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C t t t t D t

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A R I C L E I N F O

G - t
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 tt - , t t , t t t t . H , t t t t t t 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). I t t (N = 90), t t t t t t t t - t. M t t tt (M PA) 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 A t t t t " fi (I , 1991) t t t (M t t ., 2016; , 1986), t " t t " fi t t t t t t (G , 2007). P t t t t t t t t M , 2015). - t t t t t (. ., t) (B t t ., 1994, 1995; D , 2003; , 1985). G t (, 2017; P , 2003), t t t - t t (H t t t t (B t ., 2004; -E , 2019; C , 2018): D t ., 1998; F B , 2014; t ., 2006). t t tt t I t , t t t t t - , / t t - t - t t t t . H , t t t fl t (B t ., 2008; D t ., (t) t t t t t t .

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* C t . P C t , P t , 5 R , B , 100871, C .
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tt :// . /10.1016/ .2019.116488
R 13 t 2019; R 19 D 2019; A t 20 D 2019
A 27 D 2019
1053-8119/© 2019 A t . P E I . t t CC B (tt :// t . / / /4.0/).

1998; M G t t ., 2005). t t t t t - t t t t (C t G - , 2006; Č ´-C t ., 2011), t 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 tt : (1) D t - t t fl t t fl t t t t t fi t t ? t , t t t- t t t t, t t t t t t t ? (2) H t - t? fi , - t t t t?

A t t I t E t (IE ; M t ., 2008; t M , 2015), - t t - t t t t t t, t t (R t ., 2008). I t t, t t D R H t (D R , 2003; M t t , 1993), t t t t t fi t t. E t t t, t t t t / . t t t , - t t t . t t t ' t- t t t (K t ., 2013; t ., 2014). I 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. L t , t - t t t fi t t t t t t t t- t t t (C t ., 2015; K t ., 2013; R t ., 2011; t ., 2014). M , t - t t . (2014) t t t t t t (MCC) t (AI) t t t- t t t t t t t t t t t , - t t , t t t (ACC) t t t (LPFC) (B t , 2015; C tt t ., 2017; G t ., 2008; M R t ., 2010). fi t t t t t t t t , , t - t t t , t t t tt t t t t (. ., MCC, AI). I , t t , t t - t t , t t t t t t t - (. ., ACC, LPFC). t t t t , t t t t t t t (K t ., 2013; t ., 2014) t t t t t t t (D , 2018; Ott , 2016). I t , t t t ' t t t t - / t- t t t t t t t t tt t t , t t t 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 t t t (E - t 1) 20 (3 D) t t t t (E t 2). t t , t t t t t t , t t t t t t t t t t t t t t t t (K t A , 2003; G t ., 2018; t ., 2014). t t t - t - (t t t) t t , t - t t, t , t - t t t t. I t , t t t t t tt (MP A) t t - t t t t t t t (E t 2). I - t t t t - t t, t t t t t t t t t, t t t t M PA - fi t t - t.

2. Materials and methods

2.1.

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

2.2. E

2.2.1. E 1 ( )

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

2.2.1.2. . I t fi t , t t - t A t t - t (" G " "B G "). t - t t t - . E - t t t t t " t " (J J , 1991) t t t . t t t t t t t t t t - t

t t t ; 2) t t t t -
, t t t, t t t t
20 (. 3 D) t / t 3 B
t t t , t t t t t B
t t t t t . t
t t t t
t t t (K t
A , 2003; t ., 2014). , t t t t t
B t t t t .
A t , t t t t t , , ,
t 9- t L t (1 = t t , 9 = t)
t t t . At E t 2, t t -
t t t t t t t t t t t
t. , t t t ’ fi t
(100 , t 15 D) t t t -
t t t t t t .

(t 64 × 64, t). I t 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. . .

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 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. . . - 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 . At t t 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 t 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 t . At t - , t t t t t t t t fl t t .

At t - , fi t t t :

- - t: - > - ;
- t: - > - ;
- t A : (- + -) > (- + -);
- t : (- + -) > (- + -);

t - t t t (- > -) t t t t (- > -) t t t . t 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 . I t t t , ‘ t’ fi t t t ‘ - > - ’. It t t t t t t ‘ - > - ’ t t . I t t , fi t t t t t t. H , t 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 t ‘ - > - ’. t t t t t - t fi < 0.005 t t t t ≥46 . t t t t : F t, t fi t t t - t, t t t , t - t , t t. It 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 2 t t t - t t , , t . , t t L C (2009), 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 1 . A 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. . . t t t t - t, t (P F t , 1997) t t t t (- > -) t - t t t (- > --). 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 fi t t fl t t fl 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 fi t 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 t t t t t “ t t t t t .” t , t t t ‘ ’, t t t t t fi t t t t t fi t.

2. . . C t t t , t M t t tt (M PA) t t t t t t t (. . t tt). , t M PA t t t t t t t t tt - t t t t.

O t t t fi t t t t t t t t t fi t t - t t t t t t t t (. ., t, - t, t) (D , 1999; , 1987; t ., 1987). t t t t t “ t”, t t , t t t - t fi t. I t t , t t - t t t t t, t t t t t t fi t t t fi t t t. t t M (M) (F t ., 2001; t ., 2013) t t t t tt fi t t t fi t t - t. t - - t - t t , t t t M fi t - t t (C t ., 2015; t ., 2013; t ., 2014). t t . - . t t t, t M t t t t GLM , t t t t t t (C t , 2013; t t ., 2011).

3. Results

.1. - -

A t , fi t t t t t t t - t t t t-. I E t 1, -t t t t t t t t t t t t t t - t t t t- t (1): , (23) = 10.0, < 0.001, = 2.08; t t , (23) = 9.8, < 0.001, = 1.99. t E t 2: t t t t t fi t t - t t t t- t (1): , (30) = 7.8, < 0.001, = 1.41; t t , (30) = 6.4, < 0.001, = 0.77. t t t t t - / t- t . D t t t t t t t t t t t t ’ ? M t t , t t t t ’ t t ’ t t t t t t ? t - t , t tt - t t (E t 1) t t (E t 2) t . N t - , t t E t 1 t t t t t tt t t t , $\beta = 0.68$, $E = 0.08$, = 8.50, 0.001. M t t t t t , t t t t - t t t t t- t t , $\beta = 0.29$, $E = 0.06$, = 4.90, 0.001. t t t , t fi t G × A t t , $\beta = 0.08$, $E = 0.04$, = 2.26, = 0.03 (2; F . 3A). M t t E t 2 tt t - t t t E t 1 (F . 3B). I , t t t t t t tt t t t t , $\beta = 0.73$, $E = 0.09$, = 7.44, 0.001. M fi , t t t t t t - t t t t t- t t , $\beta = 0.38$, $E = 0.11$, = 3.53, 0.001. t t tt - t t, t t t , t fi t G × A t t , $\beta = 0.16$, $E = 0.08$, = 2.14, = 0.04 (2; F . 3B). Ot t t t t t t t t t

E 1 2.

t t t t ’ - t, t G (I - O t-) A (C t O) ( ) t ANO A t t (E . 1) t t (E . 2&3), t t t t t t t t t t ’ . t - t t t fi t 3 t (t t : E . 1: F (1, 22) = 1.04, = 0.32; t : F (1, 29) = 0.15, E . 2: = 0.70; E . 3: F (1, 33) = 0.29, = 0.58). P t t ’ t fi t t t .

.2. - -

t t t t - t, t 01.3088 D (t ,)70 tt t - 219.93825.56445 (D (-)

Table 2
B t E t 1 2.

It	I - C t	O t- C t	I - O	O t- O	I t t /
E t **1**					
O					I 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 (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
M t t	13.5(.2)	13(.2)	12.3(.2)	11.2(.2)	2.14*
P t- t					I t t (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

. t (*E*) t . *E* O E t 1 E t 2 t t t t t . *E* P t- t t . fi t t - t t t * < .05.

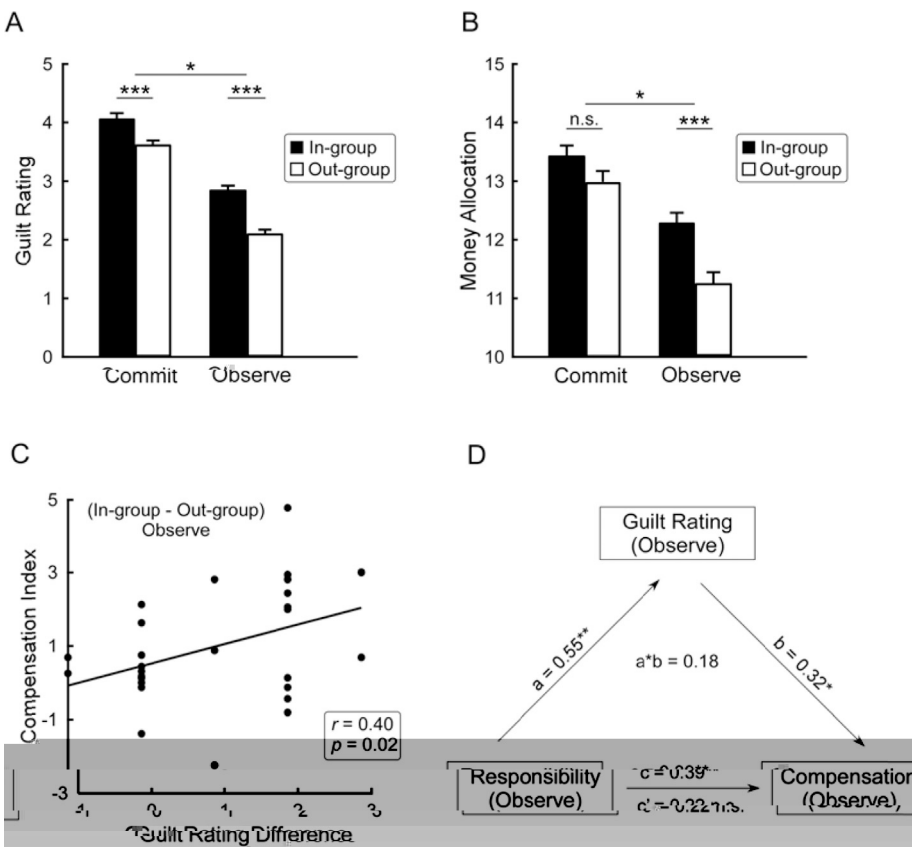

Fig. 3. Behavioral results of Experiment 1 (A) and Experiment 2 (B). F F . 2A B, t t t t fi t G (I - . O t-) A (C t . O) t t . A t t fi t t t. **(C)** I E t 2, t t- t t t - (O : - > -) t t t t - t . **(D)** t t t t , t t , t t E t 2. E t t - t t t . *** < .001, ** < .01, * < .05.

. . - MCC t AI t t t t (C t ., 2011; t ., 2014) H t t t t tt t t - t t t (I - t ., 2009; t t t t fl t - t, K´ t ., 2008; K t ., 2013; t ., 2003; t ., t ., t . t t tt t t t 2007). t t t t t tt , t t t A G . t t t 27 t t t t t t - t, MCC t AI. t t t t t MCC t t t t t (F . 4B) t AI (F . 4C) t tt t t tt t t . fi t t t t “ - > - t t . M , MCC 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 (= 0.45, = (MCC; MNI t = 6, 26, 28 ; = 85) t t 0.011), t t t t MCC t (AI; MNI t = 27, 20, −11 ; = 78) (F . 4A). - t.

t t - t -
t t t. I 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 fl t -
t. R t fi t
t (K t ., 2013; t ., 2014), t t t (-
> -) t t t MCC (MNI
t = 12, 17, 40 ; = 153) t t
(MA) (MNI t = 15, 5, 67 ; = 62) (F . 5A).
t t t t t t 27
t t MCC (F . 5B) t t t t t
t MCC t t (- > -)
t t t t - t t -
t t t t (= 0.43, = 0.02). t AI
t 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 - t t t
t - t , = 2.75, = 0.01.

MCC 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 -
t t t . t fi t t
fi t tt MCC ((MNI t = 6,
26, 28 ; = 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 (= 68% ± 6%, < 0.001;
F . 6B). M t t , t fi t t t
- t t (- . -)
t 71% ± 8%, = 0.01 (F . 6B), t t t tt
t t t t
- t.

4. Discussion

I t t , t fi - t
t t t t. fi , -
t - t t t t
- t t t (B t t ., 1994;
H , 2001; - K , 1990). M , t
MRI t 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 tt
t t t t t t
t (H , 2001; - K , 1990).
, t 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 t t t ,
t t t t tt
- t t t- t , t t
t t t t t (- >
-). t t t t t -
t t - t (, 2017; ,
2006): t t t t t t

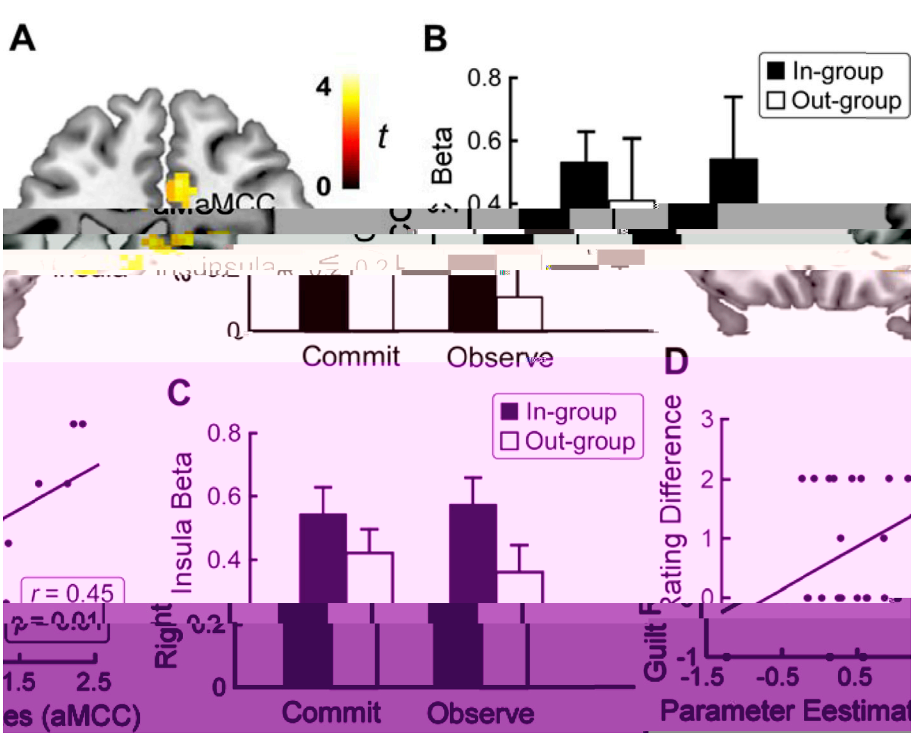

Fig. 4. Brain activations related to group-based guilt. R t t t t ‘ - >
- ’ -t - t
(A). t t t t t <
0.005 t t t t ≥46
. R t t tt (. ., t t -
t) t t MCC (B) AI (C)
- - t t (27 t -
t MCC (MNI t = 6, 26, 28)

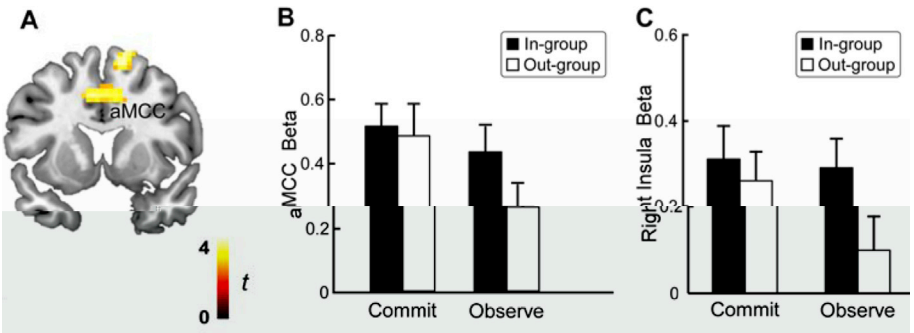

Fig. 5. Brain activations related to personal guilt (‘*Out-group_ Commit* > *Out-group_ Observe*’). (A). R t t t t ‘ - > - , -t - t . < 0.005 t t ≥46 (B). R t t tt (. ., t t t). MCC t t 27 t t MCC (MNI t = 12, 17, 40). (C). R t t tt AI t t t fi t t (27 t t AI t t ., 2014; MNI t = 36, 30, −8). E t t t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

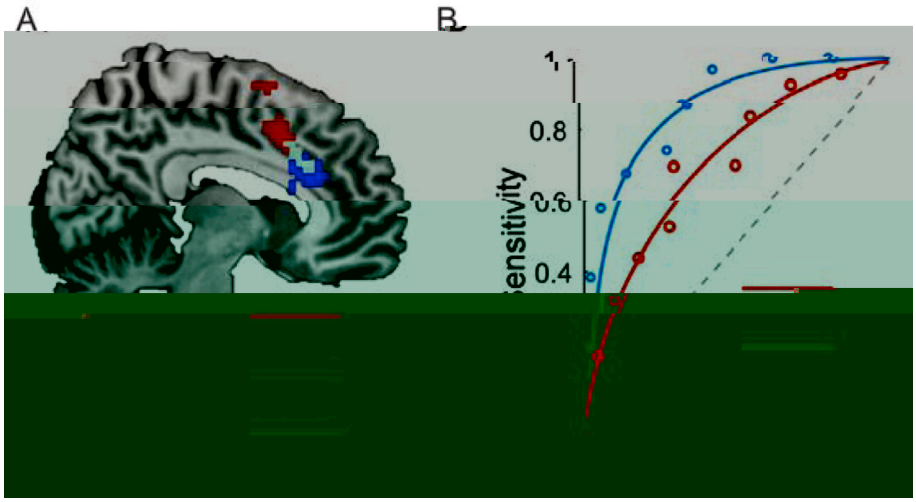

Fig. 6. Results of multi-variate pattern analysis (MVPA). (A) C t - t MCC. < .005 t t ≥30 . **(B)** R t t (ROC) t t - - t t . R : P t; B : G - t. C F . 6 t.

fi t t t t t t t t . B t t , t t t t t t t . I t, t t - t t t - t t . F t t t t t t t t t t t t . t , t t - t , t t t t ' t t t . It t t t - t t t ' t , t t t " M (M)" . t t t - t t - M t (. ., t t , - t t , t .) t - t t t t t t . I t , - t t t t : t ' t' t t t t t t t t t t (L t ., 2005), 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 t t (H tfi t ., 1993), t t t M t (N t ., 2008; M t ., 2015; M -P t ., 2016). I t t , t - t t t t t fi t t t : 1) t t t t - ' t t tt t t t , t t t - t t , t t - t t t t t - t t t t ; 2) t t t t - t t ' t - ' t (t t t t) t t t - t t (F . 3D). , t t t t t t- t t t t M- t t t t t . It t t t t t - t t t t - t t - ' t . N t t t t t t t - t t t t , t . t t t t t t

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

It t t - t t t t . M - t t t , t t t t . t t t t t , t t t t t t- t , t . H , t t t t t t t - , "I" t , t , , t t t t t " " t- t - , t "I" t t t - t (. . , t ,). t t t t

t t t tt . MRI t t t t t t t t. F t , t t t t t t t t t (PJ) - t (t t t , ACC), t t t t t tt t t t tt t t t (PFC) ACC t t (t ., 2019). I , t t t . A 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 - t t t t , t t t t t t t t t t MPFC/ACC t t t (t ., 2012). , t E t A t t t (, 1995) t t t , t E -A - t t t t (, 1989). , t - t t - t . M fi , E t A t t t E -A , t t t t t t t t t (M K t , 1991). F t - t t t - t - t. t t t t t t t t fi t t t t t t . F t t t t - t fi t t t t - t - t t - fl t t . N - t , t t t t t t t , t t t t t t . F t, t , t t t - (- t) t t C t (. . B t t ., 1994; Č ´-C t ., 2011; I t ., 2004). It t t t - t t t t , t- , t t t t (. ., C - t t , , t .). , t t , t t t t - (- t) t t t t(t) t - .E.I.R.D (t , E t , I t , R D t) t (N t ., 2010). I t t t, t , t t t E t A t (. ., C) t t t t fi - . , fi t t - t, t t t fi t t t t t t t - t - fl t t t . t t t t - t t t t t t t fl t t .

O fi t t - t t t t t t t t t - t . E H A t, t t t t t - t, t t “ t … t ” (A t, 2009). I t ’ t , fl t t t t t t t t - (A t ., 2014; B C tt, 2019; C tt, 2017). I 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 t t t (G t ., 2018; t ., 2019). t t , t t t t t t t t t t t t t - ’ t t t t t t - t .

5. Conclusion

B MRI t t t t , t t t t - (- t) t t t - . fi t t t t t t t t t - t t t t (t M , 2015). t t t - t, t t t t t t t t t . O fi t t t t t t t t , t t t - t .

Data and materials availability

t F , 3A-D, 4D, 1, 2, - t F . 1, 1, 2 D t fi . C t t N t (tt ://t. / t /? =), t G tH (tt ://t . / 0602/ t - - t). MRI t t - t .

Declaration of competing interest

t t t t t t .

CRediT authorship contribution statement

Zhiai Li: F , t - t. **Hongbo Yu:** F , t - t. **Yongdi Zhou:** t - t. **Tobias Kalenscher:** t - t. **Xiaolin Zhou:** t - & t .

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t N t N t F t C (31630034) N t B R P C (973 P : 2015CB856400).

Appendix A. Supplementary data

t t t t t t tt ://. /10.1016/. .2019.116488.

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