would produce mean indifference points equivalent to those used to select the immediate reward alternatives for the DD task (Bickel et al., 2009). This ensured roughly equivalent percentage of smaller vs. larger reward selections across discounting trials. Participants were instructed that persons 1 and 2 were likely to be one's closest friends or relatives whereas person number 8 might be considered a good friend but outside of their inner circle. Participants were asked to abstain from listing financial benefactors (e.g., parents, grandparents) in order to avoid potential confounding effects of financial dependence on proximal social distances. Other biological relatives (e.g., siblings, cousins) were not excluded from this list. These names were then used as stimuli during the SD task. Participants also completed control trials in which they chose between two outcomes that did not include a temporal or social component (e.g. $64.27 or $100). Control trials required participants to assess the objective value of both outcomes but minimized the deliberative decision making requirements of DD and SD trials. We used a mixed block/event-related fMRI design divided into two functional runs counterbalanced across the two discounting conditions (Fig. 1). Each run included 56 trials (28 discounting trials and 28 control trials). Trials were separated within each block by a jittered fixation ITI (2–4s). Blocks of discounting and control trials were separated by a 12s fixation inter-block interval. Trial order and outcome magnitudes were matched across runs and were the same as in Bickel et al. (2009).

2.3. MRI data acquisition

MRI data were acquired at the Virginia Tech Carillion Research Institute Human Neuroimaging Lab using a 3 T Siemens Tim Trio scanner equipped with a 12-channel head coil. Prescreening interviews were conducted to ensure safety in the scanner, and headphones were