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Research report

The effect of regulatory mode on procrastination: Bi-stable parahippocampus connectivity with dorsal anterior cingulate and anterior prefrontal cortex

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ABSTRACT

Previous research has elucidated that procrastination can be influenced by regulatory mode orientations. However, the neural mechanism of regulatory modes affecting procrastination is not well understood. To address this question, we employed resting-state functional magnetic resonance imaging (RS-fMRI) to test the influence of two regulatory modes (assessment and locomotion) on procrastination. The behavioral results showed that procrastination was positively correlated with assessment orientation but negatively correlated with locomotion orientation. Neuroimaging results indicated that the functional connectivity between parahippocampal cortex (PHC) and dorsal anterior cingulate (dACC) was negatively correlated with assessment scores, while the functional connectivity between anterior prefrontal cortex (aPFC) and parahippocampal cortex (PHC) was negatively correlated with locomotion scores. Critically, mediation analysis showed that the different effects of two distinct regulatory modes on procrastination were mediated by PHC-dACC and aPFC-PHC functional connectivity respectively. These results suggested that people's procrastination could be predicted by regulatory mode orientations, which is mediated by PHC connectivity with dACC and aPFC respectively. The present study extends our knowledge on procrastination and provides neural mechanism for understanding the link between regulatory mode orientations and procrastination.

1. Introduction

Procrastination – the voluntary but irrational delay of an intended course of action [1–3] – is a widespread phenomenon. It is harmful to our psychological, physical and financial well-being [2,4]. Procrastination has been suggested as a stable trait and influenced by a number of individual traits, including impulsiveness [2,5], conscientiousness [5–7] and perfectionism [8,9]. Previous research has indicated that regulatory mode orientations, as different personality dispositions, may influence procrastination in differed manners [10].

In goal-pursuit processes, people regulate their behaviors through two essential orientations: assessment and locomotion orientation [11,12]. According to Kruglanski et al. [12], assessment orientation constitutes "the comparative aspect of self-regulation concerned with critically evaluating entities or states, such as goals or means in relation to alternatives in order to judge relative quality" [11,12]. By contrast, locomotion orientation "constitutes the aspect of self-regulation concerned with movement from state to state and with committing the psychological resources that will initiate and maintain goal-related movement in a straightforward manner, without undue distractions or delays" [11,12]. Higgins and colleagues have proposed that assessment and locomotion modes function independently as personality dispositions [11,12]. In goal-directed behaviors, the regulatory mode is an individual characteristic that may account for many human behaviors, including counterfactual thinking, intertemporal choice and risk-taking [10,13–15]. Pierro et al. has proposed that regulatory modes may influence procrastination [10]. In order to "do the right thing", individuals with strong assessment orientation invest more effort in comparisons and critical thinking, including critically evaluating alternatives and relating their own past and potential future actions to critical standards which can hardly meet their need [10,12,15]. Their insistence on elevated standards may lead them to experience negative emotion due to anticipated unsatisfactory outcomes [10,11,15]. This negative episodic prospection is often accompanied by procrastination [16,17]. In contrast, individuals with strong locomotion orientation value "moving on" to pursue the next goal rather than dwelling on the past and engaging in critical comparison [12,15]. Thus, they are more likely to initiate goal-related actions quickly and maintain these actions

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without undue distractions or delays [10,11,18]. Pierro et al. have also demonstrated that procrastination was positively related to assessment orientation but negatively related to locomotion orientation [10]. However, little is known about the neural mechanism underlying the effect of different regulatory modes on procrastination.

Recently, functional magnetic resonance imaging (fMRI) studies were conducted to investigate the neural substrates underlying procrastination and have found three key regions involved in procrastination, including parahippocampal cortex (PHC), ventromedial prefrontal cortex (vmPFC) and anterior prefrontal cortex (aPFC) [2,5,17]. Specifically, previous studies have demonstrated that PHC is a key region responsible for episodic or semantic prospection [19,20]. Its increased activity evoked by episodic prospection is accompanied with procrastination [17]. Meanwhile, extensive literature has suggested that the activity in the vmPFC may support integrating information from episodic memory, self-directed cognition and emotion [21]. The enhanced procrastination was correlated with the hyper-activity in the vmPFC through hampering the top-down control signals of the prefrontal cortex [22–25]. In addition, it has been found that the aPFC could exert cognitive and emotional control over temporal-based action to help individuals focus on task goal in the future [24,26]. The inhibitory effect of aPFC on procrastination is achieved by suppressing the activity of the hub regions in the DMN (Default Mode Network), including PCC and the amPFC [17].

Interestingly, regulatory mode orientations as a personality disposition vary among different persons, but relatively stable across situations and over time on the same individual [11]. Previous studies have shown that individuals with strong assessment mode are inclined to relate past and possible future actions to critical standards to ensure that they are doing'the right thing'[10–12,14,15,27]. Thus, assessment mode orientation is associated with more activities recalling the past and imaging possible future actions [15,27]. Thus, high (vs. low) assessment orientation may be reflected by hyper activity of episodic memory/episodic future thinking regions. In contrast, individuals strong in locomotion want to "move on" to the next goal pursuit rather than dwell on the past [11,12,15]. Previous studies indicated that locomotion is positively associated with self-maintenance and resistance to distraction due to individuals' high intrinsic motivation [11,12,15]. Therefore, high (vs. a low) locomotion should be associated with less episodic memory/episodic future thinking and better volition inhibition ability. Thus, locomotion should be positively related to volition inhibition reflecting in the hyper activity of prefrontal cortex, but negatively related to the activity in episodic-related brain regions [10,15,26,28]. These findings suggested that regulatory mode orientations may mainly involve brain regions responsible for episodic memory, episodic future thinking, and volition inhibition. Importantly, cognitive neuroscientific research has suggested that successful self-regulation depends on top-down control from the prefrontal cortex over subcortical regions involved in emotion and reward [13,29,30]. Therefore, we anticipated that regulatory modes would be linked to the coupling between brain regions that involve cognitive control and episodic memory/future thinking. As mentioned above, procrastination were also mainly involved with episodic memory/future thinking regions and cognitive control regions, including PHC and aPFC [17,31]. Therefore, the current study attempted to further investigate the neural mechanism of regulatory modes on procrastination. More specifically, we aimed to investigate the coupling between episodic memory/future thinking regions and cognitive control regions in regulatory modes and understand how it affects procrastination.

Resting state functional connectivity (RSFC) has been demonstrated as an effective method for analyzing the neural basis of individual variations in procrastination [17,31,32]. Employing RS-fMRI, the current study attempted to investigate the effect of regulatory modes on procrastination. We assessed individuals' chronic regulatory mode orientations and procrastination using two scales [12,33]. We expected that assessment scores would be positively related to procrastination, whereas locomotion scores would be negatively correlated to procrastination. To identify the neural mechanism responsible for the influence of regulatory modes on procrastination, three spherical ROIs – PHC, vmPFC and aPFC were defined. They served as seeds to calculate the voxel-wise functional connectivity given their crucial role in procrastination [17]. First, we examined the functional connectivity related with procrastination and regulatory modes respectively. Then, mediation analyses were performed to test whether RSFCs plausibly contributed to the link between procrastination and regulatory modes.

2. Methods

2.1. Participants and procedure

The study was approved by the Institutional Review Board of the Southwest University. All participants were given informed consent. 66 right-handed college students were recruited for the study, and they were paid 50 yuan (RMB) for their participation. Four participants were removed due to excessive head movement ($>$ 2 mm) in the resting-state fMRI analysis, and 62 participants remained (48 females, 16 males; age range = 17–26, M = 21.18). All participants completed the resting-state fMRI scan before behavioral measures, which contained the Locomotion and Assessment scales and General Procrastination Scale.

2.2. Measures

2.2.1. Regulatory mode

The Locomotion and Assessment scales [12] constitute two separate 12-item self-report measures designed to tap individual differences in the strength of locomotion 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") and assessment orientation (e.g., "I spend a great deal of time taking inventory of my positive and negative characteristics"). Ratings are made on a 6-point Likert-type scale ranging from 1 (strongly disagree) to 6(strongly agree). Two composite scores (one for locomotion and one for assessment) were computed by summing across responses to each item Higher scores indicate stronger assessment or locomotion orientation. The Locomotion and Assessment scales have satisfactory reliability and validity [12,34]. The two scales in our own sample were independent from each other (r = 0.06, p = 0.645).

2.2.2. Procrastination

The General Procrastination Scale (GPS) designed by Lay was used to measure trait-procrastination. GPS contains 20 items involving learning activities and daily life behavior (e.g., "I often find myself performing tasks that I had intended to do days before.", "I do not do assignments until just before they are to be handed in", etc.). All items were rated on 5-point Likert-type scale with the response alternatives anchored at the ends with 1 (extremely uncharacteristic) to 5(extremely characteristic). The aggregate scores were computed by summing across responses to each item where higher scores indicate greater procrastination. Previous studies have demonstrated that the GPS have satisfactory internal consistencies [33].

2.3. fMRI data acquisition

Resting state functional MRI scans were collected with a Siemens TRIO 3.0T MRI scanner (Siemens Magnetom Trio TIM, Erlangen, Germany). Functional images were acquired with a T2-weighted echo-planar imaging sequence (echo time = 30 ms; repetition time = 2 s; field of view = 20 cm, matrix = 64 × 64) with 33 axial slices (slice gap = 3 mm; voxel size = 3 × 3 × 3 m^3). During resting state scanning, participants were instructed to keep their eyes closed, thought of nothing, but no sleep allowed, and remained motionless as

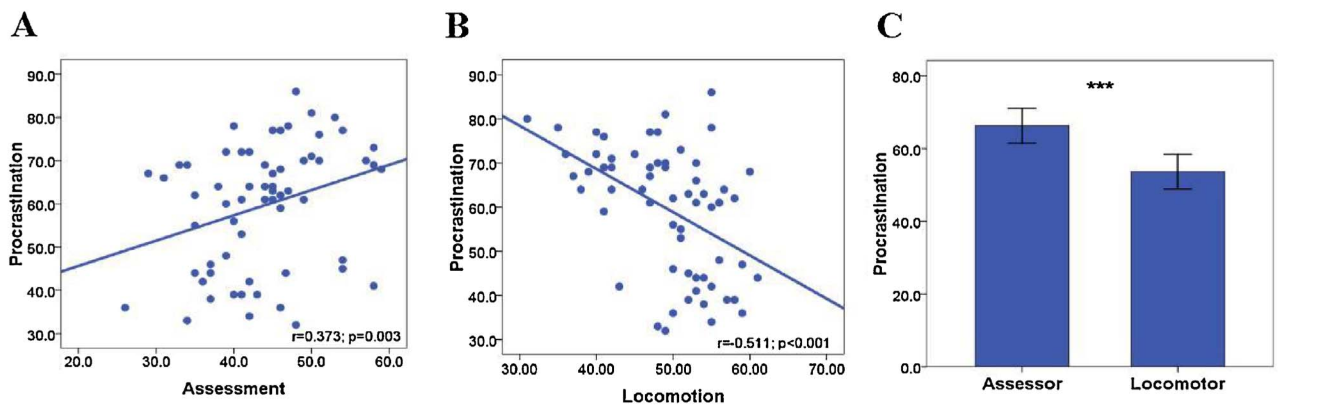

Fig. 1. Behavior results.A: significant positive correlation between procrastination and assessment orientation ($r = 0.373$; $p = 0.003$); B: significant negative correlation between procrastination and locomotion orientation ($r = -0.511$; $p < 0.001$); C: Splitting all participants into two groups of assessors and locomotors, and assessors showed a significantly higher procrastination than locomotors ($T = 3.798$, $df = 60$, $p < 0.001$). ***: $p < 0.001$.

much as possible. The resting scan lasted for 8 min (corresponding to 240 brain volumes). At the end, T1-weighted were also recorded with a total of 176 slices at a thickness of 1 mm and in-plane resolution of 0.98 × 0.98 mm (TR = 2530 ms; TE = 3.39 ms; flip angle = 7°; FOV = 256 × 256 mm^2).

2.4. fMRI data analysis

Data processing were performed using Data Processing Assistant for resting-state fMRI (DPARSF) and REST toolbox [35,36]. The first ten images were discarded to ensure that steady state tissue magnetization was reached. The raw data were corrected for temporal shifts between slices and spatially realigned to estimate and modify the six parameters of head movement. The T1-weighted images were co-registered to the EPI mean images and then segmented into white matter, gray matter, and Cerebrospinal fluid (CSF). Then, these images were normalized to MNI space in 3 × 3 × 3 mm^3 voxel sizes. The normalized data were smoothed with a Gaussian kernel of 4 mm full width at half maximum. Next, we regressed the motion data out of the time series and then preformed band pass temporal filtering (0.01–0.08 Hz) on the residual signals to reduce the effect of head motion and obtain low-frequency fluctuation from resting state fMRI data [37,38]. To further reduce nuisance signals, we regressed out the global mean signal, white matter signal and CSF signal [39].

To investigate functional network of procrastination in resting-state, we selected three brain regions – PHC, vmPFC, and aPFC (see Fig. 2A) known to be involved in procrastination. We defined spherical seed regions of interest (ROI) (diameter = 6 mm) centered at each of these coordinates: PHC (MNI: −36,−18,−30), vmPFC (MNI: 9,42,24), aPFC (MNI: 39,48,6) to calculate the voxel-wise functional connectivity respectively [17]. In the first-level analysis, for each individual, the average BOLD signal time courses within each seed ROI were correlated with every voxel in the whole brain using Pearson's correlation coefficient. Individual-level correlation maps of all voxels that were correlated with the seed ROI's time series were produced. These individual-level correlation maps were converted to normally distributed Z-value maps using Fisher z-transformed to allow for group-level random effects analysis. Then, to determine brain regions that have significantly functional connectivity with three seed ROIs, we performed random effect one-sample *t*-tests of individuals' *z*-valued functional connectivity maps in a voxel-wise manner with a threshold of $p < 0.05$(FDR correction). Further, positive and negative functional connectivity maps of the seed ROIs were saved as masks for subsequent analyses. In the group-level analyses, to test the link between functional connectivity of seed ROIs and procrastination, a correlation analysis was conducted between individuals' z-valued functional connectivity maps from seed ROIs and procrastination score for each participant. Regions from the correlation analysis that survived a height threshold of $p < 0.05$ at the voxel level and an extent threshold of Alphasim correction (voxel size ≥ 85) at the cluster level were saved as ROIs for subsequent analyses. To further examine the relation between regulatory modes and seed ROIs functional connectivity that is significantly correlated with procrastination, the connectivity value (Fisher's z-score) between three seed ROIs and each ROI was extracted from seed ROI's connectivity map for each participant. Finally, we conducted mediation analyses to explore which functional connectivity between PHC, vmPFC, aPFC and ROIs potentially contributed to the link between procrastination and regulatory modes.

3. Results

3.1. Behavioral results

To examine the link between regulatory modes and procrastination, we used two different approaches following previous research [40]. First, we computed the Pearson correlation between two regulatory modes scores and procrastination scores. Results showed that the scores of procrastination were positively correlated with assessment scores ($r = 0.301$; $p = 0.018$; see Fig. 1A), while negatively correlated with locomotion scores ($r = -0.468$; $p < 0.001$; see Fig. 1B). Second, we examined this effect in a categorical rather than continuous manner. In order to compare the difference of procrastination in a categorical manner, participants were split into two groups – assessors and locomotors based on their regulatory modes scores. Specifically, we first converted participants' assessment and locomotion scores to normally distributed z-scores. Then, participants whose $Z_{assessment}$ scores were greater than $Z_{locomotion}$ were categorized as the assessors ($n = 29$), and other participants as locomotors ($n = 33$). Two-sample T test results showed that assessors scored higher in procrastination than locomotors did ($T = 3.798$, $df = 60$, $p < 0.001$; see Fig. 1C). These results suggest that individual differences in regulatory mode orientations predicted procrastination behavior.

3.2. Resting-state functional connectivity results

First, a correlation analysis was conducted to investigate whether procrastination can be predicted by functional connectivity that used PHC, vmPFC and aPFC as seeds. Voxel-wise functional connectivity results showed that procrastination scores were negatively correlated with functional connectivity between PHC and right dorsal anterior cingulate (dACC), vmPFC and left inferior frontal gyrus(IFG), aPFC and left parahippocampal cortex (PHC). Procrastination scores were positively correlated with the functional connectivity between vmPFC and right medial frontal gyrus (MFG) (see Fig. 2 and Table 1).

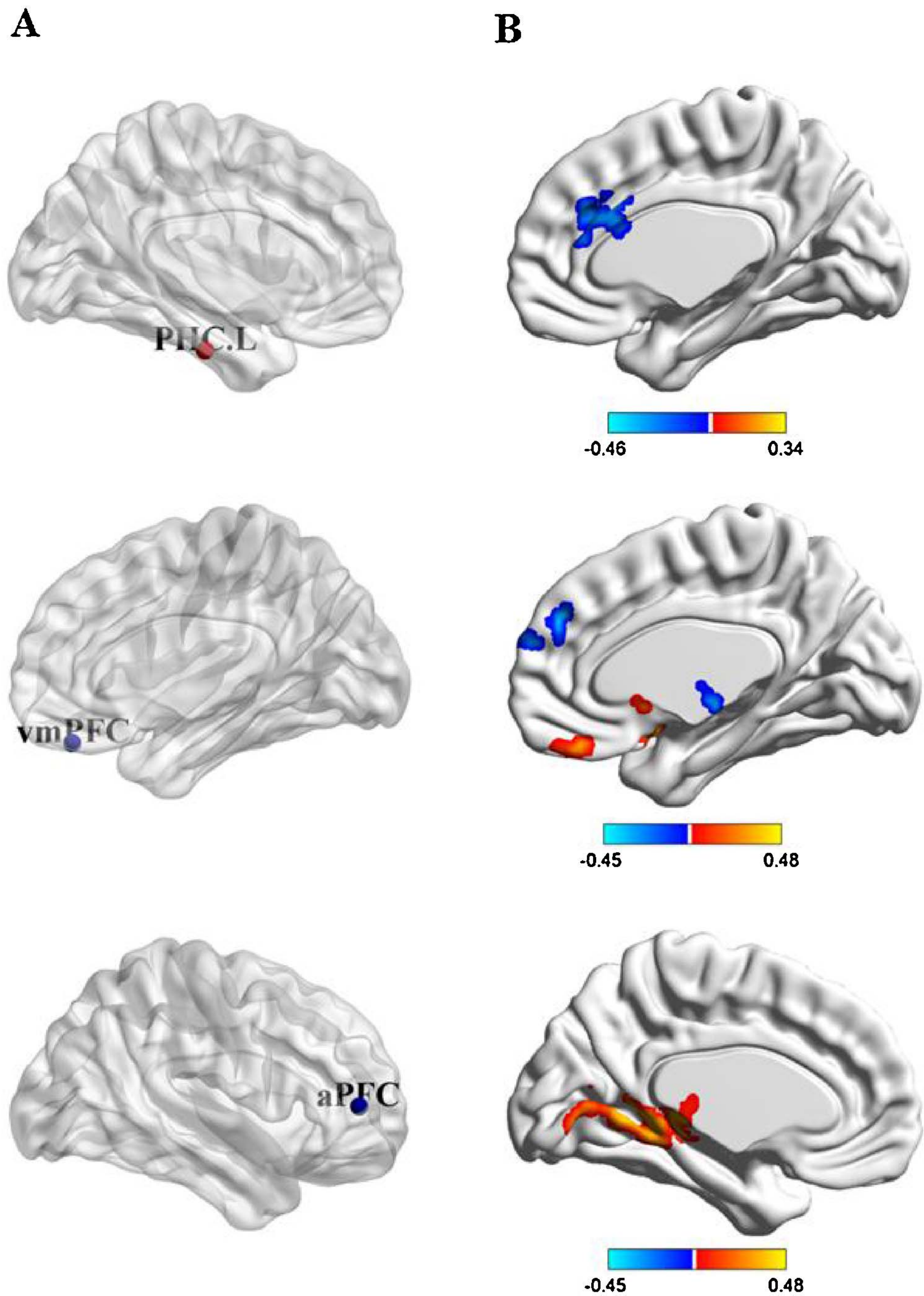

Fig. 2. Resting-state functional connectivity results. A: defined spherical seed regions of interest (ROI) (diameter = 6 mm); B:Functional connectivity between seed ROIs and other brain regions was significantly correlated with procrastination ($p < 0.05$; Alphasim corrected, *cluster size* > 85).

Table 1
Functional connectivity correlated with GPS ($p < 0.05$; Alphasim corrected, *cluster size* > 85).

Seed	Region	BA	voxels	x	y	z	correlation coefficient
PHC	R. Limbic Lobe/Anterior Cingulate	32/24	86	6	24	27	−0.386
vmPFC	L. Frontal Lobe/Rectal Gyrus	11/47/25/34/28/38	427	−6	51	−24	0.361
	R. Frontal Lobe/Medial Frontal Gyrus	9/10	100	6	48	30	−0.317
	L. Frontal Lobe/Inferior Frontal Gyrus	13/47/45	188	−27	21	−3	−0.500
	R.Sub-lobar/Lentiform Nucleus/Putame	47/13	220	18	3	3	−0.513
aPFC	L. Limbic Lobe/Parahippocampa Gyrus/Hippocampus	30/29/18/19/27/31/35	279	−21	−33	−3	0.511

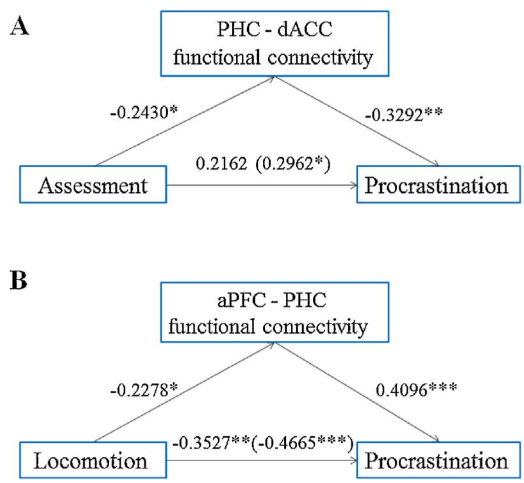

Fig. 3. Mediation results. Path analysis showed that the link between assessment mode and procrastination is mediated by the PHC-dACC functional connectivity (A), and the link between locomotion mode and procrastination is mediated by the aPFC-PHC functional connectivity (B). *: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$.

Second, a correlation analysis was performed to test the relationships between regulatory mode orientations and functional connectivity among brain areas that are correlated with procrastination. Results showed that PHC-dACC functional connectivity was negatively correlated with assessment scores ($r = -0.245$, $p = 0.055$), while aPFC-PHC functional connectivity was positively correlated with locomotion scores($r = -0.277$, $p = 0.03$). There was no other functional connectivity significantly correlated with regulatory mode orientations. These results suggest that individual differences in regulatory mode orientations were predicted by PHC-dACC and aPFC-PHC functional connectivity respectively.

Finally, we used the INDIRECT procedure in SPSS to further examine the mediating process through which regulatory modes influence procrastination [41–43]. To test our mediation hypothesis, we performed mediation analyses testing a model with the mediating role of the RSFC. Among these RSFCs, the PHC-dACC functional coupling was a significant mediator between assessment mode and procrastination. The aPFC-PHC functional coupling was a significant mediator between locomotion mode and procrastination. Using the INDIRECT procedure with 5000 bootstrap samples, we estimated (1) the indirect effect of assessment mode on procrastination through PHC-dACC functional connectivity and (2) the indirect effect of locomotion mode on procrastination through aPFC-PHC functional connectivity. Results revealed a significant indirect effect of PHC-dACC functional connectivity in the relation between assessment mode and procrastination (point estimate = 0.08, 95% percentile CI = 0.0018 to 0.1841; see Fig. 3A). Similarly, the indirect effect of aPFC-PHC functional connectivity in the relation between locomotion mode and procrastination was also significant (point estimate = = -0.1138, 95% percentile CI = -0.2230 to -0.0180; see Fig. 3B). Accordingly, these results suggested that the influence of assessment and locomotion on procrastination was mediated by the PHC-dACC and aPFC-PHC functional connectivity respectively.

4. Discussion

Employing RSFC, the present study investigated the influence of regulatory mode orientations on procrastination. Behavioral results showed that procrastination was positively correlated with assessment orientation, but negatively correlated with locomotion orientation. Neuroimaging results revealed that PHC-dACC functional connectivity was negatively correlated with assessment orientation, while aPFC-PHC functional connectivity was negatively correlated with locomotion orientation. Furthermore, mediation analysis results indicated that the influence of two distinct regulatory modes on procrastination was mediated by PHC-dACC and aPFC-PHC functional connectivity respectively. In sum, these results extended our knowledge on procrastination, and provided neural mechanism for understanding the link between regulatory modes and procrastination.

The present study showed that assessment orientation was positively correlated with procrastination, while locomotion orientation was negatively correlated with procrastination. "Assessors" prefer to evaluate their past and anticipatory future decision outcomes/actions with strict standards to ensure that they are doing the right thing [12,14,15,27]. Their insistence on such high standards may increase their negative emotion because their needs are difficult to meet [5,10,12]. Avoidance to negative emotion produced by negative episodic thinking lead to enhanced procrastination [16,17]. In contrast, "locomotors" are motivated to engage in activities immediately. They are intrinsically motivated to accomplish task early with their persistence and resistance to distraction [10,11,18]. Our findings are consistent with previous research exploring the relations of locomotion and assessment orientation to individuals tendency toward procrastination [10].

Functional connectivity analysis revealed that the PHC-dACC functional connectivity was negatively correlated with assessment orientation, while the aPFC-PHC functional connectivity was positively correlated with locomotion orientation. Pierro et al. proposed that assessment was positively related to recalling past and anticipating possible future [11,15,27], while locomotion was negatively related to dwelling on the past but positively related to resistance to distraction [10,15]. These results suggested that regulatory modes may be related to episodic memory/prospection and volition inhibition. Neuroscientific studies have demonstrated that PHC plays a critical role in episodic memory and episodic prospection [19,20]. It suggests that PHC may be an important region related to episodic thinking in regulatory modes. In general, aPFC and dACC are key regions in the cognitive control network involved in evaluation and execution of cognitive control and attention regulation [17,26,44–48]. This suggests that aPFC and dACC may be two key regions related to neural representation of cognitive control in regulatory modes. Additionally, cognitive neuroscientific research has suggested that successful self-regulation is dependent on top–down control from the prefrontal cortex over subcortical regions involved in reward and emotion [29,30,49]. In the current study, the connectivity between PHC and dACC was negatively associated with assessment orientation. This suggests that "assessors" are prone to produce more episodic thinking about possible alternatives to past actions and potential negative actions or outcomes in the future given their high standards [15,27]. However, excessive episodic thinking, especially negative episodic thinking inhibit the cognitive monitoring of dACC over goal-direct behaviors [45,50]. The connectivity between aPFC and PHC was negatively associated with locomotion orientation. This suggests that aPFC exerts cognitive and emotional control over PHC to inhibit unnecessary episodic thinking (especially negative future events) and helps individuals focus on task goal in the future without distraction [17,26]. Our results indicated that the modulation of cognitive control to episodic memory/prospection may be the neural representation of regulatory modes, which is consistent with earlier studies.

Importantly, our mediation results suggested that the effects of two distinct regulatory modes on procrastination were mediated by the PHC connectivity with dACC and aPFC respectively. Specifically, assessment orientation influenced procrastination through the PHC-dACC functional connectivity, while locomotion orientation influenced procrastination through the aPFC-PHC functional connectivity. In procrastination, PHC may mainly support episodic future thinking [16,17]. The dACC is a crucial neural substrate for exerting cognitive monitoring toward goal-direct behaviors and focusing attention on task-relevant stimuli [44,47,48]. Peters et al. found that hippocampal episodic predictions [51] influenced choice through modulating information processing in ACC and other prefrontal regions [51,52]. In line with this idea, Johnson et al. found that hippocampus may support decision-making processes through its role in mentally simulating potential future outcomes. It provides downstream prefrontal regions with a prediction signal regarding episodic aspects of a decision outcome [53,54]. Intriguingly, it has been consistently shown that episodic future thinking is associated with procrastination and imaging negative future events made individuals incline to procrastinate [16,17,55]. Our results support findings from previous research, which suggest that the episodic thinking about negative future activated the parahipocampus inhibits cognitive control and attention regulation function of dACC. These processes result in procrastination behaviors. In addition, the aPFC is another key region that is associated with exerting control over emotionally-driven responses and focusing on future goals [17,26,56]. The PFC may play a specific role by modulating activity in other areas [17,28,57]. Hare et al. found that LPFC modulates the value signal encoded in vmPFC through top-down control [57]. Coherent with this notion, the failure of top-down control exerted by aPFC on the DMN was associated with greater procrastination [17]. Our results support previous findings that the aPFC could exert cognitive control over PHC to help individuals focus on task goal in the future, and therefore reduce procrastination. Hence, our mediation results suggested that individuals with higher assessment orientation showed more procrastinating behaviors. This is partially attributed to the fact that they were involved in more negative episodic future thinking, which inhibits their cognitive control and attention regulation toward future goals. Individuals with higher locomotion orientation showed less procrastination possibly because they had stronger cognitive control ability over negative episodic prospection. To sum up, regulatory mode orientations influence procrastination, in part, through PHC connectivity with dACC and aPFC respectively.

Our findings have several implications. First, the present study revealed the neural substrates underlying the effect of regulatory modes on procrastination. More importantly, our findings shed light on the essence of procrastination. We proposed that negative episodic future thinking might be an essential mental process that leads to procrastination. Second, the current study has limitations that we used RSFC and we can only demonstrate the neural basis of procrastination from correlation analyses rather than experimental tasks. Therefore, it would be valuable for future research to explore the experimental paradigm of procrastination and manipulate specific episodic future thinking to further examine the underlying mechanism in procrastination. Third, it should be noted that two distinct orientations of regulatory mode, conceptualized as chronic individual predispositions, may show specific advantages in a given situation. For example, the present study found that individuals high in the locomotion orientation are less prone to anticipate negative futures and experience negative emotion, and they prefer to act timely. However, high locomotors may fail to learn (via counterfactual thinking or anticipation) from past success or failure experience, and therefore they may be more likely to act impulsively and repeat those mistakes in the future [13,15,58].

In summary, procrastination was positively correlated with assessment orientation but negatively correlated with locomotion orientation. Furthermore, the effects of two distinct regulatory mode orientations on procrastination were mediated by the functional connectivity between PHC with dACC and aPFC respectively. Accordingly, the present study extends our knowledge on procrastination and provides neural mechanism for explaining the link between regulatory modes and procrastination.

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