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ORIGINAL ARTICLE

Intrinsic prefrontal organization underlies associations between achievement motivation and delay discounting

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Abstract

Achievement motivation is a core component of human decision making. However, neural mechanisms that link achievement motivation and intertemporal choice have not yet been elucidated. Here, we examined neural pathways underlying the relationship between achievement motivation and intertemporal choice using a delay discounting task and resting-state functional magnetic resonance imaging on 86 healthy subjects. Behaviorally, delay discounting rate was positively correlated with achievement motivation. Functional coupling of the dorsolateral prefrontal cortex (dlPFC) with the medial prefrontal cortex (mPFC), medial orbitofrontal cortex and ventral striatum was positively correlated with achievement motivation. Notably, the mediation analysis showed that the impact of achievement motivation on delay discounting was mediated by intrinsic connectivity between the dlPFC and mPFC. Our findings suggest that intrinsic organization within the prefrontal cortex plays a key role in linking achievement motivation and intertemporal choice.

Keywords Delay discounting · Achievement motivation · Resting-state functional connectivity

Introduction

Achievement motivation has been conceived as a relatively stable disposition to strive for achievement or success (Atkinson 1957). It can affect many human behaviors, including goal setting (Hinsz and Jundt 2005; Matsui et al. 1982), risk decision making (Atkinson 1957; Raynor and Smith 1966), academic expectations and performance (Steinmayr and Spinath 2009; Uhlinger and Stephens 1960), and career success (Wainer and Rubin 1969). In contrast, lack of motivation is a core symptom in depression (Treadway and Zald 2011).

However, it remains unclear how achievement motivation affects intertemporal choice, the decision making of time–money tradeoff. Delay discounting is the dominant model in intertemporal choice, which refers to the degree of preference for smaller but immediate rewards over larger but delayed ones (Ainslie 1975). The discounting behavior is generally taken as a manifestation of impulsivity, while some other perspectives like heuristic models (Ericson et al. 2015), adaptive response (McGuire and Kable 2013), present-focus preference (Ericson and Laibson 2019) or cognitive noise (Gabaix and Laibson 2017) have been raised in recent years. Many trait factors can influence intertemporal choice, e.g., age (Eppinger et al.

Yuanyuan Xin and Pengfei Xu contributed equally to this work.

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2012; Halfmann et al. 2013), time perception (Peters and Büchel 2011), and personality (Manning et al. 2014). Specifically, studies have showed that reward sensitivity is a characteristic linked with delay discounting. For example, higher responsivity to reward is found associated with more immediate choice (Eppinger et al. 2012; Hariri et al. 2006; Mason et al. 2012), while anhedonia predicts less myopic decision (Lempert and Pizzagalli 2010).

Individuals with high drive for achievement tend to have stronger reward responsiveness. Behaviorally, achievement motivation is associated with human approach system characterized by pleasant stimulus sensitivity (Elliot and Thrash 2002, 2010). Neurally, people of higher power motivation have stronger activations in reward brain regions in response to pleasant stimuli (Schultheiss et al. 2008; Swanson and Tricomi 2014). Thus, high achievement motivation may predict larger delay discounting rate in intertemporal choice as they give attention priority to reward.

Previous neuroimaging studies have shown that regions from two interacting neural circuits are vital for achievement motivation: the striatum, insula, medial orbitofrontal cortices (mOFC), medial prefrontal cortex (mPFC) and precuneus from valuation system (Mizuno et al. 2008; Schultheiss et al. 2008; Schultheiss and Schiepe-Tiska 2013; Takeuchi et al. 2014), and the dorsolateral prefrontal cortex (dlPFC) involved in integrating motivation and cognition (Pochon et al. 2002; Taylor et al. 2004) from cognitive control system. The neural model underlying delay discounting has also been proposed according to its different subprocesses (Peters and Büchel 2011; Frost and McNaughton 2017), which mainly consist of the valuation network, including the mPFC, mOFC and ventral striatum (VS), and the cognitive control network, including the dlPFC and anterior cingulate cortex (ACC) (McClure et al. 2004; Hariri et al. 2006; Kable and Glimcher 2007; Luo et al. 2009; Figner et al. 2010a; Hare et al. 2014).

Recently, some studies showed that resting-state functional connectivity (RSFC) by correlations among time courses of low-frequency fluctuations in BOLD signal from different brain regions is also able to predict delay discounting rate. For example, higher delay discounting rate was found to be predicted by the RSFC between valuation network (i.e., striatum, ventral medial PFC and posterior cingulate cortex (PCC)) and control network (i.e., dlPFC, dorsal mPFC, inferior parietal lobe and inferior frontal gyrus) negatively (Li et al. 2013); and also by a positive RSFC within valuation regions (i.e., VS, mPFC and PCC) with a large effect size (Han et al. 2013; Calluso et al. 2015). These studies suggested that intrinsic functional organization of the human brain might be a good indicator of delay discounting, though the number of RSFC study on delay discounting is still limited.

The present study aimed to examine the effect of achievement motivation on delay discounting and the underlying neural pathways. We expected that individuals with high achievement motivation would prefer immediate rewards associated with altered intrinsic organizations of brain networks.

Materials and methods

Participants

Eighty-six college students were recruited for the study, and were paid for their participation. All subjects gave informed consent, and none had a history of affective disorder, neurological or psychiatric diseases, or regular medication use confirmed by self-reported questionnaires. The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of the Southwest University. All subjects completed a resting-state functional magnetic resonance imaging (fMRI) scan prior to behavioral measures which contained the Chinese version of Achievement Motives Scale (AMS), self-control scale (SCS), Barratt impulsiveness Scale (BIS-11) and a delay discounting (DD) task. Three participants were excluded due to incomplete delay discounting data and five participants were excluded from imaging data analysis because of head motion exceeding 2.0 mm or 2.0°. Thus, data from 78 participants (39 males; age = 20.17 ± 1.86 years) were analyzed.

Achievement motives scale

The achievement motivation score was derived from achievement motives scale (AMS) (Gjesme and Nygard 1970), which is a reliable and widely used instrument (Göttert and Kuhl 1980). The AMS includes two subscales. One is the disposition to approach success (hope for success, HFS), the other is the disposition to avoid failure (fear of failure, FOF). The AMS contains 30 items, with 15 items per subscale. All items were answered on a 4-point Likert scale ranging from “does not apply at all” to “fully applies”, and achievement motivation score was calculated by distracting HFS from FOF. Higher total scores of AMS indicate stronger disposition to strive for achievement or success.

Self-control scale

The self-control scale (SCS) is a 36-item measure of self-control with high reliability and validity among college students (Tangney et al. 2004; de Ridder et al. 2012). Higher summary scores represent higher level of self-control ability.

Barratt impulsiveness scale

The Barratt impulsiveness Scale (BIS)-11 is a 30-item self-report questionnaire designed to measure impulsiveness from three aspects which are attentional impulsiveness, motor impulsiveness and plan impulsiveness (Patton et al. 1995). All items are answered on a 4-point scale (Rarely/Never, Occasionally, Often, Almost Always/Always). Higher summary scores indicate higher levels of impulsiveness.

Delay discounting task

We administered a modified version of delay discounting task (Kable and Glimcher 2007), in which participants made a series of hypothetical choices between immediate rewards and delayed rewards. The small immediate amount was ¥20 on all trials. The larger delayed option was constructed using one of five delays (7, 15, 30, 60 and 120 days) and one of the ten add-percentages (10–200%) of the immediate reward, thus there were 50 unique choices and each was repeated four times, 200 trails in total. Participants were allowed as much time to respond as they desired to make decisions. Responses were made by pressing one of two buttons corresponding to immediate or delayed rewards.

Delay discounting rate was calculated as the area under the curve (AUC) (Myerson et al. 2001; Sellitto et al. 2011), and was subtracted from 1.00 so that higher value indicates larger delay discounting rate (Shamosh et al. 2008). Previous studies have shown that delay discounting rate is stable over time (Harrison and Mckay 2012; Kirby 2009; Ohmura et al. 2006).

Image acquisition and analysis

fMRI data acquisition

Imaging data were obtained from a Siemens TRIO 3.0T full-body MRI scanner in the Key Laboratory of Cognition and Personality (SWU), Ministry of Education. The anatomical images were acquired using a sagittal 3D gradient-echo T1-weighted sequence (TR/TE = 2530 ms/3.39 ms; flip angle = 7°; FoV = 256 × 256 mm^2; matrix size: 256 × 256; voxel size: 1.3 × 1.0 × 1.3 mm^3; 128 slices at a thickness of 1.33 mm). A gradient-echo echo-planar (EPI) sequence was used to collect resting-state fMRI images (TR/TE = 2000 ms/30 ms; flip angle = 90°; FoV = 200 × 200 mm^2; matrix size = 64 × 64; voxel size = 3.1 × 3.1 × 3.0 mm^3, 33 slices at a thickness of 3.0 mm) and it was used to acquire 240 images. Participants were explicitly instructed to relax without falling asleep, to keep their eyes open in darkness and to keep their heads steady during all scans.

fMRI data preprocessing

Resting-state fMRI data were preprocessed using the DPARSFA toolbox (Yan 2010) and SPM8 (http://www.fil.ion.ucl.ac.uk/spm/spm8). The first ten EPI images were discarded to achieve a steady state. Then we did slice timing, realignment and segmentation. T1-weighted images were co-registered to the EPI mean images and segmented into white matter, gray matter, and cerebrospinal fluid (CSF). The EPI images were then normalized to the MNI space with voxel size of 3 × 3 × 3 mm^3. Spatially smoothing was done with an 8-mm Gaussian kernel.

The confounders of head motion parameters, global mean signal (GMS) and average signals in white matter and CSF were regressed out from the voxel-wised time series. The resulting residual time series were bandpass filtered (range: 0.01–0.08 Hz) to remove high-frequency noise related to cardiac and respiratory activity (Biswal et al. 1995).

Localizing regions of interest

Based on previous studies, three hub regions of the valuation network and cognitive control network were selected, including the mPFC, mOFC and VS, which are engaged in reward processing (Ballard and Knutson 2009; Kable and Glimcher 2007; Peters and Büchel 2011; Pine et al. 2009), and the dlPFC, which plays a key role in cognitive control (Figner et al. 2010a; Cho et al. 2010).

Specifically, the ROIs were defined as 8-mm-diameter spheres (about 19 voxels) around the MNI coordinates [the mPFC (0, 44, 12), the mOFC (− 8, 48, − 4), the VS (6, 8, − 4) and the dlPFC (44, 44, 16)] of peak voxels reported in a previous study (McClure et al. 2004); see Fig. 1).

Resting-state functional connectivity

The functional connectivity analysis was conducted using a ROI-driven approach with the REST toolkit (REST, by Song Xiao-Wei et al. http://resting-fmri.sourceforge.net). The mean time course of each ROI was computed by averaging the time series of all voxels within that ROI. Then we calculated the Pearson correlation coefficients between time courses of dlPFC and mPFC, dlPFC and mOFC, dlPFC and VS. These r values were converted to normally distributed z-scores using Fisher's transform for group level analysis.

Statistical analysis

To examine the impact of achievement motivation on delay discounting, partial correlation coefficients between achievement motivation scores and delay discounting rates were calculated, controlling for self-control and impulsivity which were potentially associated with delay discounting rates

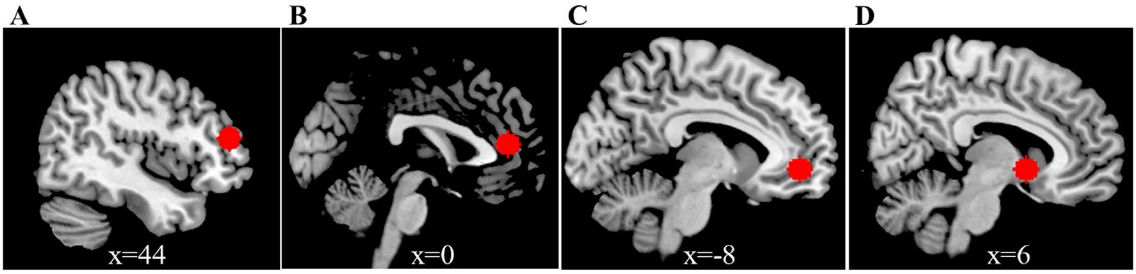

Fig. 1 ROIs for RSFC analysis. Brain networks engaged in different processes of delay discounting, including dlPFC (**a**) in cognitive control system and mPFC (**b**), mOFC (**c**), and VS (**d**) from reward system

Table 1 Descriptive statistics of measurements ($N = 78$)

	Range	Mean	SD
AMS	[− 14, 28]	1.95	9.13
SCC	[79, 146]	113.88	13.84
BIS	[49, 89]	65.23	8.55
DD (1-AUC)	[0.74, 0.86]	0.798	0.028

AMS achievement motivation scale, *SCC* self-control scale, *BIS* Barratt Impulsiveness Scale, *DD* delay discounting, *AUC* area under curve as delay discounting rate, *SD* standard deviation

(Jimura et al. 2013). To identify whether achievement motivation could be related to the RSFC between regions related to reward system and regions of cognitive control, we computed the correlation coefficients between achievement motivation scores and RSFCs of dlPFC–mPFC, dlPFC–mOFC, dlPFC–VS. To examine which RSFC potentially contributed to account for the effect of achievement motivation on delay discounting, we conducted a mediation analysis with bootstrap analysis (Preacher and Hayes 2008) and the aid of the "Process" macro for SPSS (Hayes 2012) using 10,000 resamples. All variables were normalized prior to model entry to facilitate centering and interpretation of coefficients.

Results

Behavioral results

Table 1 shows the ranges, means and standard deviations of scores for achievement motivation, self-control, impulsivity and delay discounting rate. The correlation analysis showed that delay discounting rates were positively correlated with scores of achievement motivation ($r = 0.533$, $p < 0.001$) (see Fig. 2). This correlation remained significant after controlling for scores of self-control and impulsivity ($r = 0.456$, $p < 0.001$). In addition, the correlation matrix among delay discounting rate, achievement motivation, self-control and impulsivity was shown in Supplementary Table S1.

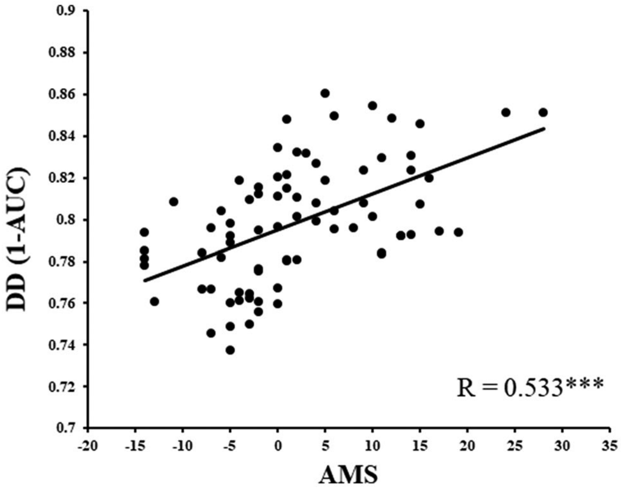

Fig. 2 Associations between achievement motivation and delay discounting. There is a positive correlation between achievement motivation and delay discounting rate (1—AUC). *AMS* achievement motives scale, *DD* delay discounting, *AUC* area under curve as delay discounting rate. ***$p < 0.001$

The result suggested that achievement motivation is predictive of impulsive decision making.

The correlation between achievement motivation and RSFC

The results of RSFC analyses revealed that two functional couplings were positively correlated to achievement motivation, including dlPFC–mPFC functional coupling ($r = 0.491$, $p < 0.001$) (Fig. 3a), dlPFC–mOFC functional coupling ($r = 0.355$, $p < 0.001$) (Fig. 3b), and dlPFC–VS functional coupling ($r = 0.330$, $p < 0.01$) (Fig. 3c). All associations remained significant after controlling for scores of self-control and impulsivity ($r = 0.545$, $p < 0.001$; $r = 0.455$, $p < 0.001$; $r = 0.432$, $p < 0.01$, respectively).

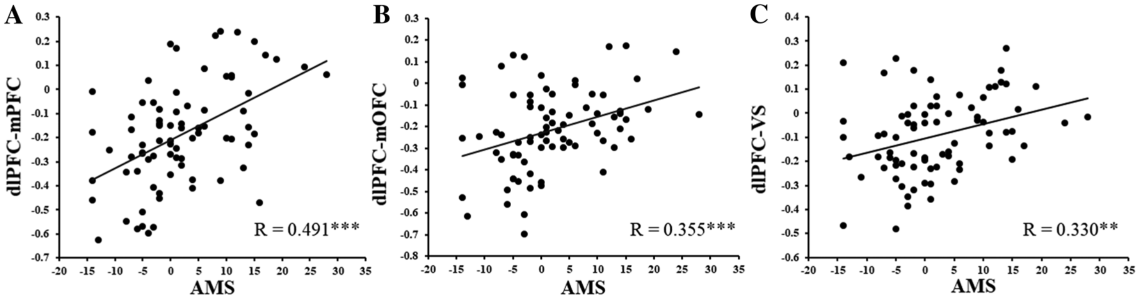

Fig. 3 Associations between achievement motivation and the RSFCs. **a** Achievement motivation is positively associated with dlPFC–mPFC functional connectivity; **b** achievement motivation is positively associated with dlPFC–mOFC functional connectivity; **c** achievement motivation is positively associated with dlPFC–VS functional connectivity. *AMS* achievement motivation scale. $^{**}p < 0.01$, $^{***}p < 0.001$

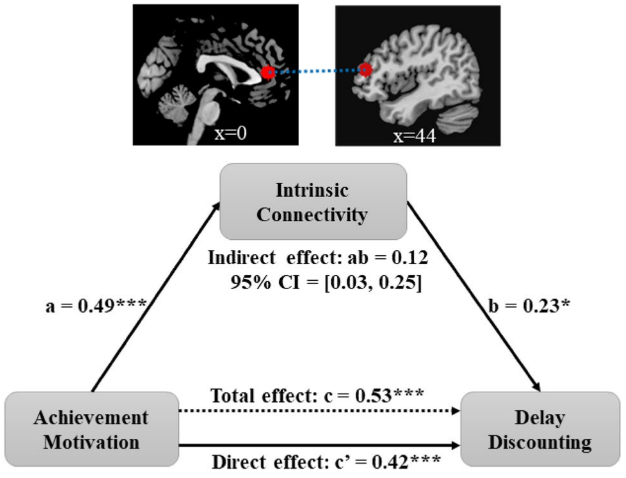

Fig. 4 Results of the path analysis. The relationship between achievement motivation and delay discounting is mediated by an increasing RSFC of the dlPFC with the mPFC. The mediation effect is 27% (ab/c'). $^{*}p < 0.05$, $^{***}p < 0.001$

Results of mediation analysis

The mediation analysis showed that the dlPFC–mPFC functional connectivity was the only significant mediator (Fig. 4). Functional coupling between dlPFC–mPFC and between dlPFC–mOFC was predictive of delay discounting rate ($r = 0.439$, $p < 0.001$; $r = 0.287$, $p < 0.05$). Specifically, the path analysis elucidated that the impact of achievement motivation on delay discounting was partially mediated by dlPFC–mPFC functional connectivity. For the dlPFC–mPFC functional coupling, the indirect effect of achievement motivation on delay discounting was significant (indirect effect: ab = 0.12, 95% CI [0.03, 0.25]), and the direct effect of achievement motivation on delay discounting remained significant after including the indirect path in the model (direct effect: $c' = 0.42$) (Fig. 4). The mediation effect is 27% (ab/c'), which suggests that the effect of achievement motivation on delay discounting can be mediated by RSFC between the dlPFC and mPFC.

Discussion

The main findings of this study are threefold. First, the delay discounting rate was positively correlated with achievement motivation scores. Second, higher achievement motivation scores predicted stronger RSFCs of the dlPFC–mPFC, dlPFC–mOFC, and dlPFC–VS. Finally, the impact of achievement motivation on delay discounting was mediated by the dlPFC–mPFC functional connectivity. Together, these results provide neuroimaging evidence suggesting that the relationship between achievement motivation and intertemporal choice may be modulated by intrinsic functional prefrontal organization.

Our results show that individuals with high achievement predicted larger delay discounting rate, i.e., immediate reward was much more valued than future reward. Achievement motivation has been considered as the orientation for rewards or goals and attainments of excellence (Mischel 1961). Of note, the self-reported achievement motives scale we used does not focus on rewards in the far future, which may explain the association with sensitivity to immediate reward. Indeed, some items of the scale explicitly describe immediate action, e.g., "When I am confronted with a problem, which I can possibly solve, I am enticed to start working on it immediately." Li (2008) demonstrated that a general motivational state induced by appetitive stimulus can make subjects be more present oriented, and more likely to choose smaller-sooner rewards. Furthermore, choosing a smaller-sooner reward has also been raised as an adaptive response to one's environment instead of a limited self-control capacity (McGuire and Kable 2013), which may be more apparent in the high achievement motivations who can perform better with a periodical feedback (Matsui et al. 1982; Schultz 2010). Additionally, the study showed that there was no significant correlation between achievement motive and impulsiveness (see Supplementary Table S1). These results support our finding that individuals with high achievement motivation preferred a seemingly short-sighted choice, which may be due to that they were keener on getting rewards than those low in achievement motivation, enhancing adaptive and flexible behavior.

Regarding the neural basis of the relationship between achievement motivation and delay discounting, our findings reveal that individuals with high achievement motivation show stronger resting-state functional coupling of the dlPFC–mPFC, dlPFC–mOFC and dlPFC–VS than individuals with low achievement motivation. Given that motivation has been shown to be related to reward and expectation (Mizuno et al. 2008), individuals with high achievement motivation tend to have stronger intrinsic expectation for rewards which may render greater spontaneous fluctuations of reward-related brain region, in turn resulting in increasing engagement of regions of cognitive control to achieve a homeostatic state. Thus, our results provide neuroimaging evidence that inherent achievement motivation may be represented by the intrinsic connectivity between the reward system and the cognitive control system. A recent review (Frost and McNaughton 2017) summarized findings from studies on the neural basis of delay discounting by concluding that higher rate of discounting is associated with a set of brain regions linked to valuation (e.g., striatal structures and cingulate), while lower rate of discounting is associated with structures involved in long-term planning (prefrontal structures). This is consistent with the circuits found to be of relevance in our study.

More specifically, our findings showed that the dlPFC–mPFC connectivity was the mediator for the relationship between achievement motivation and delay discounting. Previous studies have shown that the dlPFC is a key region responsible for cognitive control in delay discounting task (McClure et al. 2004; Figner et al. 2010b), while the mPFC is involved in the representation of the incentive value of a broad range of different classes of rewards (Chib et al. 2009; Peters and Büchel 2010). The dlPFC has been found to play a role in top-down modulation of other brain areas which includes the region of mPFC (Miller and Cohen 2001). Hare et al. (2009) has found that the dlPFC processes self-control by modulating the value signal encoded in the vmPFC. Speculatively, individuals with high achievement motivation may be focused so much on reward that inhibitory effects of the dlPFC on mPFC was attenuated, which could be reflected by a reduced anti-correlation between dlPFC and mPFC in our study. Indeed, the present results suggest that the dlPFC–mPFC functional coupling is vital for the association between achievement motivation and delay discounting.

This study has several limitations. First, we assessed achievement motivation only with the self-reported scale, so further studies are needed to confirm the present result with other measurements of achievement motivation, like the method by content coding of picture story (Brunstein and Heckhausen 2018). Second, we only chose ROIs from the valuation network and the cognitive control network, so future research should examine if other networks also play important roles in the relationship between intertemporal choice and achievement motivation.

In conclusion, our results provided evidence that achievement motivation contributed to preference for immediate-sooner reward in intertemporal choice, mediated by dlPFC–mPFC functional coupling. The findings suggest that intrinsic prefrontal organization plays a critical role in translating inherent motivation into decision making.

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Compliance with ethical standards

Conflict of interest The authors assert that they have no competing final or personal interests.

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