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# The mediating role of LPFC–vmPFC functional connectivity in the relation between regulatory mode and delay discounting

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## HIGHLIGHTS

- We explored the effect of regulatory modes on delay discounting (DD) using RSFC.
- DD negatively correlated with assessment, but positively correlated with locomotion.
- Regulatory mode can be represented by LPFC–vmPFC functional coupling.
- Effect of regulatory mode on DD is mediated by LPFC–vmPFC functional coupling.

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## ABSTRACT

Previous studies have shown that regulatory mode orientation can affect many human behaviors, such as risk-taking, counterfactual thinking and economic decision making. However, little is known about how regulatory mode affects delay discounting. To address this question, we used resting-state functional magnetic resonance imaging (rs-fMRI) to investigate whether regulatory mode orientations can be represented by functional connectivity and the influence of two regulatory modes (assessment and locomotion) on delay discounting. The behavioral results showed that delay discounting was negatively correlated with assessment scores but positively correlated with locomotion scores. Neuroimaging results indicated that the functional connectivity between lateral prefrontal cortex (LPFC) and ventromedial prefrontal cortex (vmPFC) was negatively correlated with assessment scores but positively correlated with locomotion scores. Furthermore, mediation analysis showed that the effect of regulatory mode on delay discounting is mediated by LPFC–vmPFC functional connectivity. These results suggested that people's regulatory mode orientation could predict delay discounting, which is mediated by LPFC–vmPFC functional connectivity. Therefore, the present study extends our perspective on regulatory mode and provides neural mechanism for understanding the link between regulatory mode and delay discounting.



## 1. Introduction

In goal-pursuit, people self regulate their behaviors through two essential orientations: assessment and locomotion [1,2]. Assessment constitutes the comparative aspect of self-regulation. It is concerned with critical evaluation of entities or states, such as goals or means in relation to alternatives in order to judge relative quality [2]. For example, an individual may assess preferences among alternatives, and how well he or she performed in the past. Individuals strong in assessment mode are preoccupied with these comparative judgments. In contrast, locomotion is the self-regulatory aspect concerned with movement from state to state and with committing the psychological resources that will initiate and maintain goal-directed progress in a straightforward and direct manner, without undue distractions of delays [2]. In the locomotion mode, individuals emphasize "doing", "getting on with it", "making something happen" rather than critical evaluation. Previous studies have shown that regulatory mode orientation can affect many human behaviors, such as risk-taking, counterfactual thinking and economic decision making [3–5]. However, little is known about how regulatory mode affects delay discounting.

Regulatory mode theory proposes that assessment and locomotion are independent and can be manifested chronically as a personality disposition [1,2,6]. The independence of the two modes allows for a possible predominance of one mode over the

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other. In the context of decision-making, regulatory mode has been included as individual characteristics, which may account for choice behavior [7]; but surprisingly, there is little empirical evidence on its relation with intertemporal choice. Higgins et al. [1] pointed out that individuals strong in assessment mode are more likely to critically evaluate options and relate future actions to critical standards in order to make the most appropriate decision. Such "evaluative criticism" leads assessors to make fewer impulsive choices, because they will compare current states to future outcomes to secure their interests in the long run. However, individuals with a strong locomotion tendency are motivated to quickly engage in activities, perceiving them as ends in themselves rather than means. Thus, they are presumed to live for the sake of the moment with less regard for future consequences of their actions. Furthermore, with respect to consuming behavior, locomotion (initiation and maintenance) prompts one to initiate compulsive or planned spending, presumably accruing less savings for the future. Assessment involves making budgets, keeping track of spending and setting financial goals, which can lead to increase in savings for the future by controlling overall spending. Thus, low locomotion and high assessment lead to more savings in the spending domain. In addition, the two different mode orientations induce distinctive preferences for decisional strategies: assessors prefer "full evaluation" strategy, whereas locomotors prefer "progressive elimination" strategy [8,9]. Hence, we expected that when assessment overrides locomotion, lower delay discounting would be in intertemporal choice; when locomotion overrides assessment, steeper delay discounting would be.

Generally, delay discounting is an important indicator of impulsivity of intertemporal choice, which refers to the degree of preference for smaller but immediate rewards over larger but delayed ones. The extent of preference for delayed rewards is captured by the discount rate, which expresses the subjective value of a delayed reward declines as a function of delay. Discounting rates vary between individuals, and are relatively stable over time [10]. Recently, functional magnetic resonance imaging (fMRI) studies have shown that the neural mechanisms underlying delay discounting mainly involved three distinct brain networks: valuation network (such as ventromedial prefrontal cortex, posterior cingulate cortex and ventral striatum), cognitive control network (such as lateral prefrontal cortex, anterior cingulated cortex), and prospection network (such as hippocampus, amygdala) [11–15]. Furthermore, some studies have suggested that the vmPFC plays a central role in intertemporal decision-making. First, neuroimaging studies of delay discounting have found that BOLD activity in vmPFC scales with the subjective value of the options being considered [13,14]. Second, values are assumed to be represented in vmPFC but are subject to top–down modulation by prefrontal control regions such as the lateral PFC in the self-control model [15,16].

Additionally, previous studies have found that assessment was positively related to the perceived value of the goals but negatively related to risk taking [4,17]. These results suggested that regulatory mode may be linked to the valuation and cognitive control network. Importantly, cognitive neuroscience research have suggested that successful self-regulation is dependent on top–down control from the prefrontal cortex over subcortical regions involved in reward and emotion [18,19]. Therefore, we anticipated that regulatory mode would be linked to coupling between the cognitive control and valuation networks.

Interestingly, Li et al. [20] found that the resting-state functional connectivity (RSFC) of the brain regions in delay discounting task (DDT) related networks was significantly correlated with participants' discounting rate among healthy individuals. This finding suggested that resting-state functional organization of the human brain may be a biomarker of impulsivity and can predict economic decision-making behavior. Therefore, RSFC may offer a valuable tool for analyzing the neural basis of individual variation in impulsive decision-making.

The present research was conducted to investigate the effect of regulatory mode on delay discounting using RSFC. We used the locomotion and assessment scale [2] to assess the individuals' chronic regulatory mode. Based on previous studies, we anticipated that assessment scores would be negatively related to delay discounting, whereas locomotion scores would be positively related to delay discounting. To identify the neural mechanism responsible for the influence of regulatory mode on delay discounting, we used a vmPFC mask from the meta-analysis on valuation [21] as seed to calculate the voxel-wise functional connectivity because vmPFC may have a crucial role in delay discounting. We first examined functional connectivity maps from the vmPFC correlated with delay discounting. We then used mediation analyses to test whether RSFCs plausibly contributed to the link between delay discounting and regulatory mode.

## 2. Methods

### 2.1. Participants and procedure

Eighty-two college students were recruited for the study, and they were paid for their participation. All subjects gave informed consent, and none had a history of neurological or psychiatric disorder. The experimental protocol was approved by the Institutional Review Board of the Southwest University. We removed eight participants due to excessive head movement in the resting-state fMRI analysis, and 74 subjects remained (38 female, 36 male; age range = 17–26, $M = 20.2$; all right-handed). All subjects completed the resting-state fMRI scan prior to behavioral measures, which contained the locomotion and assessment scales [2] and delay discounting task.

### 2.2. Measures

#### 2.2.1. Regulatory mode

The locomotion and assessment scales [2] constitute two separate 12-item self-report measures designed to tap individual differences in these tendencies, which measures chronic individual differences in the strength of locomotion orientation and assessment orientation. Specifically, respondents rate the extent to which they agree with self-descriptive statements reflecting locomotion (e.g., "By the time I accomplish a task, I already have the next one in mind") or assessment (e.g., "I spend great deal of time taking inventory of my positive and negative characteristics"). Ratings are made on a 6-point Likert type scale with the response alternatives anchored at the ends with 1 (strongly disagree) to 6 (strongly agree). We computed assessment and locomotion scores separately by summing responses to each item. Previous studies have demonstrated that the locomotion and assessment scales have satisfactory reliability and validity [2,22]. In this sample, the two scales were not significantly correlated ($r = -0.075$, $p = 0.520$).

#### 2.2.2. Delay discounting

We administered a modified version of delay discounting task [13], 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, 120 days) and one of ten add-percentages (10–500%) of the immediate reward, thus there were 50 unique choices. Participants were allowed as much time as they desired to make decision. Responses were made by pressing one of two buttons corresponding to immediate or delayed rewards.