



Universiteit
Leiden
The Netherlands

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

Zhang, S.M.; Verguts, T.; Zhang, C.Y.; Feng, P.; Chen, Q.; Feng, T.Y.

Citation

Zhang, S. M., Verguts, T., Zhang, C. Y., Feng, P., Chen, Q., & Feng, T. Y. (2021). Outcome value and task aversiveness impact task procrastination through separate neural pathways. *Cerebral Cortex*, 31(8), 3846-3855. doi:10.1093/cercor/bhab053

Version: Accepted Manuscript

License: [Leiden University Non-exclusive license](#)

Downloaded from: <https://hdl.handle.net/1887/3280207>

Note: To cite this publication please use the final published version (if applicable).

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

Journal:	<i>Cerebral Cortex</i>
Manuscript ID	CerCor-2020-00896
Manuscript Type:	Original Article
Date Submitted by the Author:	27-Oct-2020
Complete List of Authors:	Zhang, Shunmin; Zhejiang University, Department of Psychology and Behavioral Science Verguts, Tom; Ghent University, Department of Experimental Psychology Zhang, Chenyan; Leiden University, Faculty of Social and Behavioural sciences Chen, Qi; South China Normal University, School of Psychology Feng, Tingyong; Southwest University, School of Psychology
Keywords:	task valuation, procrastination, hippocampus-striatum coupling, amygdala-insula coupling, dual-process theory

1
2
3
4
5 **Outcome value and task aversiveness impact task**
6
7 **procrastination through separate neural pathways**
8
9

10
11 **Shunmin Zhang^{1,2}, Tom Verguts³, Chenyan Zhang⁴, Qi Chen⁵ & Tingyong Feng^{1,6}**
12

13 ¹ School of Psychology, Southwest University, Chongqing, China

14 ² Department of Psychology and Behavioral Sciences, Zhejiang University, Hangzhou, China

15 ³ Department of Experimental Psychology, Ghent University, Ghent, Belgium,

16 ⁴ Institute of Psychology, Leiden University, Leiden, Netherlands

17 ⁵ School of Psychology, South China Normal University, Guangzhou, China

18 ⁶ Key Laboratory of Cognition and Personality, Ministry of Education, Chongqing, China
19
20
21
22
23
24
25
26
27
28
29
30
31

32 Please address correspondence to:

33 **Qi Chen**, School of Psychology, South China Normal University, No. 55, West of

34
35
36
37
38 Zhong Shan Avenue, Guangzhou 510631 China. E-mail: chen.qi@m.scnu.edu.cn; or

39
40 **Tingyong Feng**, School of Psychology, Southwest University, No. 2 Tian Sheng

41
42
43 Road, Beibei, Chongqing 400715, China. Tel: +86 23 68367572. Fax: +86 23

44
45
46 68253629. E-mail: fengty0@swu.edu.cn.
47
48
49
50
51
52
53
54
55
56
57
58
59
60

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.

1
2
3
4 Procrastination is a stable harmful tendency within individuals (Elliot, 2002), a
5 heritable trait across generations (Gustavson, Miyake, Hewitt, & Friedman, 2014),
6 and a widespread problematic behavior across different cultures (Steel & Ferrari,
7 2013). This behavior consistently harms people's work efficiency, health, and
8 psychological well-being (Sirois, 2007, 2015; Stead, Shanahan, & Neufeld, 2010). A
9 recent temporal decision model suggests that procrastination is associated with
10 evaluations of future outcome and task aversiveness (S. Zhang & Feng, 2020).
11 Specifically, people are less likely to procrastinate a task when finding its future
12 outcome more valuable (Prévost, Pessiglione, Météreau, Cléry-Melin, & Dreher,
13 2010), but more likely to procrastinate when finding the task aversive (Ferrari &
14 Scher, 2000; Nauts, Kamphorst, Sutu, Poortvliet, & Anderson, 2016; Onwuegbuzie &
15 Collins, 2001). However, the neural pathway underlying the effect of outcome value
16 or task aversiveness on procrastination is still unrevealed.

17
18
19
20
21
22
23
24
25
26
27
28
29 The value of future outcomes represents the extent to which future rewards (e.g., a
30 good grade) or future punishments (e.g., failure in an exam) can motivate task
31 engagement (Strunk, Cho, Steele, & Bridges, 2013). On the other hand, task
32 aversiveness refers to how unpleasant or unenjoyable a task is to perform (Blunt &
33 Pychyl, 2000; Steel, 2007). The representation of future outcome likely relies on
34 episodic future thinking (Boyer, 2008; Peters & Büchel, 2011), whereas task
35 aversiveness is an emotional response (Bechara & Damasio, 2005; Clore &
36 Huntsinger, 2007). It has been suggested that a hippocampus-centered cognitive
37 system is specialized for episodic representation, whereas an amygdala-based
38 affective system is specialized for quick emotional processing (Yonelinas & Ritchey,
39 2015). Hence, outcome value and task aversiveness might be evaluated through a
40 hippocampus-based and an amygdala-based pathway, respectively.

41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
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

1
2
3 outcomes (S. Zhang, Becker, Chen, & Feng, 2019). The representation of outcome
4 value thus might involve a hippocampus-striatum circuit. In line with this proposal,
5 hippocampus-striatum couplings indeed increased when episodic memory guides
6 decisions by impacting evaluation of options (Wimmer & Shohamy, 2012). On the
7 other hand, amygdala might constitute the emotional pathway with anterior insula
8 which responds to aversion to various stimuli (Heeren et al., 2016; Sarinopoulos et al.,
9 2010). Indeed, altered amygdala-insula connections predict emotional disorders like
10 anxiety disorder and posttraumatic stress disorder (Bebko et al., 2015; Nicholson et al.,
11 2016; Rabinak et al., 2011; Roy et al., 2013). Amygdala-insula coupling also
12 processed emotional stimuli like fearful faces (Fonzo et al., 2010; Gorke et al., 2015).
13 Therefore, we hypothesized that outcome value and task aversiveness impact
14 procrastination through a hippocampal-striatal pathway and an amygdala-insula
15 pathway, respectively.

16
17 To test these hypotheses, we measured participants' neural signals while freely
18 viewing personal tasks and corresponding future outcomes. During the free viewing,
19 participants can spontaneously generate thoughts related to future outcomes and task
20 aversiveness (see Supplementary Experiment and Fig. S1). Thus, this method
21 guarantees high ecological validity and allows us to investigate the neural mechanism
22 in an uncontaminated manner.

23 **Materials and Methods**

24 **Participants**

25
26 41 right-handed volunteers were recruited to test our hypotheses; none of these
27 participants reported a history of psychiatric or neurological disorder. Data collection
28 was approved by the Institutional Review Board of a local university. All participants
29 provided written informed consent. Due to excessive head movement (> 2 mm or $> 2^\circ$)
30 during the fMRI acquisition, data from 5 participants were excluded, leading to 36
31 participants (9 males, mean age = 21.1 years, $SD = 1.65$) in the final analysis. The
32 sample size was chosen to ensure adequate power to detect an assumed medium-size

1
2
3
4 effect (effect size $\rho = 0.5$, type I error $\alpha = 0.05$, power $1 - \beta = 0.90$) based on a
5
6 G*Power calculation, which resulted in a minimum sample size of 34 participants.
7
8

9 10 **Pre-scan interview**

11 Before scanning, participants were asked to list self-planned tasks (number of tasks:
12 $M = 6.46$, $SD = 0.77$) and future outcomes for those tasks. All participants offered
13 only one primary future outcome for each task, and explicitly indicated whether this
14 future outcome was rewarding or punishing. They also rated frequency of
15 procrastination on a 1–5 scale (“Do you procrastinate on this task?”: 1 = not at all; 2 =
16 almost no; 3 = occasionally; 4 = often; 5 = always). In the current study, only tasks
17 with future rewarding outcomes are modeled because the number of tasks which are
18 motivated by future punishing outcomes was too small for fMRI analysis. For
19 example, half of the participants offered none or only one task that is motivated by
20 punishing future outcome. We also collected task aversiveness and outcome value to
21 investigate neural pathways mediating their effects on procrastination. Specifically,
22 outcome value refers to how desirable a rewarding outcome is when the task is
23 completed (or how aversive a punishing outcome is when the task is failed).
24 Participants rated outcome value for each task separately on 0–8 scales (ranging from
25 “not at all” to “extremely”). Participants rated task aversiveness on the question “how
26 aversive are you going to feel if you have to start or complete [a certain task] within
27 24 hours” on a 0–8 scale (0 indicates “totally neutral”, 8 indicates “extremely
28 unpleasant”) for each task. Since participants arrived at the lab at different times of
29 the day, the question was phrased as “within 24 hours” instead of “immediately”. In
30 addition, we collected the deadline before which the task had to be done for each task
31 to control its effect on procrastination (Ariely & Wertenbroch, 2002).
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53

54 **fMRI experiment**

55 In a fMRI scanner, each participant was presented with their own tasks and
56 outcomes obtained in the pre-scan interview. Data were collected via a mixed
57 block/event-related design (see Fig. 1), incorporating separate blocks for tasks and
58
59
60

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.

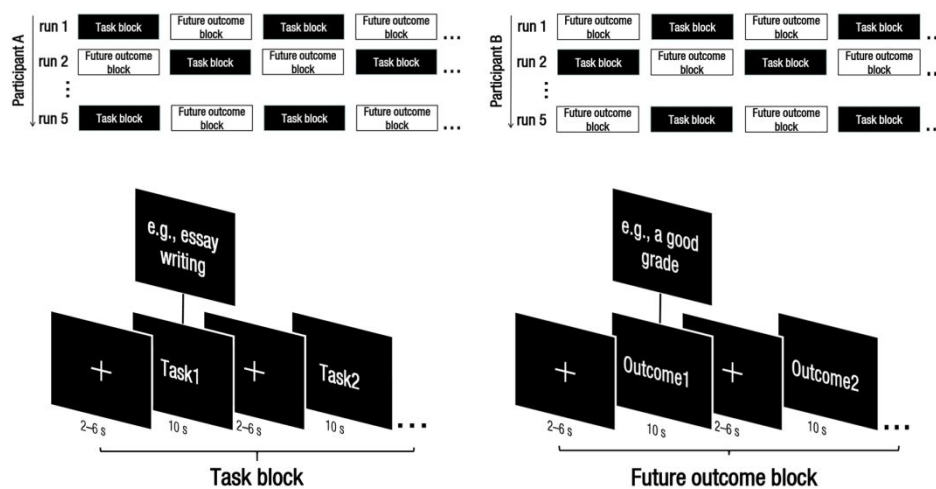


Fig. 1 Experimental task and design. The order of task block and future outcome block was balanced across runs and participants. Within each run, task blocks and future outcome blocks were presented in alternating order. In each block, personalized tasks (in a task block) or future outcomes (in a future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

fMRI data acquisition and preprocessing

1
2
3
4 The data was acquired on a Siemens 3T MRI system (Siemens Magnetom Trio
5 TIM, Erlangen, Germany) using a T2*-weighted echoplanar BOLD-sensitive
6 sequence with interleaved acquisition [64×64 ; 3×3 mm pixels; repetition time (TR),
7 2000 ms; echo time (TE), 30 ms; flip angle 90°]. Each volume comprised 32 axial
8 slices (3 mm slice thickness) allowing whole brain coverage. 183 volumes were
9 acquired for each of the five runs. Before preprocessing, the first 3 volumes were
10 discarded to allow for T1 equilibration effects. Additionally, MPRAGE
11 (magnetization-prepared rapid-acquisition gradient echo) structural images were
12 acquired (250×250 ; 1 mm^3 cubic voxels; 176 slices; TR, 1900 ms; TE, 2.52 ms; flip
13 angle 9°).

14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
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 $3 \times 3 \times 3 \text{ mm}^3$. The images were finally smoothed using an isotropic 8 mm full-width half-maximal Gaussian kernel.

ROI selection

41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
This study adopted small volume correction with pre-defined spherical ROIs (radius = 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

1
2
3
4 the amygdala ROI will be used for searching for the amygdala-insula pathway of
5
6 interest.
7
8

9 10 **Data Analysis**

11 We have two aims in data analysis. First, we searched for striatal activations that
12 respond to outcome value, and insular activations that respond to task aversiveness.
13
14 Second, we tested whether there are hippocampus-striatal couplings and
15
16 amygdala-insula couplings that support our hypotheses.
17
18

19 To search for striatal (or insular) activation, we first generated neural-contrast
20 signals that are related to presentation of future outcomes (or aversive tasks) at a
21 within-subject level. Then, we looked for neural-contrast signals that are positively
22 associated with outcome value (or task aversiveness) in the striatal (or insular) ROI at
23 a between-subject level. Specifically, we performed a mean-split on each participant's
24 tasks and outcomes according to personal mean procrastination frequency, yielding
25 high- and low-procrastination groups. The first-level neural-contrast signals were
26 generated by comparing neural signals that respond to future outcomes (or aversive
27 tasks) between high- and low-procrastination groups within each participant. Then,
28 we regressed those contrasts responding to future outcomes (or aversive tasks) across
29 participants with corresponding outcome value (or task aversiveness) difference.
30
31

32 To search for the hypothesized hippocampus-striatum (or amygdala-insula)
33 couplings, we first generated couplings with striatum (or insula) using PPI analysis
34 (Friston et al., 1997) at a within-subject level. Then, we tested whether there are
35 hippocampus-striatum (or amygdala-insula) couplings that support our hypothesis at a
36 between-subject level. Specifically, the PPI analysis revealed differences in functional
37 coupling with striatum (or insula) for each participant when viewing future outcomes
38 (or aversive tasks) between high- and low-procrastination groups. Then, we regressed
39 those hippocampus-striatum (or amygdala-insula) couplings with corresponding
40 outcome value (or task aversiveness) difference across participants. Next, we looked
41 for hippocampus-striatum (or amygdala-insula) couplings that are positively
42 associated with outcome value (or task aversiveness) within our hippocampal (or
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

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

1
2
3 performance of a model. The $\chi^2_{(1)}$ and statistical significance (Sig.) were obtained from model
4 comparisons against the model which involves both outcome value and task aversiveness by the
5 likelihood ratio test. AIC: Akaike information criterion, BIC: Bayesian information criterion.
6
7
8

9 **Outcome value suppresses procrastination through a hippocampus-caudate** 10 **pathway**

11
12 To focus on activations in the striatum, we adopted small volume correction with
13 the pre-defined striatal ROI (see ROI selection). As we expected, a caudate cluster of
14 striatum showed increasing neural signals with the increase of outcome value
15 difference across participants (cluster level $P_{\text{FWE-SVC}} < 0.05$, peak level $P_{\text{FWE-SVC}} <$
16 0.05 , see Fig. 2a). This result supports our hypothesis that striatum codes outcome
17 value.
18
19

20
21 Next, we generated functional couplings with caudate using PPI analysis (Friston et
22 al., 1997) with the caudate as a seed (centered at $x = 6$, $y = 9$, $z = 21$; with 6 mm as
23 radius). As expected, there were hippocampus-caudate couplings that were positively
24 associated with outcome value difference across participants (cluster level $P_{\text{FWE-SVC}} =$
25 0.05 , peak level $P_{\text{FWE-SVC}} = 0.06$, see Fig. 2b). More interestingly, a mediation
26 analysis (Preacher & Hayes, 2008) at between-subject level revealed the
27 hippocampus-caudate coupling (ROI centered at $x = 26$, $y = -38$, $z = -10$; with 6 mm
28 as radius) significantly mediated the effect of the outcome value on procrastination
29 (bias corrected $CI = [-0.54, -0.09]$, $N = 36$; see Fig. 2c). Together, these results
30 indicated that outcome value suppresses procrastination through a
31 hippocampal-caudate pathway.
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

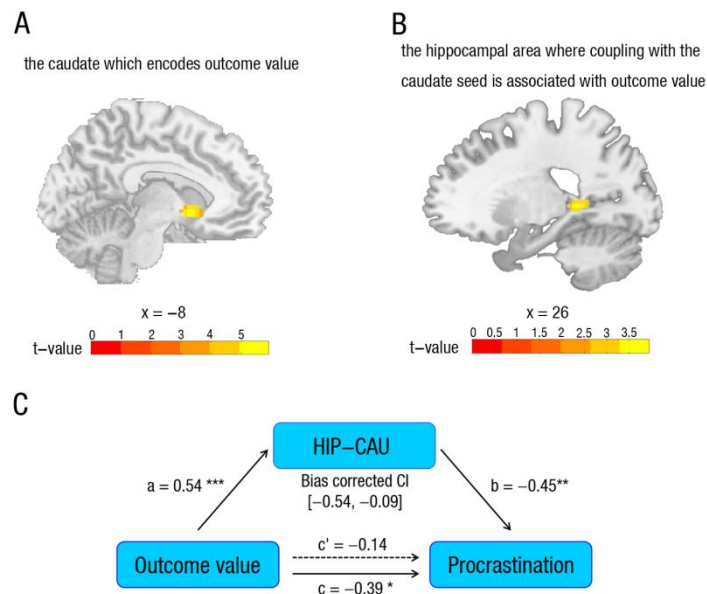


Fig. 2 Outcome value was coded in the caudate and impacted procrastination through a hippocampal-caudate pathway. **a** The signals in caudate were positively associated with outcome value. **b** The hippocampal area whose coupling with caudate is positively associated with outcome value. **c** The hippocampus-caudate 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 $P_{\text{FWE-SVC}} < 0.05$, peak level $P_{\text{FWE-SVC}} < 0.05$, 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 $P_{\text{FWE-SVC}} = 0.08$, peak level $P_{\text{FWE-SVC}} < 0.01$, 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.

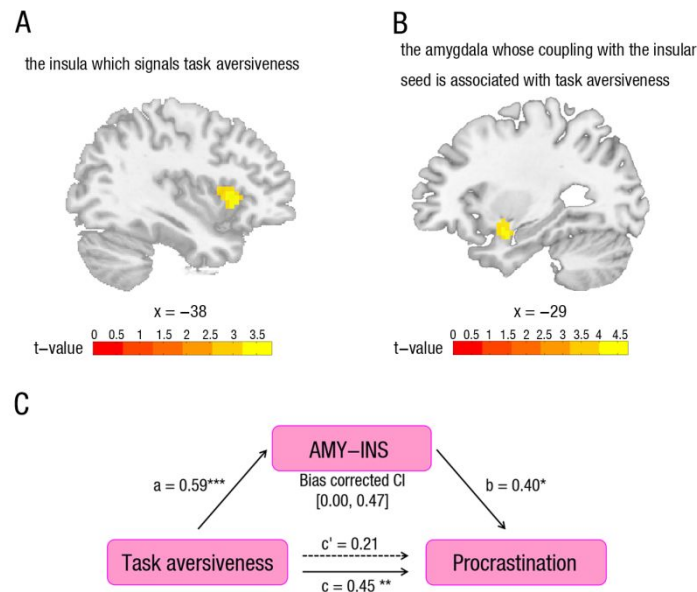


Fig. 3 Task aversiveness was represented in the anterior insula and had an effect on procrastination through an amygdala-insula pathway. **a** The signals in anterior insula were positively associated with task aversiveness. **b** The amygdala whose coupling with the insular seed is associated with task 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.,

1
2
3
4 2012) gives no instruction on how tasks or future outcome should be evaluated, thus
5 allows participants to evaluate tasks and future outcomes in their own way (Ferguson
6 & Bargh, 2004; Papiés, Stroebe, & Aarts, 2007). Because the free viewing method
7 allows participants to evaluate tasks as they prefer, it is also unbiased in testing
8 theories on procrastination. Supporting the temporal decision model (S. Zhang &
9 Feng, 2020), the current study indicates that participants spontaneously incorporated
10 outcome value and task aversiveness into task valuation (see Fig. S1 and Fig. S2).

11
12
13
14
15
16
17 The current study revealed that outcome value was coded in the caudate, and
18 suppressed procrastination through an increased hippocampus-caudate coupling. In
19 line with the role of the caudate in representing outcome value, it has been reported
20 that caudate is responsible for anticipation of a wide range of rewarding outcomes
21 (Mizuno et al., 2008; Preuschoff, Bossaerts, & Quartz, 2006; Schultz, 2000), and is
22 also implicated in representing outcomes with different valence (Hariri et al., 2006).
23 On the other hand, the increased hippocampus-caudate coupling might be implicated
24 in retrieving relevant memories to simulate and evaluate future outcomes (Johnson,
25 Häubl, & Keinan, 2007; Shadlen & Shohamy, 2016). Thus, these results suggest that
26 the abnormalities in the parahippocampal cortex in high procrastinators might also be
27 related to deficits in evaluating future outcomes (Hu, Liu, Guo, & Feng, 2018; Liu &
28 Feng, 2018; W. Zhang, Wang, & Feng, 2016). Supporting this possibility, many
29 studies have confirmed that hippocampus facilitates evaluation of future outcomes
30 through its role in episodic simulation (Barron, Dolan, & Behrens, 2013; Benoit,
31 Gilbert, & Burgess, 2011; Lebreton et al., 2013; Peters & Büchel, 2010). On the
32 contrary, the dysfunction of hippocampus reduced the choice of the delayed high
33 reward in favor of the immediately available low reward (Abela & Chudasama, 2013;
34 McHugh, Campbell, Taylor, Rawlins, & Bannerman, 2008; Mustroph, 2015).

35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52 In contrast, the current study suggested that task aversiveness was represented in
53 the anterior insula and exacerbated procrastination through an amygdala-insula
54 pathway. The amygdala-insula coupling is likely to promote procrastination by
55 constructing negative emotions. The anterior insular cortex is involved in processing
56 of different aversive stimuli, such as disgust, aversion, and pain (Huettel, Stowe,
57
58
59
60

1
2
3
4 Gordon, Warner, & Platt, 2006; Ploghaus et al., 1999; Wicker et al., 2003). Similarly,
5
6 it is suggested that amygdala facilitates judgment and decision making by
7
8 autonomically triggering emotional responses (Bechara & Damasio, 2005; Gupta,
9
10 Kosciak, Bechara, & Tranel, 2011). The negative emotions triggered by amygdala
11
12 enables animals to avoid threatening and aversive stimuli (Machado, Kazama, &
13
14 Bachevalier, 2009; Vazdarjanova, Cahill, & McGaugh, 2001), and helps humans
15
16 avoid disadvantageous options and potential money losses (Bechara & Damasio, 2005;
17
18 Schlund & Cataldo, 2010). Of note, the insula and amygdala have anatomical and
19
20 functional connections (Baur, Hänggi, Langer, & Jäncke, 2013). Furthermore,
21
22 amygdala-insula coupling indeed becomes stronger after repeated presentation of
23
24 negative stimuli (Denny et al., 2014).

25
26 This result strengthens the temporal decision model's emphasis that outcome value
27
28 and task aversiveness act independently to impact procrastination (S. Zhang & Feng,
29
30 2020). Similarly, dual-process theorists also agree that there is one neural system
31
32 responsible for rapid, parallel and automatic processes, whereas another relatively
33
34 separate system enables uniquely human facilities, such as hypothetical thinking,
35
36 mental simulation, and consequential decision making (Bechara, Noel, & Crone, 2006;
37
38 Evans, 2003; Frankish, 2010). In dual-process theories, task aversiveness might be
39
40 represented through the former system because emotions are responsible for faster
41
42 evaluation (Bechara & Damasio, 2005; Clore & Huntsinger, 2007). In contrast,
43
44 representation of future outcome is believed to involve mental simulation, thus
45
46 depends on the latter system (Evans & Stanovich, 2013; McClure & Bickel, 2014).
47
48 Thus, it is reasonable for the temporal decision model to take both outcome value and
49
50 task aversiveness into consideration when linking task value to procrastination.

51
52 In summary, the current study revealed that outcome value was represented in the
53
54 caudate and can suppress procrastination through a hippocampus-caudate pathway,
55
56 whereas task aversiveness was coded in the anterior insula and can drive
57
58 procrastination via an amygdala-insula pathway. Together, these results demonstrate
59
60 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.

Acknowledgements: This study was supported by the National Natural Science Foundation of China (31971026) and the Fundamental Research Funds for the Central Universities (SWU2009104).

Reference

- Abela, A. R., & Chudasama, Y. (2013). Dissociable contributions of the ventral hippocampus and orbitofrontal cortex to decision - making with a delayed or uncertain outcome. *European Journal of Neuroscience*, *37*(4), 640-647.
- Ariely, D., & Wertenbroch, K. (2002). Procrastination, deadlines, and performance: Self-control by precommitment. *Psychological science*, *13*(3), 219-224.
- Balleine, B. W., Delgado, M. R., & Hikosaka, O. (2007). The Role of the Dorsal Striatum in Reward and Decision-Making. *Journal of Neuroscience the Official Journal of the Society for Neuroscience*, *27*(31), 8161-8165.
- Barron, H. C., Dolan, R. J., & Behrens, T. E. (2013). Online evaluation of novel choices by simultaneous representation of multiple memories. *Nature neuroscience*, *16*(10), 1492-1498.
- Baur, V., Hänggi, J., Langer, N., & Jäncke, L. (2013). Resting-state functional and structural connectivity within an insula-amygdala route specifically index state and trait anxiety. *Biol Psychiatry*, *73*(1), 85-92.
- Bebko, G., Bertocci, M., Chase, H., Dwojak, A., Bonar, L., Almeida, J., . . . Travis, M. (2015). Decreased amygdala-insula resting state connectivity in behaviorally and emotionally dysregulated youth. *Psychiatry Research: Neuroimaging*, *231*(1), 77-86.
- Bechara, A., & Damasio, A. R. (2005). The somatic marker hypothesis: A neural theory of economic decision. *Games and economic behavior*, *52*(2), 336-372.
- Bechara, A., Noel, X., & Crone, E. A. (2006). Loss of willpower: Abnormal neural mechanisms of impulse control and decision making in addiction. *Handbook of implicit cognition and addiction*, *1*, 215-232.
- Benoit, R. G., Gilbert, S. J., & Burgess, P. W. (2011). A neural mechanism mediating the impact of episodic prospection on farsighted decisions. *Journal of Neuroscience the Official Journal of the Society for Neuroscience*, *31*(18), 6771-6779.
- Blunt, A. K., & Pychyl, T. A. (2000). Task aversiveness and procrastination: A multi-dimensional approach to task aversiveness across stages of personal projects. *Personality and Individual Differences*, *28*(1), 153-167.
- Boyer, P. (2008). Evolutionary economics of mental time travel? *Trends in cognitive sciences*, *12*(6), 219-224.
- Clore, G. L., & Huntsinger, J. R. (2007). How emotions inform judgment and regulate thought. *Trends in cognitive sciences*, *11*(9), 393-399.
- Denny, B. T., Fan, J., Liu, X., Guerrerri, S., Mayson, S. J., Rimsky, L., . . . Koenigsberg, H. W. (2014). Insula-amygdala functional connectivity is correlated with habituation to repeated negative images. *Social Cognitive & Affective Neuroscience*, *9*(11), 1660.
- Elliot, R. (2002). A ten-year study of procrastination stability. *Unpublished master's thesis, University*

- of Louisiana, Monroe.
- Evans, J. S. B. (2003). In two minds: dual-process accounts of reasoning. *Trends in cognitive sciences*, 7(10), 454-459.
- Evans, J. S. B., & Stanovich, K. E. (2013). Dual-process theories of higher cognition: Advancing the debate. *Perspectives on psychological science*, 8(3), 223-241.
- Ferguson, M. J., & Bargh, J. A. (2004). Liking Is for Doing: The Effects of Goal Pursuit on Automatic Evaluation. *Journal of Personality & Social Psychology*, 87(5), 557.
- Ferrari, J. R., & Scher, S. J. (2000). Toward an understanding of academic and nonacademic tasks procrastinated by students: The use of daily logs. *Psychology in the Schools*, 37(4), 359-366.
- Fonzo, G. A., Simmons, A. N., Thorp, S. R., Norman, S. B., Paulus, M. P., & Stein, M. B. (2010). Exaggerated and disconnected insular-amygdalar blood oxygenation level-dependent response to threat-related emotional faces in women with intimate-partner violence posttraumatic stress disorder. *Biological psychiatry*, 68(5), 433-441.
- Frankish, K. (2010). Dual - process and dual - system theories of reasoning. *Philosophy Compass*, 5(10), 914-926.
- Frankort, A., Roefs, A., Siep, N., Roebroek, A., Havermans, R., & Jansen, A. (2012). Reward activity in satiated overweight women is decreased during unbiased viewing but increased when imagining taste: an event-related fMRI study. *International Journal of Obesity*, 36(5), 627-637.
- Friston, K., Buechel, C., Fink, G., Morris, J., Rolls, E., & Dolan, R. (1997). Psychophysiological and modulatory interactions in neuroimaging. *Neuroimage*, 6(3), 218-229.
- Gorka, S. M., Fitzgerald, D. A., Labuschagne, I., Hosanagar, A., Wood, A. G., Nathan, P. J., & Phan, K. L. (2015). Oxytocin modulation of amygdala functional connectivity to fearful faces in generalized social anxiety disorder. *Neuropsychopharmacology*, 40(2), 278.
- Gupta, R., Kosciak, T. R., Bechara, A., & Tranel, D. (2011). The amygdala and decision-making. *Neuropsychologia*, 49(4), 760-766.
- Gustavson, D. E., Miyake, A., Hewitt, J. K., & Friedman, N. P. (2014). Genetic relations among procrastination, impulsivity, and goal-management ability implications for the evolutionary origin of procrastination. *Psychological science*, 25(6), 1178-1188.
- Hariri, A. R., Brown, S. M., Williamson, D. E., Flory, J. D., Harriet, D. W., & Manuck, S. B. (2006). Preference for immediate over delayed rewards is associated with magnitude of ventral striatal activity. *Journal of neuroscience*, 26(51), 13213-13217.
- Heeren, G., Weber, B., Reuter, M., . . . C. (2016). Loss aversion is associated with bilateral insula volume. A voxel based morphometry study. *Neuroence Letters: An International Multidiplinary Journal Devoted to the Rapid Publication of Basic Research in the Brain ences*, 619, 172-176.
- Hu, Y., Liu, P., Guo, Y., & Feng, T. (2018). The neural substrates of procrastination: A voxel-based morphometry study. *Brain and cognition*, 121, 11-16.
- Huettel, S. A., Stowe, C. J., Gordon, E. M., Warner, B. T., & Platt, M. L. (2006). Neural Signatures of Economic Preferences for Risk and Ambiguity. *Neuron*, 49(5), 765-775.
- Johnson, E. J., Häubl, G., & Keinan, A. (2007). Aspects of endowment: a query theory of value construction. *J Exp Psychol Learn Mem Cogn*, 33(3), 461-474.
- Keise, Izuma, and, Daisuke, N., Saito, . . . Sadato. (2008). Processing of Social and Monetary Rewards in the Human Striatum. *Neuron*.

- 1
2
3 Lebreton, M., Bertoux, M., Boutet, C., Lehericy, S., Dubois, B., Fossati, P., & Pessiglione, M. (2013).
4 A Critical Role for the Hippocampus in the Valuation of Imagined Outcomes. *Plos Biology*,
5 *11*(10), 363-367.
6
7 Liu, P., & Feng, T. (2018). The effect of future time perspective on procrastination: the role of
8 parahippocampal gyrus and ventromedial prefrontal cortex. *Brain imaging and behavior*, 1-8.
9
10 Machado, C. J., Kazama, A. M., & Bachevalier, J. (2009). Impact of amygdala, orbital frontal, or
11 hippocampal lesions on threat avoidance and emotional reactivity in nonhuman primates.
12 *Emotion*, *9*(2), 147.
13
14 McClure, S. M., & Bickel, W. K. (2014). A dual - systems perspective on addiction: contributions
15 from neuroimaging and cognitive training. *Annals of the New York Academy of Sciences*,
16 *1327*(1), 62-78.
17
18 McHugh, S., Campbell, T., Taylor, A., Rawlins, J., & Bannerman, D. (2008). A role for dorsal and
19 ventral hippocampus in inter-temporal choice cost-benefit decision making. *Behavioral*
20 *neuroscience*, *122*(1), 1.
21
22 Mizuno, K., Tanaka, M., Ishii, A., Tanabe, H. C., Onoe, H., Sadato, N., & Watanabe, Y. (2008). The
23 neural basis of academic achievement motivation. *Neuroimage*, *42*(1), 369-378.
24
25 Murty, V. P., Ritchey, M., Adcock, R. A., & LaBar, K. S. (2010). fMRI studies of successful emotional
26 memory encoding: A quantitative meta-analysis. *Neuropsychologia*, *48*(12), 3459-3469.
27
28 Mustroph, M. (2015). *Effects of physical exercise and exercise-induced adult hippocampal*
29 *neurogenesis on conditioned place preference for cocaine in mice*. University of Illinois at
30 Urbana-Champaign,
31
32 Nauts, S., Kamphorst, B. A., Sutu, A. E., Poortvliet, R., & Anderson, J. H. (2016). Aversive bedtime
33 routines as a precursor to bedtime procrastination. *European Health Psychologist*, *18*(2),
34 80-85.
35
36 Nicholson, A. A., Sapru, I., Densmore, M., Frewen, P. A., Neufeld, R. W., Théberge, J., . . . Lanius, R.
37 A. (2016). Unique insula subregion resting-state functional connectivity with amygdala
38 complexes in posttraumatic stress disorder and its dissociative subtype. *Psychiatry Research*
39 *Neuroimaging*, *250*, 61-72.
40
41 Onwuegbuzie, A. J., & Collins, K. M. (2001). Writing apprehension and academic procrastination
42 among graduate students. *Perceptual and motor skills*, *92*(2), 560-562.
43
44 Papies, E., Stroebe, W., & Aarts, H. (2007). Pleasure in the mind: Restrained eating and spontaneous
45 hedonic thoughts about food. *Journal of Experimental Social Psychology*, *43*(5), 810-817.
46
47 Pennartz, C., Ito, R., Verschure, P., Battaglia, F., & Robbins, T. (2011). The hippocampal–striatal axis
48 in learning, prediction and goal-directed behavior. *Trends in neurosciences*, *34*(10), 548-559.
49
50 Peters, J., & Büchel, C. (2010). Episodic future thinking reduces reward delay discounting through an
51 enhancement of prefrontal–mediotemporal interactions. *Neuron*, *66*(1), 138-148.
52
53 Peters, J., & Büchel, C. (2011). The neural mechanisms of inter-temporal decision-making:
54 understanding variability. *Trends in cognitive sciences*, *15*(5), 227-239.
55
56 Ploghaus, A., Tracey, I., Gati, J. S., Clare, S., Menon, R. S., Matthews, P. M., & Rawlins, J. N. (1999).
57 Dissociating pain from its anticipation in the human brain. *Science*, *284*(5422), 1979-1981.
58
59 Preacher, K. J., & Hayes, A. F. (2008). Asymptotic and resampling strategies for assessing and
60 comparing indirect effects in multiple mediator models. *Behavior Research Methods*, *40*(3),
879.

- risk in human subcortical structures. *Neuron*, 51(3), 381-390.
- Prévost, C., Pessiglione, M., Météreau, E., Cléry-Melin, M.-L., & Dreher, J.-C. (2010). Separate valuation subsystems for delay and effort decision costs. *The Journal of Neuroscience*, 30(42), 14080-14090.
- Rabinak, C. A., Angstadt, M., Welsh, R. C., Kennedy, A., Lyubkin, M., Martis, B., & Phan, K. L. (2011). Altered amygdala resting-state functional connectivity in post-traumatic stress disorder. *Frontiers in psychiatry*, 2, 62.
- Roy, A. K., Fudge, J. L., Kelly, C., Perry, J. S., Daniele, T., Carlisi, C., . . . Pine, D. S. (2013). Intrinsic functional connectivity of amygdala-based networks in adolescent generalized anxiety disorder. *Journal of the American Academy of Child & Adolescent Psychiatry*, 52(3), 290-299. e292.
- Sarinopoulos, I., Grupe, D. W., Mackiewicz, K. L., Herrington, J. D., Lor, M., Steege, E. E., & Nitschke, J. B. (2010). Uncertainty during Anticipation Modulates Neural Responses to Aversion in Human Insula and Amygdala. *Cerebral Cortex*(4), 929.
- Schlund, M. W., & Cataldo, M. F. (2010). Amygdala involvement in human avoidance, escape and approach behavior. *Neuroimage*, 53(2), 769-776.
- Schultz, W. (2000). Multiple reward signals in the brain. *Nature Reviews Neuroscience*, 1(3), 199-207.
- Shadlen, M., & Shohamy, D. (2016). Decision Making and Sequential Sampling from Memory. *Neuron*, 90(5), 927-939.
- Sirois, F. M. (2007). “I’ ll look after my health, later”: A replication and extension of the procrastination–health model with community-dwelling adults. *Personality and Individual Differences*, 43(1), 15-26.
- Sirois, F. M. (2015). Is procrastination a vulnerability factor for hypertension and cardiovascular disease? Testing an extension of the procrastination–health model. *Journal of Behavioral Medicine*, 38(3), 578-589.
- Stawarczyk, D., & D'Argembeau, A. (2015). Neural correlates of personal goal processing during episodic future thinking and mind - wandering: An ALE meta - analysis. *Human brain mapping*, 36(8), 2928-2947.
- Stead, R., Shanahan, M. J., & Neufeld, R. W. (2010). “I’ll go to therapy, eventually”: Procrastination, stress and mental health. *Personality and Individual Differences*, 49(3), 175-180.
- Steel, P. (2007). The nature of procrastination: a meta-analytic and theoretical review of quintessential self-regulatory failure. *Psychological bulletin*, 133(1), 65.
- Steel, P., & Ferrari, J. (2013). Sex, education and procrastination: an epidemiological study of procrastinators' characteristics from a global sample. *European Journal of Personality*, 27(1), 51-58.
- Strunk, K. K., Cho, Y., Steele, M. R., & Bridges, S. L. (2013). Development and validation of a 2× 2 model of time-related academic behavior: Procrastination and timely engagement. *Learning and Individual Differences*, 25, 35-44.
- Treadway, M. T., Buckholtz, J. W., Cowan, R. L., Woodward, N. D., Li, R., Ansari, M. S., . . . Zald, D. H. (2012). Dopaminergic mechanisms of individual differences in human effort-based decision-making. *The Journal of Neuroscience*, 32(18), 6170-6176.
- van der Meer, M. A., Ito, R., Lansink, C. S., & Pennartz, C. M. (2014). Hippocampal projections to the ventral striatum: from spatial memory to motivated behavior. In *Space, Time and Memory in the Hippocampal Formation* (pp. 497-516): Springer.

- 1
2
3 Vazdarjanova, A., Cahill, L., & McGaugh, J. L. (2001). Disrupting basolateral amygdala function
4 impairs unconditioned freezing and avoidance in rats. *European Journal of Neuroscience*,
5 *14*(4), 709-718.
6
7 Wicker, B., Keysers, C., Plailly, J., Royet, J. P., Gallese, V., & Rizzolatti, G. (2003). Both of us
8 disgusted in My insula: the common neural basis of seeing and feeling disgust. *Neuron*, *40*(3),
9 655.
10
11 Wimmer, G. E., & Shohamy, D. (2012). Preference by association: how memory mechanisms in the
12 hippocampus bias decisions. *Science*, *338*(6104), 270-273.
13
14 Yonelinas, A. P., & Ritchey, M. (2015). The slow forgetting of emotional episodic memories: an
15 emotional binding account. *Trends in cognitive sciences*, *19*(5), 259-267.
16
17 Zhang, S., Becker, B., Chen, Q., & Feng, T. (2019). Insufficient task - outcome association promotes
18 task procrastination through a decrease of hippocampal - striatal interaction. *Human brain*
19 *mapping*, *40*(2), 597-607.
20
21 Zhang, S., & Feng, T. (2020). Modeling procrastination: asymmetric decisions to act between the
22 present and the future. *Journal of Experimental Psychology: General*, *149*(2), 311.
23 doi:<https://doi.org/10.1037/xge0000643>
24
25 Zhang, W., Wang, X., & Feng, T. (2016). Identifying the Neural Substrates of Procrastination: a
26 Resting-State fMRI Study. *Scientific Reports*, *6*(1), 1-7.
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60