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Intelligence and Extraversion in the neural evaluation of delayed rewards

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ABSTRACT

Temporal discounting (TD), the preference for earlier, smaller rewards over delayed, larger rewards, is a pervasive phenomenon that covaries with Big Five personality traits and Intelligence (IQ). This study provides novel insight by identifying correlates for IQ and Extraversion in the neural representation of TD preferences. An intertemporal choice task was employed, where offers were sequentially presented, distinguishing between one evaluation phase (first offer is presented) and one comparison phase (second offer is presented and values are compared). IQ correlated with responses of caudate nucleus to the subjective values of the offers, suggesting a role of cognitive abilities in modulating reward responses. Extraversion correlated with the strength of functional connectivity of a reward evaluation network centered on ventromedial prefrontal cortex.

1. Introduction

The consequences of our decisions are not always immediate. Many decisions specifically require us to evaluate current options for their future outcomes. When future outcomes are positive—that is, rewards—human and non-human animals reveal a preference, all else being equal, for earlier delivery (see Frederick, Loewenstein, & O'donoghue, 2002 for a review). Later rewards are thus discounted relative to sooner rewards. Relatively stable individual differences in this temporal discounting (TD) tendency are linked to a number of life outcomes. Preference for larger delayed rewards over smaller immediate rewards (i.e., reduced TD) has been shown to predict both income and academic performance (Duckworth & Seligman, 2005; Duckworth, Tsukayama, & Kirby, 2013; Evans & Rosenbaum, 2008). TD also serves as a risk factor for externalizing problems, including substance abuse disorders, aggression, and delinquency (Krueger, Caspi, Moffitt, Silva, & McGee, 1996; Verdejo-García, Lawrence, & Clark, 2008). A better understanding of the underlying factors contributing to stable individual differences in TD can contribute critically to understanding human decision-making, as well as potentially lead to improvements in both clinical treatment and social intervention.

A promising pathway toward understanding the source of individual variations in TD is to link it simultaneously to well-studied, broad dimensions of psychological variation and at the same time to associated underlying neural substrates. Variations in TD, as modeled by decision theory, can be interpreted and understood within the broader frame of personality theory, and the addition of the neural underpinnings allows a deeper understanding of the decision-making mechanisms. This extension aids us in attributing the sources of the individual differences in choice to deeper individual differences in information processing and control functions (DeYoung, 2015), clarifying for instance the roles of Extraversion and intelligence. Toward this end, we carried out a study of the neural basis of TD in relation to the Big Five personality traits and intelligence. TD is robustly associated with intelligence (IQ); meta-analysis has estimated the correlation at $r = -.23$ (Shamosh & Gray, 2008). TD has also been linked to Big Five traits (most often Extraversion), but less strongly (Hirsh, Guindon, Morisano, & Peterson, 2010; Hirsh, Morisano, &

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Peterson, 2008; Ostaszewski, 1996). One very large study ($N = 5888$) found that TD was associated positively with Extraversion and Neuroticism and negatively with Conscientiousness and Openness/Intellect (and unrelated to Agreeableness), but the strongest effect (for Extraversion) was only equivalent to a correlation of .10 (Mahalingam, Stillwell, Kosinski, Rust, & Kogan, 2014). Nonetheless, theories of the psychological functions underlying the Big Five render these associations intelligible (e.g., DeYoung, 2015). Extraversion appears to reflect sensitivity to reward (Depue & Collins, 1999), which may increase the desirability of sooner rewards relative to later rewards, whereas Neuroticism appears to reflect sensitivity to threat (Gray & McNaughton, 2000), which may increase the aversiveness of waiting for a delayed reward (in part due to the threat posed by uncertainty; Hirsh & Inzlicht, 2008). Conscientiousness reflects self-discipline and the tendency to resist distraction and act deliberatively, which are clearly conceptually opposed to TD. Openness/Intellect is the Big Five trait most strongly related to intelligence, which probably explains its association with TD (which was the weakest of the four effects found by Mahalingam et al. (2014)).

Research on the neurobiology of TD provides additional guidance for developing hypotheses regarding TD's link to the Big Five and intelligence. In-depth research has been carried out on the neural processes that subserve intertemporal decision-making (see Peters and Büchel, 2011, for a review). Most of this research has been organized around the differentiation between two systems thought to be central to value-based decisions. The first is a core evaluation network, including ventral striatum and ventromedial prefrontal cortex (VMPFC), which represents neural subjective value signals (Kable & Glimcher, 2007; McClure, Laibson, Loewenstein, & Cohen, 2004; for a review on VMPFC and the representation of unified subjective value see Rangel & Clithero, 2013). The second is a modulating control network, including dorsal and ventral lateral prefrontal areas and the dorsal anterior cingulate (ACC), which engages in maintaining information in working memory and inhibiting prepotent responses (Figner et al., 2010; Hare, Camerer, & Rangel, 2009; Kable & Glimcher, 2009). Recent research showed that functional connectivity between VMPFC and dorsolateral prefrontal cortex (DLPFC) plays an important role in determining intertemporal choice. A study by Hare, Hakimi, and Rangel (2014) found that the DLPFC was more strongly connected to the VMPFC at the moment of choice and, in particular, during selection of later rewards, suggesting that DLPFC may contribute to revealed preferences by modulating VMPFC value signals during decision-making. This interpretation is supported by brain stimulation data (Figner et al., 2010), which demonstrates that delivering TMS over the DLPFC and disrupting its activation decreases the choice of delayed rewards without changing participants' ratings of how much they like those same rewards.

These two brain systems involved in TD clearly implicate the known neural substrates of Extraversion and Intelligence, precisely the two basic traits that appear to be most strongly linked to TD behaviorally. Many studies have now shown that Extraversion is related to the sensitivity of the dopaminergic reward system that is the core of the evaluation network (Depue & Fu, 2013; DeYoung, 2013; Wacker & Smillie, 2015). (Dopaminergic neurons in the midbrain send signals reflecting reward value via axons extending to the ventral striatum and VMPFC.) In functional magnetic resonance imaging (fMRI), Extraversion has been found to predict increased neural activity in the ventral striatum in anticipation of reward (Wu, Samanez-Larkin, Katovich, & Knutson, 2014), and several structural MRI studies have found that Extraversion is positively correlated with volume of VMPFC (Cremers et al., 2011; DeYoung et al., 2010; Grodin & White, 2015; Omura, Constable, & Canli, 2005; although other studies have not replicated this finding: Bjørnebekk et al., 2013; Hu et al., 2011; Kapogiannis, Sutin, Davatzikos, Costa, & Resnick, 2013; Liu et al., 2013).

Intelligence has been strongly linked to the cognitive control network with nodes in lateral PFC, dorsal ACC, and parietal lobes (Deary, Penke, & Johnson, 2010; Jung & Haier, 2007). Working memory appears to be the cognitive process most important for intelligence, and variation in the well-studied neural substrates of working memory appears to be crucial for IQ (Choi et al., 2008). Of particular relevance to the present study, one fMRI study found that neural activity in the lateral PFC during a working memory task predicted both TD and intelligence assessed outside the scanner (Shamosh et al., 2008). Further, IQ has been linked to both the functional reward response and the anatomical volume of the caudate nucleus in the striatum (Grazioplene et al., 2015; Hawes, DeYoung, Gray, & Rustichini, 2014). The association of IQ with the caudate may reflect that Intelligence modulates how prediction-error signals in this region respond to the perceived statistical features of the environment, given that higher intelligence is likely to afford enhanced evaluation of the context of reward. Such modulation may provide a mechanism by which intelligence becomes linked to preferences through processes of basic reinforcement (Chen, 2014; Hawes et al., 2014).

Based on the clear correspondence between neural systems involved in TD and those involved in Extraversion and intelligence, the current study aimed at combining personality and fMRI data to produce a more integrated understanding of individual differences in TD. Our primary hypothesis was that Extraversion and IQ would predict distinguishable patterns of neural activity during intertemporal choice. We developed a new variation of the basic intertemporal choice task, in which we presented two payment options, one earlier and smaller and one later and larger, sequentially, before requiring participants to choose between them. The sequential presentation was novel and made it possible to distinguish a first phase of evaluation—when only a single option is known—from a second phase of integration—when the second and last option becomes known and during which the two options and their values can be compared. Differentiating these two phases allows a better understanding of the different contributions of the evaluation and the cognitive control systems in processing delayed rewards.

2. Methods

2.1. Participants

A sample of 304 right-handed participants between the ages of 20 and 40 years was scanned in fMRI as part of a larger study. Of these, only 250 (123 female; age: $M = 26.31$ years, $SD = 4.96$) had usable data for our analyses of the TD task; 46 were excluded due to computer or operator errors in MRI data collection; 2 were excluded for excessive movement during MRI; 4 were missing data from intelligence or personality measures; 2 were excluded for missing data in the connectivity analysis. Participants were recruited from the larger community around the twin cities of Minneapolis and St. Paul, Minnesota, using a regional classified advertisements website (Craigslist). During recruitment, potential participants were excluded for current use of psychotropic medications, including antipsychotics, anticonvulsants, and stimulants, as well as for history of neurologic or psychiatric disorders or current drug or alcohol problems. MRI contraindications (e.g., ferromagnetic implants, pacemakers) were also exclusionary. Participants were paid $50 dollars per hour for the scanning session, plus any amount gained in the task, as well as $20 per hour for a separate assessment session in which they completed questionnaires and cognitive tests. The ethical review board at the University of Minnesota approved the study.