Neural basis of increased costly norm enforcement under adversity

Yan Wu,[1,2] Hongbo Yu,[2] Bo Shen,[2] Rongjun Yu,[3] Zhiheng Zhou,[2] Guoping Zhang,[2,4] Yushi Jiang,[5] and Xiaolin Zhou[2,6,7]

[1]D… E… 310036, C…, [2]C… B… C… D… B… 100871, C…, [3]… C… A… C… 510631, C…, [4]… C… A… C…

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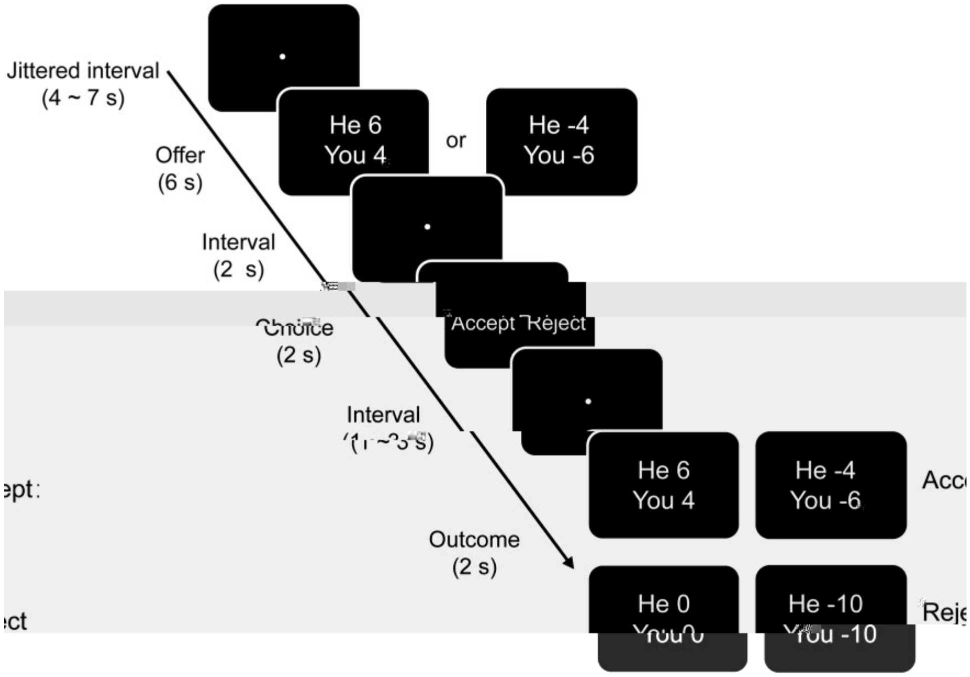

Fig. 1 Sequence of events and timing in a trial. Each trial began by presenting the offer to the participant for 6 s. The participant was told to evaluate the offer but not to press any button at this moment. After a 2 s interval, the participant had to decide whether to accept or to reject the offer by pressing one of two buttons. After another interval, the duration of which varied from 1 to 3 s, the outcome of this trial was presented. Upon acceptance, the amount of gain or loss would be divided according to the proposer's offer. Upon rejection, both the participant and the proposer would get nothing (in the gain domain) or have to pain the full price (in the loss domain).

A (: vs) (: 5:5, 4:6, 3:7, 2:8, 1:9) D 5/5, 4/6, 3/7, 2/8, 1/9 , −5/−5, −6/−4, −7/−3, −8/−2 −9/−1 ,

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fMRI data acquisition

F 3 C , B

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Behavioral modeling

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Table 2 Brain activations in the gain *vs* loss contrast

Regions	Hemisphere	Max *T*-value	Cluster size (voxels)	Cluster level corrected P_{FWE}	MNI coordinates *x*	*y*	*z*
Gain–loss							
VMPFC	R	6.85	155	<0.001	6	47	−11
PCC	R	4.37	60	0.019	9	−10	−11
VTA	L	6.73	167	<0.001	−6	−52	16
Loss–gain							
Putamen	R	5.50	52	0.034	30	5	7
DLPFC	L	7.01	138	<0.001	−36	2	34
Rolandic	R	7.01	112	0.001	45	−10	22
IPL/angular	R	5.32	153	<0.001	27	−61	46
SOG	L	6.54	58	0.022	−21	−67	40
Calcarine	L	8.15	554	<0.001	−18	−73	16

SOG, superior occipital gyrus.

Table 3 Brain activations in parametric contrast (conjunction of gain and loss domains)

Regions	Hemisphere	Max *T*-value	Cluster size (voxels)	Cluster level corrected P_{FWE}	MNI coordinates *x*	*y*	*z*
Increase with SU							
VMPFC	L/R	4.55	181	0.021	6	53	−17
VS	L/R	3.78	10	0.039 [a]	−3	8	−11
Parahippocampus	R	4.02	151	0.044	18	−28	−10
Fusiform	L	5.65	361	<0.001	−33	−28	−19
Precuneus	L	4.09	178	0.022	−9	−55	13
Decrease with SU							
ACC	L/R	3.99	17	0.025 [a]	−6	32	25
DLPFC	R	5.36	246	0.004	39	26	28
	L	5.90	437	<0.001	−42	20	31
Putamen/insula	R	4.58	149	0.047	30	20	1
PAG	R	5.12	278	0.002	3	−22	−14
IPL	R	6.13	1342	<0.001	24	−55	34
	L	5.66			−24	−51	40
IOG	L	4.60	674	<0.001	−42	−76	−8

PAG, periaqueductal gray; IOG, inferior occipital gyrus. [a]SVC based on independently defined ROI (see Methods).

… A, ACC, D FC, … (FC) … (Figure 4A, 4) … 3) … D FC … (… *vs* …), $F_{(4,\ 68)} = 2.62$, $P < 0.05$, … (Figure 4B). … D FC … (1:9; $t_{(17)} = 4.43$, $P < 0.001$), … (5:5; $t_{(17)} = -1.82$, $P = 0.087$). … D FC (…) … $r = 0.80$, $P < 0.001$; Figure 4C) (… *et al.*, 2005).

Gain–loss domain modulates rejection-related activation in the dorsal striatum (DS)

… D … (… 2) … (… *vs* …). C … D … : −15, 2, 22; P_{FWE} (…C) < 0.05, $k = 10$; Figure 5A … 6 … D … (C… *et al.*, 2013) … (Figure 5B). A …

… D … (1:9 *vs* 5:5) …, $F_{(1,\ 17)} < 1$, $P > 0.1$, … D … (*vs* …) … D … $r = 0.67$, $P < 0.05$; Figure 5C).

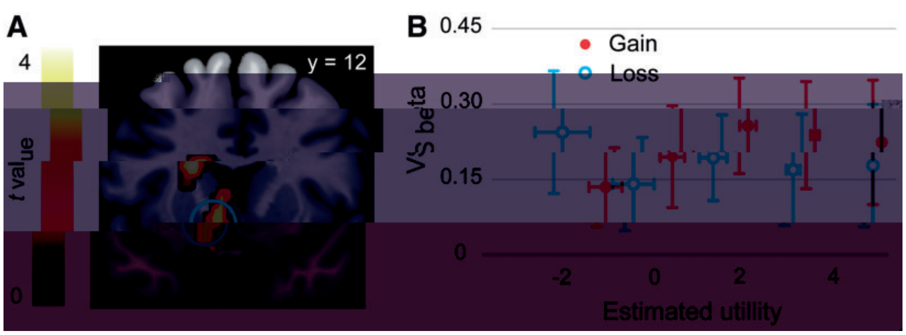

Fig. 3 Positive effect of SU modulated by frame. (**A**) Whole-brain exploratory analysis of the contrast 'Gain$_{+}$ [masked (excl.) by Loss$_{+}$]'. (**B**) Beta values corresponding to 10 types of offers (based on GLM 3) extracted from the VS peak. Error bars represent s.e.m.

Table 4 Brain activations in parametric contrast (domain-specific activations)

Regions	Hemisphere	Max *T*-value	Cluster size (voxels)	Cluster level corrected P_{FWE}	MNI coordinates		
					x	*y*	*z*
Positive association with SU only in gain domain							
VMPFC	L	5.02	378	<0.001	−6	62	1
Caudate	L	4.62	673	<0.001	−18	14	19
MTG	R	4.23	154	0.041	51	−22	−11
Fusiform	L	5.10	232	0.006	−60	−43	−8
Angular	R	5.16	182	0.020	60	−52	25
Negative association with SU only in loss domain							
LOFC	L	4.93	170	0.027	−48	47	1

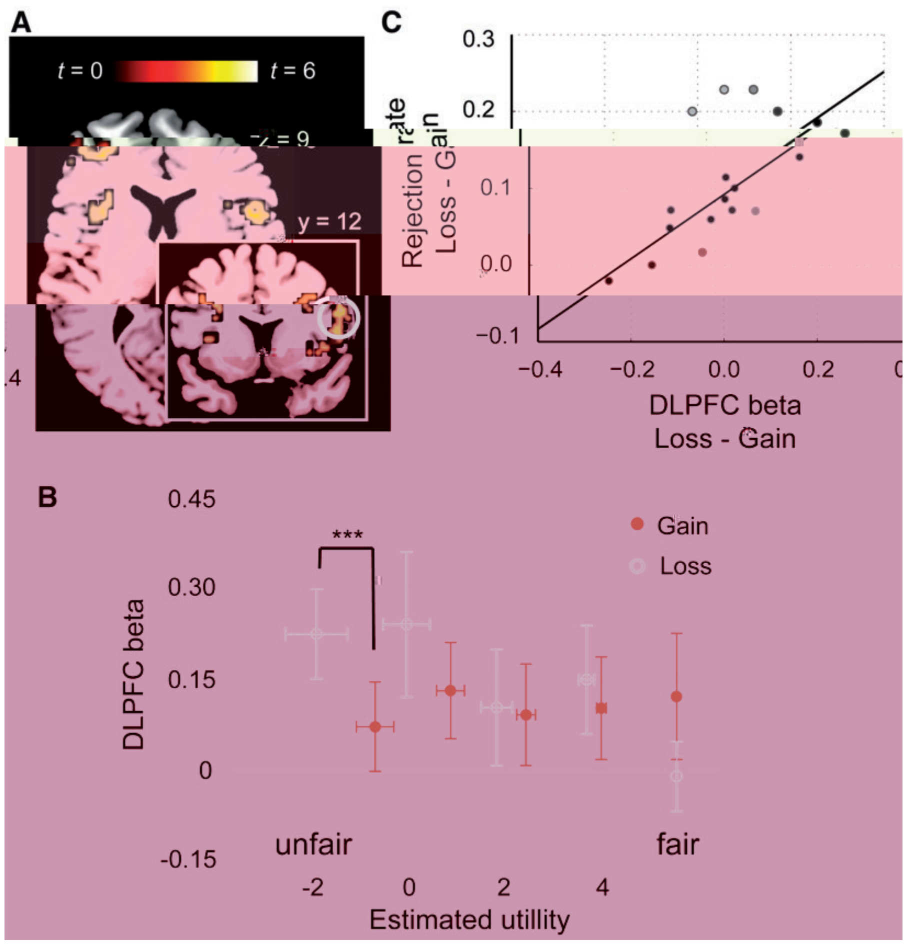

Fig. 4 Negative effect of SU modulated by frame. (**A**) Whole-brain level exploratory analysis of the contrast 'Loss_ [masked (excl.) by Gain_]'. (**B**) Beta values corresponding to 10 types of offers (based on GLM 3) extracted from the DLPFC peak. (**C**) The difference in the mean beta values in the gain and loss domain predicted the differences in rejection rates between the loss and gain domain ($r = 0.80$, $P < 0.001$). ***$P < 0.001$ (two-tailed). Error bars represent s.e.m.

Gain–loss domain and third-party punishment

(F 6). … $F_{(4,120)} = 48.87$, $P < 0.001$). … : $F_{(1,30)} = 1.30$, $P = 0.264$; … : $F_{(4,120)} = 1.03$, $P = 0.395$.

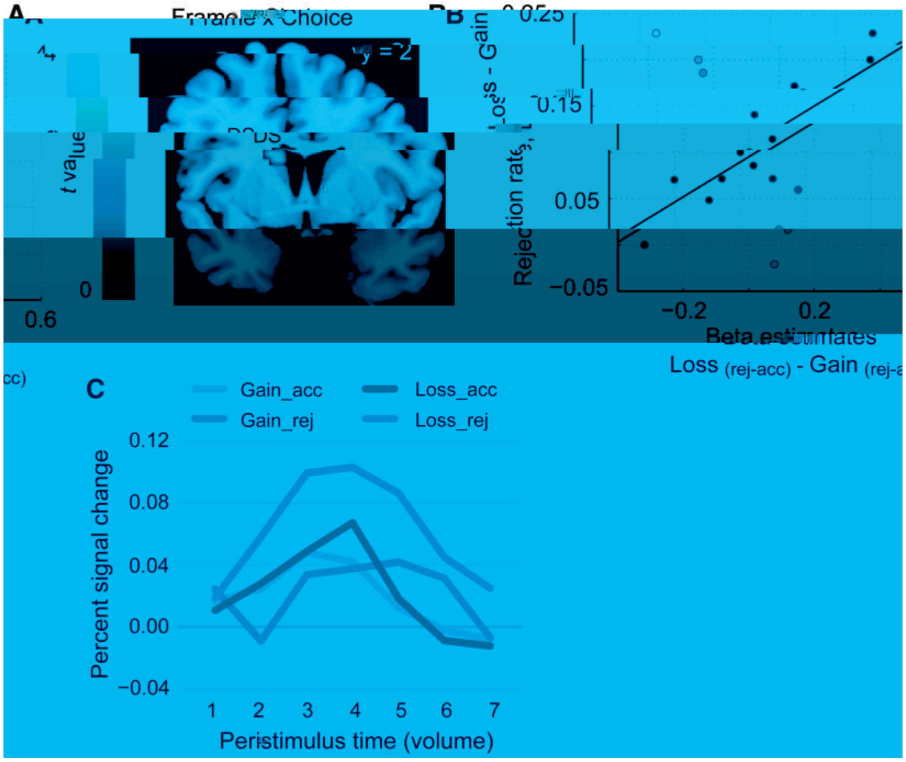

Fig. 5 Neural effects of interaction between choice and frame. (**A**) ROI-based analysis of the contrast 'Loss (rej-acc) — Gain (rej-acc)'. SVC revealed an activation cluster in the left DS, whose rejection-induced activation was higher in the loss compared with gain domain. (**B**) Activation timecourse extracted from a 6 mm sphere around the maximum coordinates indicates that this interaction effect was driven by the amplified activation difference in the loss relative to the gain domain. (**C**) The differences in beta estimates extracted from the activation maximum (Loss — Gain) predicted the increases in rejection rate in the loss relative to the gain domain ($r = 0.67$, $P < 0.05$). Note, the white and grey dots are outliers identified by robust regression and they are down-weighted in computing the correlation coefficients (Wager *et al.*, 2005).

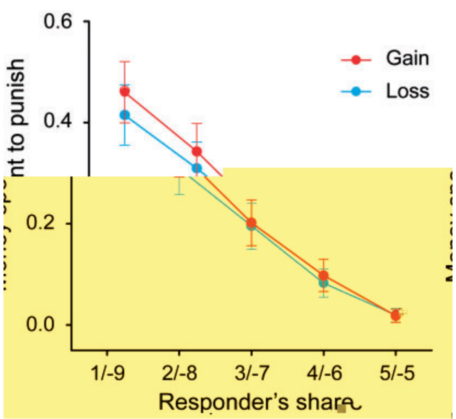

Fig. 6 Effect of fairness and domain on third-party punishment behavior. The amount spent on punishment increased as the offer fairness decreased. Gain–loss domain did not modulate third-party punishment. Error bars represent s.e.m.

DISCUSSION

[illegible] *et al.*, 2013) [illegible] ([illegible] W [illegible], 2011). [illegible] *subjective value* [illegible]

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[illegible] ([illegible] *et al.*, 2013). [illegible] ([illegible] *et al.*, 2002; [illegible] *et al.*, 2008; [illegible] *et al.*, 2010). [illegible] B [illegible]. B [illegible]

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