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M
P t
MRI
C t t

A B R A C

P t t t, t, t t (. ., t); t t t, tt t t t - (. ., t - t). D - , t t - t t, t. t, tt - , t, t t t t, . H , t t t t t t t, t t t t - t, t t t t t . . H , t MRI t t t - t t t t t t (. ., t), - t t t (. ., - t). I t t (N = 90), t, t t t t, t t t t t t - t. M t t, tt (MVPA) t t MRI t t, t - t t tt t t t, t t t t t t t t t t t t .

1. Introduction

G t , "t t t t, t t t " fi (I , 1991), t "t t t" fi (G , 2007). P t t t t, t t t t t, t t t, t t, t, tt t, (. ., t) (B t t, ., 1994, 1995; D , 2003; , 1985). G t t t - t t (H -E , 2019; W C , 2018): t t, tt t t - , / t t t t, . H , t

- (t) t, t t t, t t.

A t t t t t , tt , t (M t t, ., 2016; , 1986), t t t t t t t tt t - (M t ., 2008; t M , 2015). - - t t t t t fl t t t (, 2017; P , 2003), t t t t t t t (B t ., 2004; D t ., 1998; F B , 2014; t ., 2006). I t t t t t - t - t t t fl t (B t ., 2008; D t .,

* C t . P C t , P t , 5 R , B , 100871, C .
E-mail address: 104@ . . (. 7).
[1] t t t t t .

tt :// /10.1016/ . .2019.116488
R 13 t 2019; R 19 D 2019; A t 20 D 2019
A 27 D 2019

1998; M G t t ., 2005). t t, t t, t t t t t t (C t G - , 2006; Č ´-C t ., 2011), t t t (A t ., 2014; D t ., 2004; H -E , 2019; L t ., 2011; t ., 2019), t t (A t ., 2007; P t ., 2005).

A t t t t t t t t t t t (B t ., 2008; D t ., 1998; M G t t ., 2005), t t t t tt : (1) D t t t fl t t fl t t t t t fi ? t t ? (2) H t? fi t?

A t t I t E t (IE ; M t ., 2008; t M , 2015), t (R t ., 2008). I t t t t D R H t (D R , 2003; M t t , 1993), t t fi t t E t t t t t t t t (K t ., 2013; t ., 2014). I t t L t fi (C t ., 2015; K t ., 2013; R t ., 2011; t ., 2014). M t . (2014) t (MCC) (AI) (ACC) (LPFC) (B t , 2015; C tt t ., 2017; G t ., 2008; M R t ., 2010). fi (. ., MCC, AI). I (. ., ACC, LPFC). t (K t ., 2013; t ., 2014) t t (D , 2018; Ott , 2016). I fi (In-group_ Observe) (Out-group_ Observe) (In-group_ Commit) (Out-group_ Commit) t (E t 1) 20 yuan (3 D) (E t 2).

t t (K t A , 2003; G t ., 2018; t ., 2014). t I t (MPFA) t (E t 2). I t t MPFA fi t

2. Materials and methods

2.1. Participants

F E t 1 (t), 24 t (12 19.3 ± 0.8). F E t 2 (MRI t), t t -fi t (>3), 31 t (19 21.3 ± 1.1) E t 2 t . N tt D H Et C tt P C P t .

2.2. Experimental design and procedures

2.2.1. Procedures of Experiment 1 (behavioral experiment)

2.2.1.1. Overview. I t). A (-) (B (-). I fi A / R A (F . 1). (. ., -)

2.2.1.2. Minimal group manipulation. I fi A (" G ", "B G "). E " (J J , 1991)

; 2)

20 yuan (3 D) / 3 B

B

(K

A, 2003; ., 2014).

B .

A

9- L (1 = , 9 =)

. A E 2,

(100 yuan, 15 D)

.

(t 64 × 64, t). I
t t - (R = 2000 , E = 30 ,
= 3.5 × 3.5 × 3.5 , fi = 224 × 224
, fl = 90°). A - t , - t t (1
× 1 × 1 3 t MPRAGE) t
.

2.3.3. Imaging data preprocessing

MRI t t t P t
M t PM8 (t C t N ,
L , K). fi t fi t
t t t t . -t
t , t - t , - t 3 × 3 × 3 3 t
, t t M t N I t t t (MNI) ,
t, t 8- t t G
fi t , t fi t - fi t t 1/128 H
t .

2.3.4. Whole-brain general linear model analyses

- t t t
t fi t t t t , t t t .
t t t , t t
t t t t t t t
t t t t . A t t t t -
, t - t t t t t -
t t 18 t t
G L M (GLM). t GLM fi
MRI t :

- R1: C t t (t = 4.3),
t t t t - / t t
t t t t t (“ t ”), t t
, t t ’ t t t (“ t t t ”
);
- R2-R5: C t (t = 2),
t t 2 t 3 tt . E t
t t t ;
- R6-R9: F t t t t (2), t
t t t ;
- R10-R13: t t t t (2), t
t fi t ;
- R14: t t (1.5);
- R15: A t , t t tt t 20
t / t t (5);
- R16: M t (4.3);
- R17-R22: t t , -
t t GLM t t t t t .

A t . A t t - , t t
t t t t t t t t
fl t t .
A t t - , fi t t t :

- - t: In-group_ Observe > Out-group_ Observe;
- t: Out-group_ Commit > Out-group_ Observe;
- t A : (In-group_ Commit + Out-group_ Commit) > (In-group_ Observe + Out-group_ Observe);
- t : (In-group_ Commit + In-group_ Observe) > (Out-group_ Commit + Out-group_ Observe);

t - t t t (In-group_ Observe > Out-group_ Observe) t t t t (Out-group_ Commit > Out-group_ Observe) t t t . t t t t t ‘In-group_ Observe > Out-group_ Observe’ t fi t t - t t t ’ t t t t t ; t t t ’ t t t . I t t t , ‘ t ’ fi t t t ‘Out-group_ Commit > Out-group_ Observe’. I t t t t t t ‘In-group_Commit > In-group_Observe’ t t t . I t t , fi t t t t t H , t t t ’ t t t t t t fi t t B t t , t t t t t t ‘O t- C t > O t- O ’ t t t t ‘I - C t > I - O ’. t fi ‘ t t t t t ‘Out-group_ Commit > Out-group_ Observe’.

t t t t t - t t , fi P < 0.005 t t t t t ≥46 . t t t t : F t, t fi t t t - t, t t t , t - t t , , t t . I t t t t t I/ II (L C , 2009). A t t t t fi . t, fi t t t t t t t fi . N t t t - t t t t 2 t t , t - t t t , , t , . , t t L C (2009), t t t t (. ., -) t t - t t t < 0.005. , t tt t t t , t t - , t ROI , t t t t - - t t t t t 1 . A t , t t - t t t - t t t t t t t , t t t t t t . G t t t , t t t - t t , .

2.3.5. Conjunction analyses

t t t t t - t, t t (P F t , 1997) t t t t (Out-group_ Commit > Out-group_ Observe) t - t t t (In-group_ Observe > Out-group_ Observe). C t t t t t t t - t t t t t t t t t . , t t t t t t t t (t t t, , t t t t t t - t t t), t fi t t t fl t t fl t t t t t (P F t , 1997). t t t t t (F t t , 2005; N t , 2005) t t t t t t fi t t t t t t t t t . t “ t t ” t t “ t t t t t t t .” I t t t fi t, t t t t t t t “ t t t t t t .” t , t t t ‘ ’, t t t t t fi t t t t fi t.

2.3.6. Multivariate pattern analysis of imaging data

C t t t t , t M t t tt (MVPA) t t t t t t t t t (. . t , tt). , t MVPA t t t t t t t t t t , tt - t , t t t t.

O ... (D ..., 1999; ..., 1987; ... ., 1987). ... "...", ... fi ... M ... (MM) (F ... ., 2001; ... ., 2013) ... fi ... MM ... fi ... (C ... ., 2015; ... ., 2013; ... ., 2014). ... In-group_Observe vs. Out-group_Observe. ... MM ... GLM ... (C ... , 2013; ... ., 2011).

3. Results

3.1. Group-based guilt elicited by an interaction-based minimal group paradigm

A ... fi ... I E ... 1, ... (... 1): ..., t (23) = 10.0, p < 0.001, d = 2.08; ... , t (23) = 9.8, p < 0.001, d = 1.99. ... E ... 2: ... fi ... (... 1): ..., t (30) = 7.8, p < 0.001, d = 1.41; ... , t (30) = 6.4, p < 0.001, d = 0.77. ... / ... D ... ? M ... ? ... (E ... 1) ... (E ... 2) ... N ... E ... 1 ... , $\beta = 0.68$, SE = 0.08, t = 8.50, p < 0.001. M ... , $\beta = 0.29$, SE = 0.06, t = 4.90, p < 0.001. ... Commit ... fi ... G ... × A ... , $\beta = 0.08$, SE = 0.04, t = 2.26, p = 0.03 (... 2; F . 3A). M ... E ... 2 ... E ... 1 (F . 3B). I ... , $\beta = 0.73$, SE = 0.09, t = 7.44, p < 0.001. M ... fi ... , $\beta = 0.38$, SE = 0.11, t = 3.53, p < 0.001. ... Commit ... fi ... G ... × A ... , $\beta = 0.16$, SE = 0.08, t = 2.14, p = 0.04 (... 2; F . 3B). O ... Supplementary Results of Experiments 1 and 2.

... G ... (I - ... O ...) A ... (C ... O ...) ... (...) ... ANOVA ... (E . 1) ... (E . 2&3), ... fi ... 3 ... (... : E . 1: F (1, 22) = 1.04, = 0.32; ... : F (1, 29) = 0.15, E . 2: = 0.70; E . 3: F (1, 33) = 0.29, = 0.58). P ... fi ...

3.2. Shared responsibility explains group-based guilt and compensation

... 3), 33=¼ ... -319 -2

Table 2
B , t E t 1, 2.

It	I - C t	O t- C t	I - O	O t- O	I t, t T/F
E t 1					
O ,					I t, t T
G t, t	4.0 (.1)	3.6 (.1)	2.8 (.1)	2.1 (.1)	2.26*
P t- t ,					I t, t F(1, 23)
R t	6.8 (.3)	6.6 (.4)	4.5 (.5)	3.3 (.4)	7.55*
F ,	3.5 (.5)	3.2 (.6)	3.1 (.5)	2.2 (.3)	2.47
A	3.5 (.4)	2.9 (.5)	2.8 (.4)	2.4 (.4)	0.10
E t 2					
O ,					I t, t T
M t, t	13.5(.2)	13(.2)	12.3(.2)	11.2(.2)	2.14*
P t- t ,					I t, t F(1, 30)
R t	6.9 (.3)	6.7 (.3)	4.4 (.4)	3.3 (.4)	5.41*
G t	6.5(.3)	5.9 (.4)	4.1 (.4)	3.2 (.4)	1.05
F ,	3.6 (.3)	2.7 (.4)	3.3 (.3)	2.6 (.3)	0.16
A	3.1 (.4)	2.7 (.4)	3.0 (.3)	2.6 (.3)	0.11

Note. t , (SEs) , , t . SEs O , E t 1, E t 2, t , t , t t , , t . SEs P t- t , t , t , , . fi tt - , t , t t * p < .05.

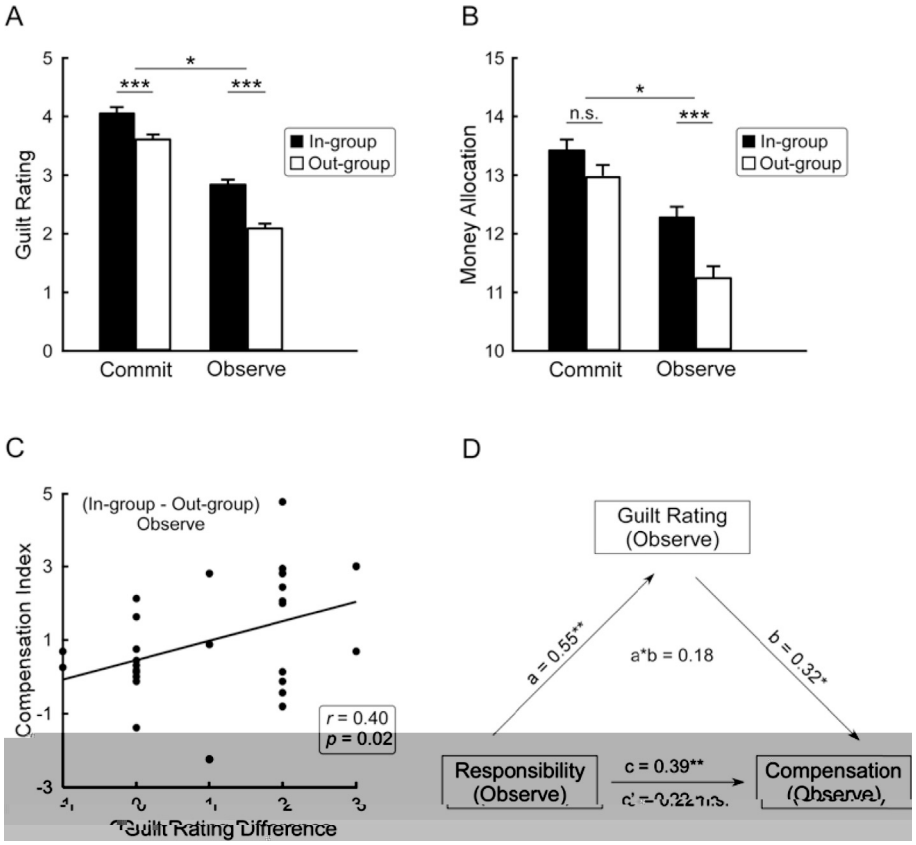

Fig. 3. Behavioral results of Experiment 1 (A) and Experiment 2 (B). F F . 2A, B, t t t , t fi t G (I - vs. O t-) A (C t vs. O) t , t . A t , t fi t t t. **(C)** I E t 2, t t- . t t , t - (O : In-group_ Observe > Out-group_ Observe) t , t t t , - t . **(D)** t , t , t , , t , t , t , t E t 2. E , t , t - , t t , t . ***p < .001, **p < .01, *p < .05.

3.3. Brain activations associated with personal and group-based guilt

H t t , t , t tt t t , t t t fl t - , t, t . , t , t tt t t t A , G Supplementary Neuroimaging Results. t , , t t - t, , t t t t t t . fi t t , t , t "In-group_ Observe > Out-group_ Observe", t t t - t. t , t , t , t t , t t (MCC; MNI , t = 6, 26, 28 ; k = 85), t t (AI; MNI , t = 27, 20, −11 ; k = 78) (F . 4A). MCC , t AI , t t , t , t (C , t ., 2011; , t ., 2014) , t - , t t t (I -, t ., 2009; K´ , t ., 2008; K , t ., 2013; , t ., 2003; Z , t ., 2007). t , t t , t , t tt , , t t , t t 27 , t , t , t MCC , t AI. , t t , t , t , t MCC (F . 4B), t AI (F . 4C) , t , tt , t t , tt t , t , t . M , MCC , t t (In-group_ Observe > Out-group_ Observe) t , t , t t t. , t t t t t t (r = 0.45, p = 0.011), , t t , t t , MCC , t - , t.

t t t t t I t t t t ‘Out-group_ Commit > Out-group_ Observe’. t t t t t t t t t t t t t t t t fl t t R t fi t t (K t ., 2013; t ., 2014), t t t (Out-group_ Commit > Out-group_ Observe) t t t MCC (MNI t = 12, 17, 40 ; k = 153) t t (MA) (MNI t = 15, 5, 67 ; k = 62) (F . 5A). t t t t t 27 t t MCC (F . 5B) t t t t t t MCC t t (Out-group_ Commit > Out-group_ Observe) t t t t t t t t (r = 0.43, p = 0.02). t AI t t (K t ., 2008; K t ., 2013; t ., 2014). t t t t t t 27 t t t fi t AI t t (36, 30, −8 , t t t ., 2014). t t t t ROI (F . 5C) tt t t t t MCC. t t t t fi t t t ROI, t t t t Out-group_ Commit t t t t Out-group_ Observe t , t = 2.75, p = 0.01.

3.4. Group-based guilt shares brain representation with personal guilt

MCC t t t t t t t (In-group_ Observe > Out-group_ Observe) t t t (Out-group_ Commit > Out-group_ Observe). t t t t t t t fi t t t t t t t t fi t t fi t t t MCC ((MNI t = 6, 26, 28 ; k = 31), F . 6A). t t t t t M t t tt

(M PA) t t MCC t t t t t t t t t t t t t t t tt fi t t t t t t MCC t t t t t t t t t (= 68% ± 6%, p < 0.001; F . 6B). M t t t fi t t t t (Out-group_ Commit vs. Out-group_ Observe) t 71% ± 8%, p = 0.01 (F . 6B), t t t tt t t t t t t

4. Discussion

I t t t fi t t t t t fi t t t t t t (B t t ., 1994; H , 2001; Z K , 1990). M t MRI t t t t O fi t t I t E t t (M t ., 2008; t M , 2015), t t t t t t t t t t P t t t t t t t t t t t (H , 2001; Z K , 1990). t t t t t t (Č -C t ., 2011; I t ., 2004). A t t t t t t t t t t t Observe t t t tt t t t t t t t t t t t t t (In-group_ Observe > Out-group_ Observe). t t t t t t t (, 2017; , 2006): t t t t t t

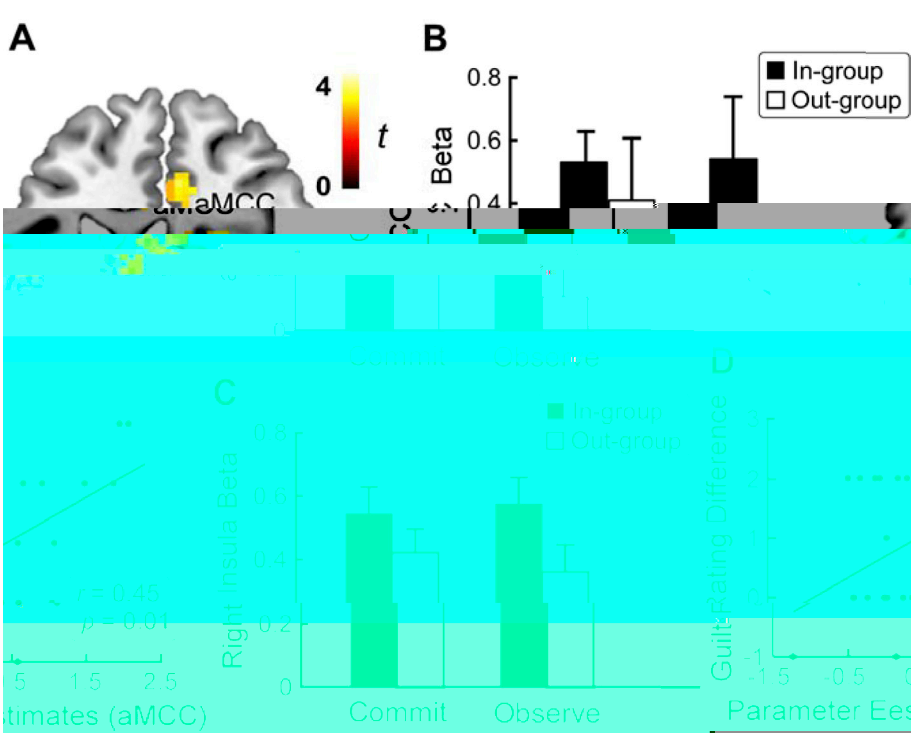

Fig. 4. Brain activations related to group-based guilt. R t t t t ‘In-group_ Observe > Out-group_ Observe’ t t (A). t t t t t P < 0.005 t t t t ≥46 R t t tt (. ., t t t t) t t MCC (B) AI (C) t t (27 t t t MCC (MNI t = 6, 26, 28)

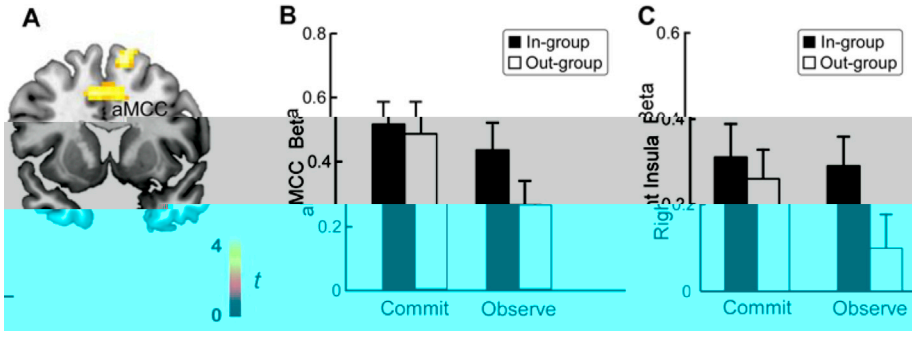

Fig. 5. Brain activations related to personal guilt (*'Out-group_ Commit > Out-group_ Observe'*). (A). R t t t t 'Out-group_ Commit > Out-group_ Observe' -t - t . P < 0.005 t t ≥46 (B). R t t tt (. , t t t). MCC t t 27 t t MCC (MNI t = 12, 17, 40). (C). R t t tt AI t t t fi t t (27 t t AI t t , 2014; MNI t = 36, 30, −8). E t t t . C F . 5 t.

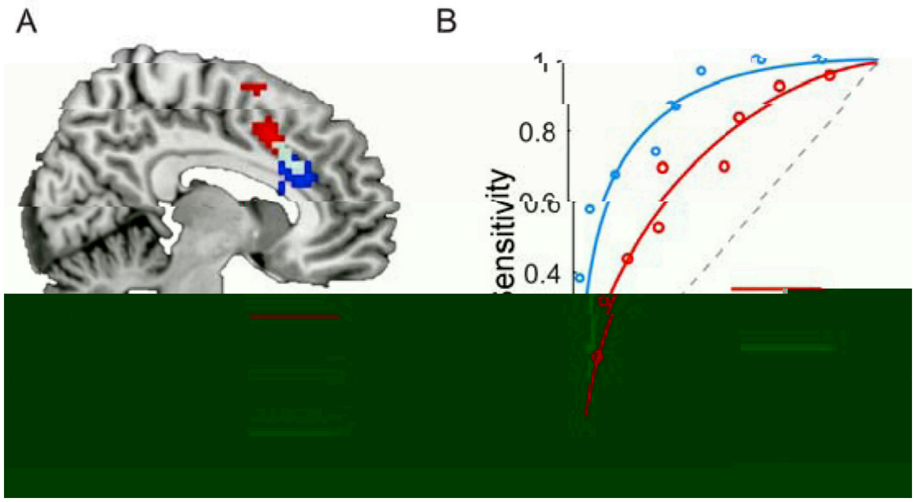

Fig. 6. Results of multi-variate pattern analysis (MVPA). (A) C ... MCC. ... P < .005 ... ≥30 ... **(B)** R ... (ROC) ... R ... : P ... ; B ... : G ... . C ... F . 6 ...

... B ... . I ... . F ... It ... "M (M)" ... M ... (L ... ., 2005), ... (H ... ., 1993), ... (N ... ., 2008; M ... ., 2015; M -P ... ., 2016). I ... : 1) ... ; 2) ... (F . 3D). ... M- ... . It ... N ...

(G ... , 2004; L ... B ... , 2012; ... ., 2016; ... ., 2015), ... (E ... , 1988; F ... , 1993). A ... (B ... ., 1994; ... D ... , 2003). ... (B ... ., 2016; C ... ., 2015; F ... ., 2019; K ... ., 2008; K ... ., 2013; L ... ., 2017; -C ... ., 2016; ... ., 2014). P ... (B ... ., 1995). I ... (B ... , 1988; ... , 1976). ... (F ... ., 2007; ... ., 2007; Z ... ., 2019): ... (. ., A ... ., 2017; E ... ., 2016; K ... ., 2019; K ... ., 2016; ... ., 2014; ... ., 2019).

It ... . M ... . H ... "I" ... "I" ...

MRI

MPFC/ACC

5. Conclusion

Data and materials availability

Declaration of competing interest

CRediT authorship contribution statement

Zhiai Li: **Hongbo Yu:** **Yongdi Zhou:** **Tobias Kalenscher:** **Xiaolin Zhou:**

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(31630034) (973 : 2015CB856400).

Appendix A. Supplementary data

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