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Individual differences in resting-state functional connectivity predict procrastination

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ABSTRACT

Procrastination is to voluntarily delay an intended course of action and is considered an archetypal human failing. A popular hypothesis is that procrastination is representative of self-regulatory failure. Although there is extensive behavioral evidence consistent with the predictions of this theory, there is no neural evidence for it. To test directly the extent to which individual differences in trait procrastination can be related to resting-state functional connectivity (RSFC) between brain regions implicated in self-regulation, we applied resting-state functional magnetic resonance imaging (RS-fMRI) in a group of 77 healthy participants. RSFC 1) between ventral medial prefrontal cortex (VMPFC) and dorsal lateral prefrontal cortex (DLPFC), 2) between dorsal anterior cingulate cortex (dACC) and caudate, and 3) within ventral lateral prefrontal cortex (VLPFC), negatively predicted the severity of procrastination. These results provide direct evidence for the validity of self-regulatory failure account of procrastination, and implicate that trait procrastination is reflected in the intrinsic functional dynamics of neural systems associated with impulse control, performance monitoring, and behavioral inhibition.

1. Introduction

Procrastination is defined typically as an irrational tendency to delay the beginning or completion of tasks (Ferrari, 1993), and is regarded as a personality trait that has cross-temporal and situational stability (Steel, 2007). Extensive empirical work has been done on procrastination, involving its prevalence (Ferrari, O'Callaghan, & Newbegin, 2005), its cognitive, behavioral, and affective correlates, such as high anxiety, depression, and low self-confidence (Beck, Koons, & Milgrim, 2000; Ferrari, 1994; Flett, Blankstein, & Martin, 1995), and its causes and solutions (Orpen, 1998).

Why do people procrastinate? The potential causes include task aversion, uncertainty, and fear of failure (Zarick & Stonebraker, 2009). Given the voluntary delay that characterizes trait procrastination, it is not surprising that several studies suggest a link between procrastination and impulsivity. Procrastinators tend to choose short-term benefits over long-term gains (Tice & Baumeister, 1997; Ferrari & Díaz-Morales, 2007). Some people frequently procrastinate tasks because they are unable to control their desire for short-term pleasurable activities (Ferrari & Emmons, 1995). These studies suggest that procrastinators may lack the ability to ward off temptations and distractions of fun alternatives.

One of the popular beliefs is that people procrastinate out of self-regulatory failure (Steel, 2007). Previous empirical studies have supported this view, revealing that procrastination is inversely related to self-regulation (Milgram, Sroloff, & Rosenbaum, 1988). Subsequent behavior–genetics research established procrastination as an evolutionary by-product of impulsivity, with overlapping genetic influences accounted for all of the genetic influences on both procrastination and impulsivity (Gustavson, Miyake, Hewitt, & Friedman, 2014). In addition, self-control has been found to be one of best predictors of procrastination (Ferrari & Emmons, 1995; Rabin, Fogel, & Nutter-Upham, 2011).

As the research shows, self-regulation difficulties contribute to procrastination. Steel calls procrastination a "prevalent and pernicious form of self-regulatory failure that is not entirely understood" (2007, p.65), and supports this position with a massive meta-analysis where he develops Temporal Motivation Theory (TMT), creating one of the most comprehensive look at the issue to date. The TMT includes four components: expectancy (expressed by self-efficacy), value (expressed by task aversiveness), sensitivity to delay (expressed by distractibility, impulsiveness, and lack of self-control), and delay itself (expressed by the timing of rewards and punishments). Steel also notes that although "TMT provides an excellent description of procrastination, further confirmation would be desirable" (2007, p. 83).

Given the potential role of self-regulatory failure as both a contributor and outcome of procrastination, it is surprising that little attention has been directed toward the neural basis underlying this casual link. Steel (2010) discussed how the interplay between the limbic system and the prefrontal cortex could lead to procrastination (Steel, 2010); however, there is no direct evidence for the brain correlates of procrastination.

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One way to test the self-regulatory failure account of procrastination is to investigate resting-state functional connectivity (RSFC), which requires no task or stimuli. This task-independent approach detects inter-regional correlations among spontaneous low-frequency (<0.1 Hz) fluctuations in the fMRI signal within distinct functional networks (Biswal, Zerrin Yetkin, Haughton, & Hyde, 1995). Group resting-state studies have identified resting-state networks consisting of anatomically separated, but functionally linked brain regions that show a high level of ongoing functional connectivity during rest (Van Den Heuvel & Pol, 2010). Recent studies have suggested a direct link between resting-state functional connectivity patterns and cognitive behavior (Hampson, Driesen, Skudlarski, Gore, & Constable, 2006), cognitive ability (Takeuchi et al., 2012), and personality (Adelstein et al., 2011; Takeuchi et al., 2013). However, no study has directly linked resting state phenomena and trait procrastination.

Here we examine the extent to which inter-individual differences in trait procrastination can be predicted by inter-individual differences in RSFC within self-regulation related regions. Based on the TMT theory and the converging evidence that procrastinators tend to be impulsive and lacking in self-control (Steel, 2007, 2010), brain regions associated with self-regulation were selected as seeds [regions of interest (ROIs)]. Self-regulation includes three main ingredients: clear and consistent standards/goal, self-monitoring, and operation/goal pursuit (Baumeister & Heatherton, 1996). Neurally, self-regulation requires top-down control of brain reward systems by prefrontal cortex (PFC) control regions (Heatherton & Wagner, 2011). The three main areas of PFC particularly important to self-regulatory functioning are ventral medial PFC (VMPFC), lateral PFC, and anterior cingulate cortex (ACC) (Heatherton, 2011). VMPFC is a key brain area for representing the value of nearly all reward-types on a common scale (see Levy and Glimcher (2012) for a meta-analysis review). The right ventrolateral prefrontal cortex (VLPFC) and dorsolateral prefrontal cortex (DLPFC) are regions that are commonly activated when people are exerting various forms of self-control (see Cohen and Lieberman (2010) for a review). Furthermore, evidence suggests that successful self-control in decision-making depends on the interplay between DLPFC and VMPFC (Hare, Camerer, & Rangel, 2009; Hare, Hakimi, & Rangel, 2014; Saraiva & Marshall, 2015; Steinbeis, Haushofer, Fehr, & Singer, 2014). The dorsal ACC is also known to be crucial for self-regulation by monitoring the conflict and the need for cognitive control (Botvinick, Cohen, & Carter, 2004; Shenhav, Botvinick, & Cohen, 2013).

Probing above seeds derived from previous literature (Hare, Malmaud, & Rangel, 2011; Hare et al., 2014; Levy & Wagner, 2011; Pine et al., 2009), the present study aimed to test the self-regulatory failure account by assessing the relation between trait procrastination and RSFC within self-regulation related brain regions. We predicted that the patterns of RSFC within regions implicated in self-regulation would predict the severity of procrastination. Specifically, we expected a reduced connectivity between these PFC areas in severe procrastinators.

2. Method

2.1. Participants

Seventy-seven right-handed healthy adults (36 men and 41 women, mean age 22.23 ± 2.54 years) participated. Exclusion criteria were general contraindications against MRI, consummation of drugs, excessive consummation of alcohol and nicotine, medication affecting the central nervous system, history of neurologic or psychiatric disorders, and pregnancy. All participants gave written informed consent for participation in the study and were informed of their right to discontinue participation at any time. The study was approved by the local ethics committee.

2.2. Measures

2.2.1. Trait procrastination

Scores were obtained on a Chinese translation of the 20-item, 5-point General Procrastination Scale developed by Lay (1986) in a testing session after MRI scan. The Chinese version showed adequate internal consistency reliability (α = .833) (Chu, Xiao, & Lin, 2010), and had acceptable reliability with the present sample (α = .625). Sample items in the original English version of the scale include “I generally delay before starting on work I have to do” (true-keyed) and “I often have a task finished sooner than necessary” (false-keyed).

2.2.2. Self-control

Scores were obtained on a Chinese version of the 19-item Self-Control Scale (SCS) developed by Tangney, Baumeister, and Boone (2004). The SCS measures dispositional self-regulatory behaviors, which represents the tendency to be disciplined and abrogate impulses. The Chinese version showed adequate internal consistency reliability (α = .862) and test–retest reliability (α = .85) (Tan & Guo, 2008). The alpha coefficient was good in the present sample (α = .864). Example items in the original English version of the scale include “I am good at resisting temptation” (true-keyed) and “sometimes I can't stop myself from doing something, even if I know it is wrong” (false-keyed).

2.3. Data acquisition

Resting state functional MRI scans were collected on a 3.0 GE Discovery MRI-750 scanner. Resting-state functional MRI sequences lasted about 6 min (corresponding to 180 brain volumes). The scanning parameters were as follows: TR = 2000 ms; TE = 30 ms; flip angle = 90°; 43 slices; matrix = 64 × 64; FOV = 220 × 220 mm; slice thickness = 3.2 mm; acquisition voxel size = 3.4 × 3.4 × 3.2 mm. A high-resolution T1-weighted anatomical image was also acquired using a magnetization prepared gradient echo sequence (3D MPRAGE, 176 sagittal slices; TR = 8100 ms; TE = 3.1 ms; T1 = 450; flip angle = 8°; FOV = 250 × 250 mm; slice thickness = 1 mm). During resting state scanning, participants were instructed to just lie quietly in the scanner, keep their eyes closed, and think of nothing in particular and let their mind wander.

2.4. Image preprocessing

Functional MRI data were preprocessed with REST toolbox (www.restfmri.net) (Song et al., 2011) using functions of SPM 8 (www.fil.ion.ucl.ac.uk/spm/software/spm8), comprising the following steps: 1) discarding the first 10 volumes to ameliorate the possible effects of scanner instability, 2) slice timing correction, 3) realignment, 4) co-registering the T1-weighted image to the corresponding mean functional image after realignment, 5) segmentation, 6) spatial normalization, 7) smoothing with a Gaussian kernel of 6 mm full width at half maximum, 8) detrending, 9) regressing out the variance of nuisance covariates: head motion correction as well as the global mean signal, white matter signal and cerebrospinal fluid signal, and 10) filtering ($0.01 < f < 0.1$ Hz).

2.5. Individual seed-based functional connectivity analysis

For seed ROIs, we selected the VMPFC, VLPFC, DLPFC, and dACC, four functionally heterogeneous brain areas known to be involved in self-regulation (Heatherton, 2011). We created spherical seed regions of interest (diameter = 6 mm) centered at each of these coordinates in both the left and right hemispheres: VMPFC [Brodmann's area (BA) 11, MNI coordinates: (−6, 41, −14), (6, 41, −14)] (Hare et al., 2011); VLPFC [BA 45, MNI coordinates: (−48, 28, 18), (48, 28, 18)] (Levy & Wagner, 2011); DLPFC [BA 46, MNI coordinates: (−36, 42, 28), (38, 40, 34)] (Harris, Hare, & Rangel, 2013); dACC [BA 32, MNI coordinates: (−3, 33, 30), (3, 33, 30)] (Pine et al., 2009). Time series were averaged across all voxels in each seed region of interest (ROI). For each individual dataset, the Pearson correlation coefficient between the time series of the seed ROI and that of each voxel in the brain was determined. This analysis was to produce individual-level correlation maps of all voxels that were positively correlated with the seed's time series. Finally, these individual-level correlation maps were converted to Z-value maps using Fisher's r-to-z transformation for subsequent group-level analyses.

2.6. Group-level analyses

With REST toolbox, for each seed region, group-level analyses produced the following two types of thresholded *t*-statistic maps: 1) maps of voxels exhibiting significant positive functional connectivity with the seed across all individuals and 2) maps of voxels whose positive functional connectivity with the seed exhibited significant variation in association with the procrastination score. Multiple comparisons were corrected at the cluster level using Gaussian random field theory ($tp < 0.05$, corrected). Corrected significance level of $p < 0.05$ was obtained using AlphaSim. Head motion parameters, age, and gender (1 for male and 0 for female) were also added as covariates of no interests. Statistical maps were visualized with the BrainNet Viewer (Xia, Wang, & He, 2013; http://www.nitrc.org/projects/bnv/).

The multivariate stepwise logistic regression was performed with procrastination score as dependent variable. The quantitative independent variables included age, self-control score, and the functional connectivity magnitude extracted from each RSFC significantly associated with procrastination. The qualitative independent variable was gender (coded 1 and 0 respectively). The regression equation was derived by the forward stepwise selection of variables using the likelihood ratio test for determining which variables to include in the model (a threshold for inclusion of $p < .05$).

3. Results

3.1. Behavioral assessments

Procrastination was negatively correlated with self-control ($r = -.634$, $p < .001$). No gender differences were found for procrastination ($t(75) = .185$, $p = .771$) and self-control ($t(75) = 1.859$, $p = .947$).

3.2. RSFC–procrastination relationships

RSFC was negatively associated with procrastination within functional connectivity with the VMPFC, VLPFC, dACC seeds. Peak coordinates of these correlations are reported in Table 1. RSFC between the bilateral VMPFC seed and left PFC exhibited significant negative correlation with procrastination ($r = -.32$, $p = .006$ for the left VMPFC seed; $r = -.37$, $p = .001$ for the right VMPFC seed). RSFC within the right VLPFC also exhibited significant negative correlation with procrastination ($r = -.36$, $p = .002$). RSFC between the left dACC seed and right caudate (dorsal striatum, DS) exhibited significant negative correlation with procrastination as well ($r = -.42$, $p < .001$) (Table 1 and Fig. 1).

Stepwise multivariate logistic regression analysis of the procrastination score showed that the self-control score, RSFC between dACC and DS, right VMPFC and left DLPFC, within right VLPFC, and gender were included in the equation (Table 2). Single predictor of dispositional self-control could explain 40.2% of the variance in procrastination (model 1). When RSFC between regions were added in model 4, the percent of the variance explained increased to 60.7% (model 4).

4. Discussion

Our aim was to provide the neural evidence for the self-regulatory failure account of procrastination. Analyses revealed that the intrinsic functional connectivity associated with brain regions typically engaged in self-regulation, including VMPFC, dACC, and VLPFC, negatively predicted the severity of procrastination. These predictors plus dispositional self-control can explain 60.7% of the variance in procrastination. These findings therefore substantiate the proposed self-regulatory failure account of procrastination (Steel, 2007, 2010).

The greatest contributor to procrastination came from dispositional self-control, which represents the tendency to resist temptation and self-discipline (Tangney et al., 2004). This finding agrees with the theory that procrastinators tend to be lacking in self-control (Rabin et al., 2011; Steel, 2007). Importantly, 49.2% of the variance of dispositional self-control was explained by the RSFC within VLPFC, DLPFC, and VMPFC seed regions (Table S1), supporting the view that the PFC plays a pivotal role in self-control (Heatherton & Wagner, 2011).

4.1. VMPFC–DLPFC connectivity

The VMPFC is of crucial importance for adaptive behavior by direct involvement in value comparison in decision making on the basis of expected value (Ullsperger, Danielmeier, & Jocham, 2014). The DLPFC is vital in the executive top-down control of behavior (Cieslik et al., 2012). The circuit between the VMPFC and DLPFC is involved in optimal decision-making. It was shown that the difference between successful and failed self-control lies in the extent to which the DLPFC can modulate the VMPFC valuation system (Hare et al., 2009). The VMPFC may encode the combined value that could directly guide choices, whereas the DLPFC is likely to be involved in the integration of value predictions to facilitate choices in favor of long-term, goal-relevant rewards (Kahnt, Heinzle, Park, & Haynes, 2011). Stronger functional connectivity between VMPFC and DLPFC is associated with better impulse control and less impulsivity (Weygandt et al., 2013), and is related to the improvements in the ability to forego immediate pleasure (Saraiva & Marshall, 2015). On the other hand, reduced functional coupling within the network between VMPFC and DLPFC was reported in schizophrenic patients (Fan et al., 2013). Accordingly, our results demonstrating a reduced connectivity between the VMPFC and DLPFC in procrastinators substantiate the hypothesis of a disturbed connection on value-guided decision-making. The degree to which participants can control their impulses might depend on the interplay between control regions (DLPFC) and value computation regions (VMPFC). A degraded representation of long-term value in VMPFC and DLPFC may result in failures of impulse control and procrastination.

Table 1
MNI coordinates of peak RSFC–procrastination relationships.

Seed	Cluster location	BA	Peak MNI			Cluster size (voxels)	Partial correlation coefficient
			x	y	z		
L.VMPFC	Medial frontal gyrus	32	−15	44	22	87	−0.317
R.VMPFC	Middle frontal gyrus (DLPFC)	9	−22	41	31	88	−0.365
R.VLPFC	Inferior frontal gyrus (VLPFC)	45	42	36	18	127	−0.356
	Middle frontal gyrus (DLPFC)	46	37	35	21	76	−0.283
L.dACC	Caudate	0	14	12	21	69	−0.413

Note. BA, Brodmann's area; VMPFC, Ventral medial prefrontal cortex; VLPFC, Ventral lateral prefrontal cortex; DLPFC, Dorsal lateral prefrontal cortex; dACC, dorsal Anterior cingulate cortex. All values $p < 0.05$ corrected.

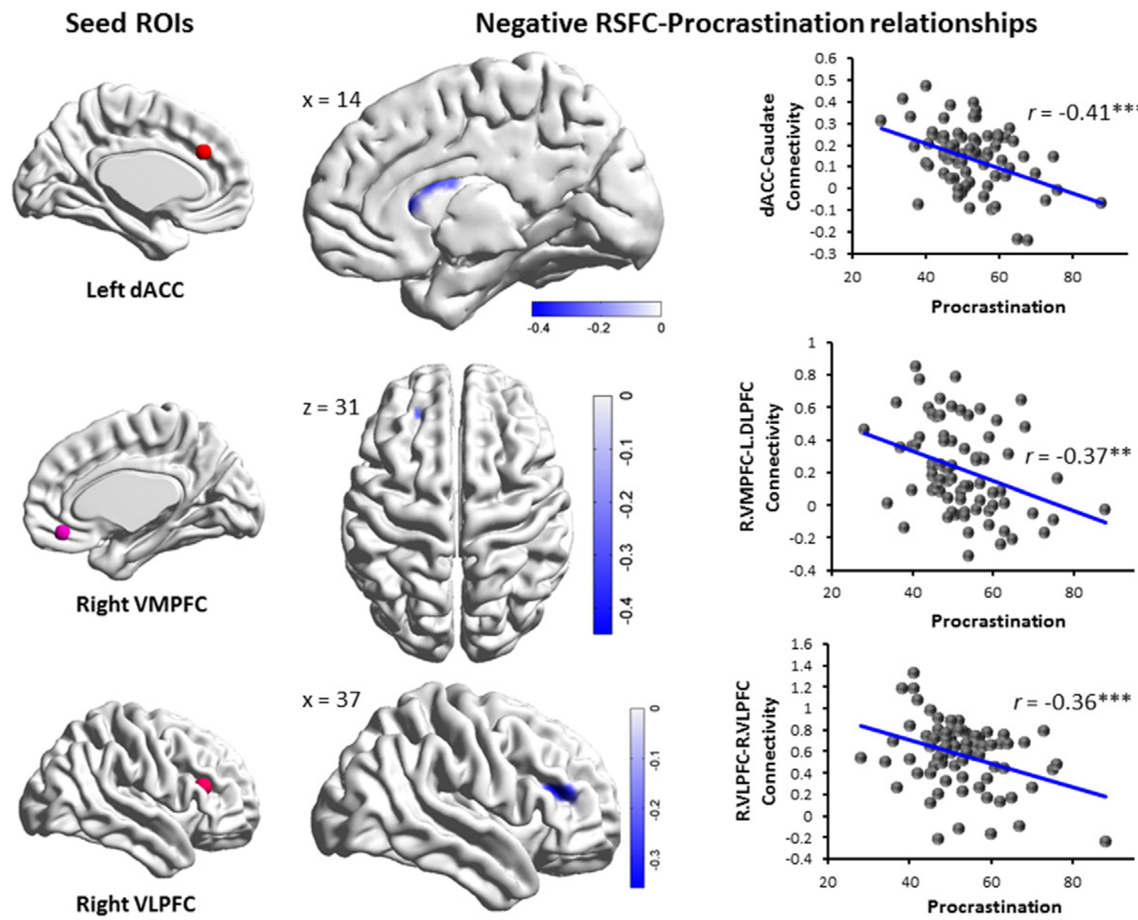

Fig. 1. Negative relationships between RSFC and procrastination. A negative relationship with procrastination was observed for resting state functional connectivity (RSFC) between the right ventral medial prefrontal cortex (VMPFC) seed and left dorsal lateral prefrontal cortex (DLPFC), dorsal anterior cingulate cortex (dACC) seed and caudate, and the right ventral lateral prefrontal cortex (VLPFC) seed and right VLPFC. These relationships are illustrated in the scatter plots comparing RSFC values and procrastination scores (right column).

4.2. dACC-caudate connectivity

The dACC is a key region of performance monitoring system by estimating the expected value of control based on the integrated information about the benefits and costs of actions, in order to signal the necessity, type, and magnitude of cognitive control (Shenhav et al., 2013; Ullsperger et al., 2014). The caudate is involved in coding reward-prediction errors during goal-directed behavior (Haruno & Kawato, 2006). Moreover, research indicates that preference for immediate over delayed rewards is positively correlated with the magnitude of caudate activity (Hariri et al., 2006).

Positive connectivity between dACC and caudate was shown when attempting to resolve the response conflict engendered by multiple response options of varying reward value, supporting the notion that these two areas were functioning in a coordinated fashion (Marsh, Blair, Vythilingam, Busis, & Blair, 2007). Given the attenuated connectivity between the dACC and caudate in severe procrastinators, it is possible that procrastinators may have difficulties in weighting response-outcome values and in linking behaviors to outcomes, which results in failure of performance monitoring and inhibition of counter-goal behaviors (Berkman, Falk, & Lieberman, 2012).

4.3. VLPFC–VLPFC connectivity

The right VLPFC plays a key role in successful inhibition of inappropriate behaviors leading to aversive outcomes (Cohen & Lieberman, 2010). The inverse relationship between the RSFC within right VLPFC and procrastination severity confirms the self-regulatory failure account. Individual differences in the severity of procrastination are associated with the impaired functioning of brain regions that are involved in behavioral inhibition.

Table 2
Coefficients derived by multiple logistic regression analysis to predict procrastination.

Predictors	Model 1			Model 2			Model 3			Model 4			Model 5		
	B	*p*-value	R^2	*B*	*p*-value	R^2	*B*	*p*-value	R^2	*B*	*p*-value	R^2	*B*	*p*-value	R^2
Constant	90.456	<0.001	0.402	89.88	<0.001	0.488	92.534	<0.001	0.555	92.293	<0.001	0.607	92.678	<0.001	0.635
Self-control	−0.611	<0.001		−0.554	<0.001		−0.519	<0.001		−0.492	<0.001		−0.528	<0.001	
dACC-caudate				−21.693	0.001		−21.038	<0.001		−20.753	<0.001		−19.421	0.001	
R.VLPFC-R.VLPFC							−8.644	0.001		−7.911	0.002		−7.279	0.004	
R.VMPFC- L.DLPFC										−8.698	0.003		−10.297	<0.001	
Gender													3.605	0.023	

Note. VMPFC, Ventral medial prefrontal cortex; VLPFC, Ventral lateral prefrontal cortex; DLPFC, Dorsal lateral prefrontal cortex; dACC, dorsal Anterior cingulate cortex.

In sum, the present study found that lack of self-control and reduced connectivity between self-regulation related brain areas contribute to procrastination. These findings may also help to explain neuropathologies that are characterized by lack of self-control, or exaggerated impulsivity, such as drug addiction, aggression, delinquency, pathological gambling, or risky sexual behavior.

4.4. Limitations

This study has some limitations that should be kept into consideration. In fact, this was performed using resting state functional connectivity and thus the neural basis of procrastination resulted from a correlation analysis rather than experimental tasks, therefore our hypothesis will need to be confirmed by specifically-designed activation studies, such as a delay task in which participants are required to choose between an option for completing tedious task immediately and an option for completing task afterwards. Secondly, because functional connectivity only reflects the synchrony of activities of brain regions, not all of the regions anatomically connected to a prior region can be found by the kind of analysis based on ROI. Another potential limitation to this study includes the seed-based RSFC, which selects a priori regions of interest. A potential strategy would have been to select regions of interest based on previous neuroimaging studies of procrastination. However, null published results did not make this a practical option. ROIs in the present study were limited in regions associated with self-regulation. Future work using RSFC can systematically interrogate other regions and networks to gain further insights into the functional specialization of procrastination.

5. Conclusions

Our data suggest that increasing procrastination was associated with reduced functional connectivity between brain areas involved in self-regulation, supporting the self-regulatory failure account of procrastination. Weakened functional connectivity between VMPFC and DLPFC, dACC and caudate, and within right VLPFC appears to be relevant for procrastination. It may be speculated that this is associated with the inability of procrastinators to weight value of options and maintain goal-directed representations, resulting in failure to control impulse and inhibit inappropriate behaviors. Our results suggest that RSFC can be used to probe the neural root causes of procrastination, and thus may serve to facilitate effective efforts to stem the tide of procrastination in society.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.paid.2016.02.016.

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