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Outcome value and task aversiveness impact task procrastination through separate neural pathways

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Abstract

Temporal decision model of procrastination has proposed that outcome value and task aversiveness are two separate aspects for deciding to procrastinate a task or not. If true, there should be separate neural pathways to mediate the effect of outcome value and task aversiveness on procrastination. Outcome value is plausibly constructed via a hippocampus-based pathway because it relies on episodic future thinking. In contrast, task aversiveness might be represented through an amygdala-involved pathway. In the current study, participants underwent fMRI scanning when viewing both tasks and future outcomes, without any experimental instruction imposed. The results revealed that outcome value increased activations in the caudate, and suppressed procrastination through a hippocampus-caudate pathway. In contrast, task aversiveness increased activations in the anterior insula, and increased procrastination via an amygdala-insula pathway. In sum, this study demonstrates that people can incorporate both outcome value and task aversiveness into task valuation to decide whether to procrastinate or not; and it elucidates the separate neural pathways via which this occurs.

Procrastination is a stable harmful tendency within individuals (Elliot, 2002), a heritable trait across generations (Gustavson, Miyake, Hewitt, & Friedman, 2014), and a widespread problematic behavior across different cultures (Steel & Ferrari, 2013). This behavior consistently harms people's work efficiency, health, and psychological well-being (Sirois, 2007, 2015; Stead, Shanahan, & Neufeld, 2010). A recent temporal decision model suggests that procrastination is associated with evaluations of future outcome and task aversiveness (S. Zhang & Feng, 2020). Specifically, people are less likely to procrastinate a task when finding its future outcome more valuable (Prévost, Pessiglione, Météreau, Cléry-Melin, & Dreher, 2010), but more likely to procrastinate when finding the task aversive (Ferrari & Scher, 2000; Nauts, Kamphorst, Sutu, Poortvliet, & Anderson, 2016; Onwuegbuzie & Collins, 2001). However, the neural pathway underlying the effect of outcome value or task aversiveness on procrastination is still unrevealed.

The value of future outcomes represents the extent to which future rewards (e.g., a good grade) or future punishments (e.g., failure in an exam) can motivate task engagement (Strunk, Cho, Steele, & Bridges, 2013). On the other hand, task aversiveness refers to how unpleasant or unenjoyable a task is to perform (Blunt & Pychyl, 2000; Steel, 2007). The representation of future outcome likely relies on episodic future thinking (Boyer, 2008; Peters & Büchel, 2011), whereas task aversiveness is an emotional response (Bechara & Damasio, 2005; Clore & Huntsinger, 2007). It has been suggested that a hippocampus-centered cognitive system is specialized for episodic representation, whereas an amygdala-based affective system is specialized for quick emotional processing (Yonelinas & Ritchey, 2015). Hence, outcome value and task aversiveness might be evaluated through a hippocampus-based and an amygdala-based pathway, respectively.

Many studies suggest that hippocampus can provide episodic information to shape reward-related activity in the ventral striatum, which then guides goal-directed behavior (Pennartz, Ito, Verschure, Battaglia, & Robbins, 2011; van der Meer, Ito, Lansink, & Pennartz, 2014). Striatum codes the subjective value of a wide range of reward (Balleine, Delgado, & Hikosaka, 2007; Keise et al., 2008), including future

outcomes (S. Zhang, Becker, Chen, & Feng, 2019). The representation of outcome value thus might involve a hippocampus-striatum circuit. In line with this proposal, hippocampus-striatum couplings indeed increased when episodic memory guides decisions by impacting evaluation of options (Wimmer & Shohamy, 2012). On the other hand, amygdala might constitute the emotional pathway with anterior insula which responds to aversion to various stimuli (Heeren et al., 2016; Sarinopoulos et al., 2010). Indeed, altered amygdala-insula connections predict emotional disorders like anxiety disorder and posttraumatic stress disorder (Bebko et al., 2015; Nicholson et al., 2016; Rabinak et al., 2011; Roy et al., 2013). Amygdala-insula coupling also processed emotional stimuli like fearful faces (Fonzo et al., 2010; Gorka et al., 2015). Therefore, we hypothesized that outcome value and task aversiveness impact procrastination though a hippocampal-striatal pathway and an amygdala-insula pathway, respectively.

To test these hypotheses, we measured participants' neural signals while freely viewing personal tasks and corresponding future outcomes. During the free viewing, participants can spontaneously generate thoughts related to future outcomes and task aversiveness (see Supplementary Experiment and Fig. S1). Thus, this method guarantees high ecological validity and allows us to investigate the neural mechanism in an uncontaminated manner.

Materials and Methods

Participants

41 right-handed volunteers were recruited to test our hypotheses; none of these participants reported a history of psychiatric or neurological disorder. Data collection was approved by the Institutional Review Board of a local university. All participants provided written informed consent. Due to excessive head movement (> 2 mm or > 2°) during the fMRI acquisition, data from 5 participants were excluded, leading to 36 participants (9 males, mean age = 21.1 years, *SD* = 1.65) in the final analysis. The sample size was chosen to ensure adequate power to detect an assumed medium-size

effect (effect size $\rho = 0.5$, type I error $\alpha = 0.05$, power $1-\beta = 0.90$) based on a G*Power calculation, which resulted in a minimum sample size of 34 participants.

Pre-scan interview

Before scanning, participants were asked to list self-planned tasks (number of tasks: $M = 6.46$, $SD = 0.77$) and future outcomes for those tasks. All participants offered only one primary future outcome for each task, and explicitly indicated whether this future outcome was rewarding or punishing. They also rated frequency of procrastination on a 1–5 scale ("Do you procrastinate on this task?": 1 = not at all; 2 = almost no; 3 = occasionally; 4 = often; 5 = always). In the current study, only tasks with future rewarding outcomes are modeled because the number of tasks which are motivated by future punishing outcomes was too small for fMRI analysis. For example, half of the participants offered none or only one task that is motivated by punishing future outcome. We also collected task aversiveness and outcome value to investigate neural pathways mediating their effects on procrastination. Specifically, outcome value refers to how desirable a rewarding outcome is when the task is completed (or how aversive a punishing outcome is when the task is failed). Participants rated outcome value for each task separately on 0–8 scales (ranging from "not at all" to "extremely"). Participants rated task aversiveness on the question "how aversive are you going to feel if you have to start or complete [a certain task] within 24 hours" on a 0—8 scale (0 indicates "totally neutral", 8 indicates "extremely unpleasant") for each task. Since participants arrived at the lab at different times of the day, the question was phrased as "within 24 hours" instead of "immediately". In addition, we collected the deadline before which the task had to be done for each task to control its effect on procrastination (Ariely & Wertenbroch, 2002).

fMRI experiment

In a fMRI scanner, each participant was presented with their own tasks and outcomes obtained in the pre-scan interview. Data were collected via a mixed block/event-related design (see Fig. 1), incorporating separate blocks for tasks and

future outcomes corresponding to each task. A total of five separate runs were used; each run lasted 6 min 6 s. Within each run, a task block alternated with a future outcome block until the run ended; block order (i.e., task block first or future outcome block first) was counterbalanced across runs and across participants. Each specific task (in task blocks) or future outcome (in future outcome blocks) was presented exactly once in each block. Within each block, a cue indicating a task (e.g., essay writing) or future outcome (e.g., a good grade) was separately presented for a duration of 10 s in a randomized order without repetition. A fixation cross was presented during the inter-trial intervals (ITI) with an average duration of 4 s (2–6 s). To promote free viewing of the personalized tasks and associated future outcomes, participants were instructed to "Just think of whatever comes to mind related to the cued words" without further constraints.

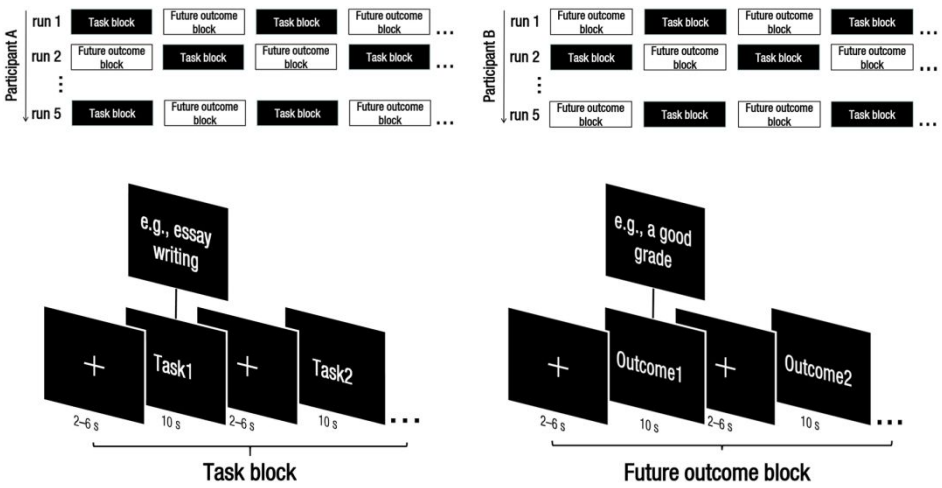

Fig. 1 Experimental task and design. The order of task block and future outcome block was balanced across runs and participants. Within each run, task blocks and future outcome blocks were presented in alternating order. In each block, personalized tasks (in a task block) or future outcomes (in a future outcome block) were presented one at a time in a random order without repetition.

fMRI data acquisition and preprocessing

The data was acquired on a Siemens 3T MRI system (Siemens Magnetom Trio TIM, Erlangen, Germany) using a T2*-weighted echoplanar BOLD-sensitive sequence with interleaved acquisition [64 × 64; 3 × 3 mm pixels; repetition time (TR), 2000 ms; echo time (TE), 30 ms; flip angle 90°]. Each volume comprised 32 axial slices (3 mm slice thickness) allowing whole brain coverage. 183 volumes were acquired for each of the five runs. Before preprocessing, the first 3 volumes were discarded to allow for T1 equilibration effects. Additionally, MPRAGE (magnetization-prepared rapid-acquisition gradient echo) structural images were acquired (250 × 250; 1 mm^3 cubic voxels; 176 slices; TR, 1900 ms; TE, 2.52 ms; flip angle 9°).

fMRI data were analyzed using SPM12 (http://www.fil.ion.ucl.ac.uk/spm/software/spm12/). Preprocessing included correction for differences in slice acquisition time, realignment, and coregistration with the structural image. Next, the structural images were spatially normalized to the Montreal Neurological Institute (MNI) space and the resulting normalization parameters were applied to the functional images using fourth-degree B-spline interpolation and a resolution of 3 × 3 × 3 mm^3. The images were finally smoothed using an isotropic 8 mm full-width half-maximal Gaussian kernel.

ROI selection

This study adopted small volume correction with pre-defined spherical ROIs (radium = 10 mm) based on previous studies. We selected a striatal (MNI coordinates: x = -8, y = 10, z = 14) and an insular (MNI coordinates: x = -24, y = 22, z = 10) ROI. The striatal ROI and insular ROI were implicated in representing outcome value and task cost, respectively (Treadway et al., 2012). We also selected a meta-analysis hippocampal ROI (MNI coordinates: x = -26, y = -38, z = -10) responsible for episodic future thinking (Stawarczyk & D'Argembeau, 2015), and a meta-analysis amygdala ROI (MNI coordinates: x = -22, y = -6, z = -12) responsible for emotional memory processing (Murty, Ritchey, Adcock, & LaBar, 2010). The hippocampal ROI will be used for searching for the hypothesized hippocampus-striatum pathway, while

the amygdala ROI will be used for searching for the amygdala-insula pathway of interest.

Data Analysis

We have two aims in data analysis. First, we searched for striatal activations that respond to outcome value, and insular activations that respond to task aversiveness. Second, we tested whether there are hippocampus-striatal couplings and amygdala-insula couplings that support our hypotheses.

To search for striatal (or insular) activation, we first generated neural-contrast signals that are related to presentation of future outcomes (or aversive tasks) at a within-subject level. Then, we looked for neural-contrast signals that are positively associated with outcome value (or task aversiveness) in the striatal (or insular) ROI at a between-subject level. Specifically, we performed a mean-split on each participant's tasks and outcomes according to personal mean procrastination frequency, yielding high- and low-procrastination groups. The first-level neural-contrast signals were generated by comparing neural signals that respond to future outcomes (or aversive tasks) between high- and low-procrastination groups within each participant. Then, we regressed those contrasts responding to future outcomes (or aversive tasks) across participants with corresponding outcome value (or task aversiveness) difference.

To search for the hypothesized hippocampus-striatum (or amygdala-insula) couplings, we first generated couplings with striatum (or insula) using PPI analysis (Friston et al., 1997) at a within-subject level. Then, we tested whether there are hippocampus-striatum (or amygdala-insula) couplings that support our hypothesis at a between-subject level. Specifically, the PPI analysis revealed differences in functional coupling with striatum (or insula) for each participant when viewing future outcomes (or aversive tasks) between high- and low-procrastination groups. Then, we regressed those hippocampus-striatum (or amygdala-insula) couplings with corresponding outcome value (or task aversiveness) difference across participants. Next, we looked for hippocampus-striatum (or amygdala-insula) couplings that are positively associated with outcome value (or task aversiveness) within our hippocampal (or

amygdala) ROI. Finally, we examined our hypothesis by testing the mediating role of the identified hippocampus-striatum (or amygdala-insula) couplings between outcome value (or task aversiveness) and procrastination.

Results

More procrastinated tasks are associated with lower outcome value but higher task aversiveness

To relate frequency of procrastination to outcome value and task aversiveness, we used a mixed linear model to predict task procrastination with outcome value and task aversiveness as the fixed factors, and with participants and outcome type (rewards or punishments) as the random factor to control for their intraclass differences (i.e., random intercept models). We found that increasing task procrastination was associated with decreasing outcome value (t = -3.64, p < 0.001, CI = [-0.20, -0.06], N = 232) and increasing task aversiveness (t = 8.47, p < 0.001, CI = [0.21, 0.33], N = 232) (see Fig. S2). This result also survived when the deadline was included as a covariate (for outcome value: t = -3.50, p < 0.001, CI = [-0.17, -0.05], N = 232; for task aversiveness: t = 6.11, p < 0.001, CI = [0.13, 0.26], N = 232). Model comparisons also revealed that the model which involves both outcome value and task aversiveness outperformed the models which involve only either outcome value or task aversiveness (see Table 1), indicating that people evaluate both outcome value and task aversiveness to form the subjective value of a task.

Table 1. Model comparisons against the model which predicts procrastination with both outcome value and task aversiveness

Model	ΔAIC	ΔBIC	R^2	$\chi^2_{(1)}$	Sig.
Outcome value + Task aversiveness	0	0	0.41	—	—
Outcome value	53.67	50.54	0.09	-55.67	< 0.001
Task aversiveness	10.32	7.19	0.34	-12.32	< 0.001

Note: The ΔAIC (ΔBIC) is the difference in AIC (BIC) obtained by subtracting those of the model involves both outcome value and task aversiveness. Smaller AIC or BIC indicates better

performance of a model. The $\chi^2_{(1)}$ and statistical significance (Sig.) were obtained from model comparisons against the model which involves both outcome value and task aversiveness by the likelihood ratio test. AIC: Akaike information criterion, BIC: Bayesian information criterion.

Outcome value suppresses procrastination through a hippocampus-caudate pathway

To focus on activations in the striatum, we adopted small volume correction with the pre-defined striatal ROI (see ROI selection). As we expected, a caudate cluster of striatum showed increasing neural signals with the increase of outcome value difference across participants (cluster level $P_{FWE\text{-}SVC} < 0.05$, peak level $P_{FWE\text{-}SVC} < 0.05$, see Fig. 2a). This result supports our hypothesis that striatum codes outcome value.

Next, we generated functional couplings with caudate using PPI analysis (Friston et al., 1997) with the caudate as a seed (centered at x = 6, y = 9, z = 21; with 6 mm as radius). As expected, there were hippocampus-caudate couplings that were positively associated with outcome value difference across participants (cluster level $P_{FWE\text{-}SVC} = 0.05$, peak level $P_{FWE\text{-}SVC} = 0.06$, see Fig. 2b). More interestingly, a mediation analysis (Preacher & Hayes, 2008) at between-subject level revealed the hippocampus-caudate coupling (ROI centered at x = 26, y = -38, z = -10; with 6 mm as radius) significantly mediated the effect of the outcome value on procrastination (bias corrected *CI* = [-0.54, -0.09], *N* = 36; see Fig. 2c). Together, these results indicated that outcome value suppresses procrastination through a hippocampal-caudate pathway.

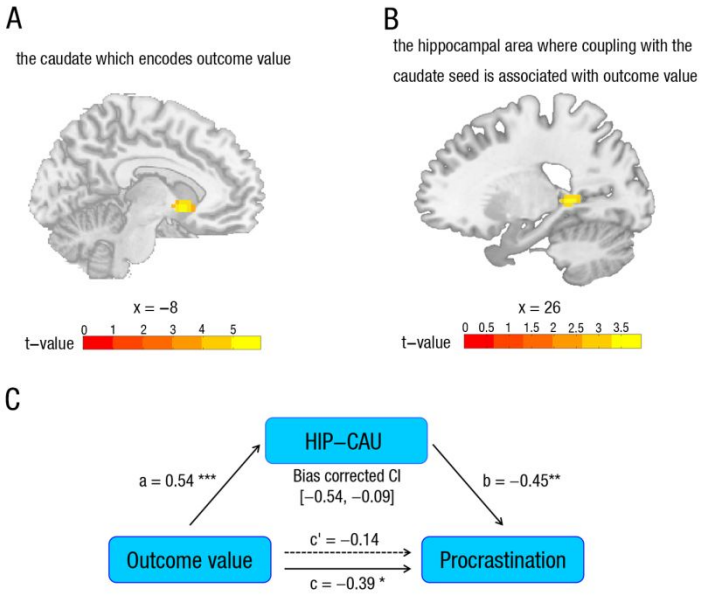

Fig. 2 Outcome value was coded in the caudate and impacted procrastination through a hippocampal-caudate pathway. **a** The signals in caudate were positively associated with outcome value. **b** The hippocampal area whose coupling with caudate is positively associated with outcome value. **c** The hippocampus-caudate coupling mediated the effect of outcome value on procrastination. HIP = hippocampus, CAU = caudate. * indicates $p < 0.05$, ** indicates $p < 0.01$, *** indicates $p < 0.001$.

Task aversiveness drives procrastination through an amygdala-insula pathway

The results showed that insular signals indeed increased with the increase of task aversiveness difference across participants (cluster level $P_{FWE\text{-}SVC} < 0.05$, peak level $P_{FWE\text{-}SVC} < 0.05$, see Fig. 3a), suggesting that task aversiveness is represented in the anterior insula. Furthermore, we found amygdala-insula couplings were positively associated with task aversiveness difference across participants (cluster level $P_{FWE\text{-}SVC} = 0.08$, peak level $P_{FWE\text{-}SVC} < 0.01$, see Fig. 3b). More interestingly, the amygdala-insula coupling (ROI centered at x = -30, y = 0, z = -18; with 6 mm as radius) indeed significantly mediated the effect of task aversiveness on procrastination (bias corrected $CI = [0.00, 0.47]$, $N = 36$, see Fig. 3c).

So far, our findings revealed two separate neural pathways mediating the opposite

effects of outcome value and task aversiveness on procrastination.

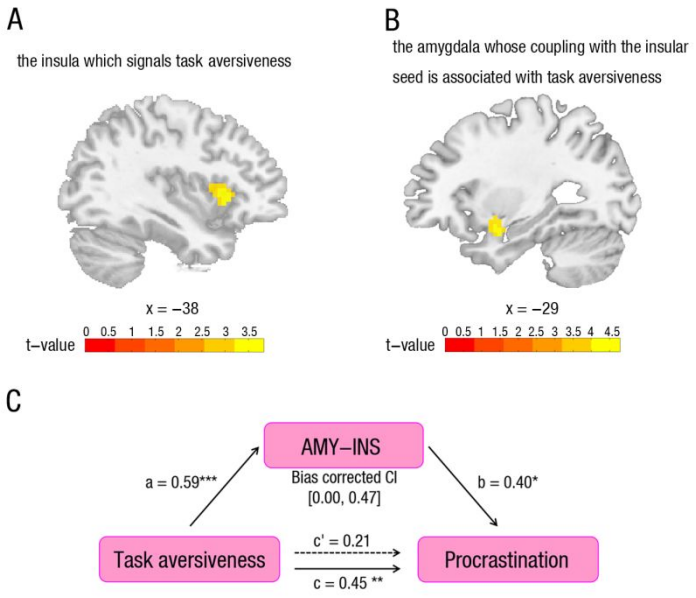

Fig. 3 Task aversiveness was represented in the anterior insula and had an effect on procrastination through an amygdala-insula pathway. **a** The signals in anterior insula were positively associated with task aversiveness. **b** The amygdala whose coupling with the insular seed is associated with task aversiveness. **c** The amygdala-insula coupling mediated the effect of task aversiveness on procrastination. AMY = amygdala, INS = insula. ** indicates $p < 0.01$, *** indicates $p < 0.001$.

Discussion

The present study specified the neural mechanism underlying representation of outcome value and task aversiveness. Specifically, outcome value was represented in the caudate, and it suppressed procrastination through a hippocampus-caudate pathway. In contrast, task aversiveness was coded in the anterior insula and drove procrastination through an amygdala-insula pathway. Together, these results demonstrate that people evaluate outcome value and task aversiveness through separate neural pathways.

It is noteworthy that the current study adopted a free viewing method to reveal the neural mechanism underlying task valuation. The free viewing method (Frankort et al.,

2012) gives no instruction on how tasks or future outcome should be evaluated, thus allows participants to evaluate tasks and future outcomes in their own way (Ferguson & Bargh, 2004; Papies, Stroebe, & Aarts, 2007). Because the free viewing method allows participants to evaluate tasks as they prefer, it is also unbiased in testing theories on procrastination. Supporting the temporal decision model (S. Zhang & Feng, 2020), the current study indicates that participants spontaneously incorporated outcome value and task aversiveness into task valuation (see Fig. S1 and Fig. S2).

The current study revealed that outcome value was coded in the caudate, and suppressed procrastination through an increased hippocampus-caudate coupling. In line with the role of the caudate in representing outcome value, it has been reported that caudate is responsible for anticipation of a wide range of rewarding outcomes (Mizuno et al., 2008; Preuschoff, Bossaerts, & Quartz, 2006; Schultz, 2000), and is also implicated in representing outcomes with different valence (Hariri et al., 2006). On the other hand, the increased hippocampus-caudate coupling might be implicated in retrieving relevant memories to simulate and evaluate future outcomes (Johnson, Häubl, & Keinan, 2007; Shadlen & Shohamy, 2016). Thus, these results suggest that the abnormalities in the parahippocampal cortex in high procrastinators might also be related to deficits in evaluating future outcomes (Hu, Liu, Guo, & Feng, 2018; Liu & Feng, 2018; W. Zhang, Wang, & Feng, 2016). Supporting this possibility, many studies have confirmed that hippocampus facilitates evaluation of future outcomes through its role in episodic simulation (Barron, Dolan, & Behrens, 2013; Benoit, Gilbert, & Burgess, 2011; Lebreton et al., 2013; Peters & Büchel, 2010). On the contrary, the dysfunction of hippocampus reduced the choice of the delayed high reward in favor of the immediately available low reward (Abela & Chudasama, 2013; McHugh, Campbell, Taylor, Rawlins, & Bannerman, 2008; Mustroph, 2015).

In contrast, the current study suggested that task aversiveness was represented in the anterior insula and exacerbated procrastination through an amygdala-insula pathway. The amygdala-insula coupling is likely to promote procrastination by constructing negative emotions. The anterior insular cortex is involved in processing of different aversive stimuli, such as disgust, aversion, and pain (Huettel, Stowe,

Gordon, Warner, & Platt, 2006; Ploghaus et al., 1999; Wicker et al., 2003). Similarly, it is suggested that amygdala facilitates judgment and decision making by autonomically triggering emotional responses (Bechara & Damasio, 2005; Gupta, Koscik, Bechara, & Tranel, 2011). The negative emotions triggered by amygdala enables animals to avoid threatening and aversive stimuli (Machado, Kazama, & Bachevalier, 2009; Vazdarjanova, Cahill, & McGaugh, 2001), and helps humans avoid disadvantageous options and potential money losses (Bechara & Damasio, 2005; Schlund & Cataldo, 2010). Of note, the insula and amygdala have anatomical and functional connections (Baur, Hänggi, Langer, & Jäncke, 2013). Furthermore, amygdala-insula coupling indeed becomes stronger after repeated presentation of negative stimuli (Denny et al., 2014).

This result strengthens the temporal decision model's emphasis that outcome value and task aversiveness act independently to impact procrastination (S. Zhang & Feng, 2020). Similarly, dual-process theorists also agree that there is one neural system responsible for rapid, parallel and automatic processes, whereas another relatively separate system enables uniquely human facilities, such as hypothetical thinking, mental simulation, and consequential decision making (Bechara, Noel, & Crone, 2006; Evans, 2003; Frankish, 2010). In dual-process theories, task aversiveness might be represented through the former system because emotions are responsible for faster evaluation (Bechara & Damasio, 2005; Clore & Huntsinger, 2007). In contrast, representation of future outcome is believed to involve mental simulation, thus depends on the latter system (Evans & Stanovich, 2013; McClure & Bickel, 2014). Thus, it is reasonable for the temporal decision model to take both outcome value and task aversiveness into consideration when linking task value to procrastination.

In summary, the current study revealed that outcome value was represented in the caudate and can suppress procrastination through a hippocampus-caudate pathway, whereas task aversiveness was coded in the anterior insula and can drive procrastination via an amygdala-insula pathway. Together, these results demonstrate that people can incorporate both outcome value and task aversiveness into task valuation through distinct neural pathways. Thus, people should not ignore neither

outcome value nor task aversiveness when intervening procrastination.

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