A Critical Role of Temporoparietal Junction in the Integration of Top-Down and Bottom-Up Attentional Control

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Abstract: I ... (MRI) ... (DCS) ... (TPJ). I ... TPJ ... (FEF) ...

C ... 973; C ... 2015CB351800; C ... 31371054; C ... 12A7D116; C ... MOST-103-2410-H-008-023-MY3; MOST-101-2628-H-008-001-MY4; C ... R01MH094305; C ... 81328008; C ...

*C ... Y ... W ... 100080 ... 320, T ...

R ... 21 M ... 2015; R ... 14 J ... 2015; A ... 16 J ... 2015.
DOI: 10.1002/ ... .22919
P ... 26 A ... 2015 W ... O ... L ...

% TPJ FEF %
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TPJ
. *Hum Brain Mapp 36:4317–4333, 2015.*

Ke words: ; MRI; ; DCS;

INTRODUCTION

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MATERIALS AND METHODS

Participants

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Task Design

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(MFT) F ., 2008, 2011, 2014 . T % %

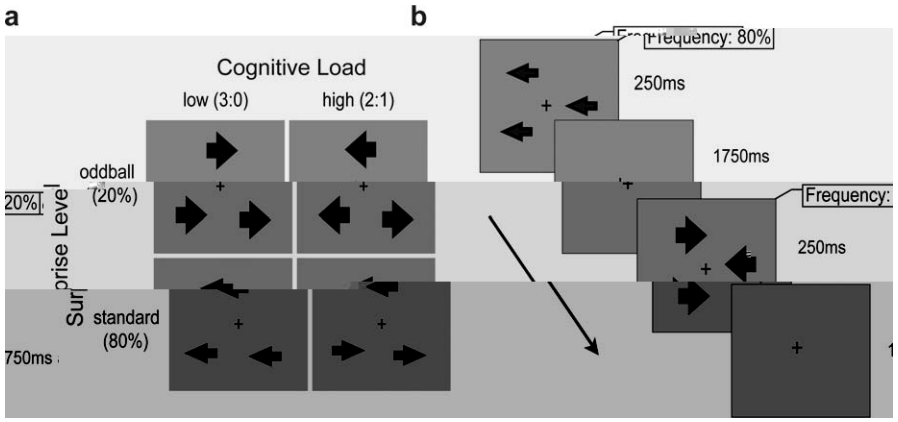

Figure 1.

Stimuli and procedure. (**a**) Stimuli used in the experiment and conditions in a 2 × 2 factorial design. Cognitive load (low load vs. high load) was manipulated by varying the ratio of arrows pointing to the same direction (3:0 vs. 2:1). Surprise level (standard vs. oddball) was manipulated by varying probabilities of two types of arrows (smaller and larger) that were irrelevant to the task (80% standard trials vs. 20% oddball trials). The size of the oddball arrows were counterbalanced across runs and participants. (**b**) A schematic description of a standard and an oddball trial. Each trial began with the presentation of three arrows for a fixed duration of 250 ms, followed by 1750 msl 6.9(s)0(c)15.7(r)23.3e(u)19.4,(.)-264.d0(u)14.70(i)(b)Tj5F61Tf2259910TDp(b)TjF11T.9449290TDA(b)Tj5F61Tf7.78110TDttenactiob

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tDCS Protocol

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GABA -
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. A M C A S (: / / . . . / / / / / A S .) % . A I $P < 0.005$, 46 % $P < 0.05$.

Psychophysiological interaction (PPI) analysis

PPI % F ., 1997 . T % T TPJ % (R). W % % TPJ % % - % . A PPI % ( ) % TPJ % % - % . T TPJ.

F % BOLD 6 TPJ, % % (MNI TPJ, : $x = -52$, $y = -54$, $z = 23$; : $x = 51$, $y = -54$, $z = 26$). T PPI % TPJ ( ) , % % (– – %). T % % . T % PPI , K ., 2012 PPI . D % PPI (ROI) TPJ . T - PPI % t % GLM . S TPJ F , 2005; T ., 2005 , % % % TPJ. R : (1) % TPJ (2) TPJ .

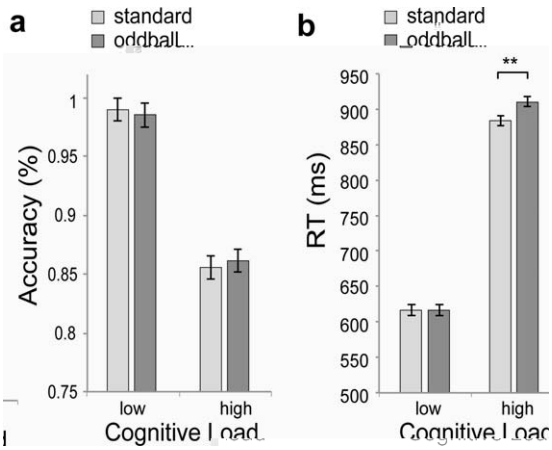

Figure 2.
Behavioral results. (**a**) The accuracy result: performance decreased in the high cognitive load condition compared with the low load condition. (**b**) The reaction time (RT) result: high cognitive load as well as the oddball condition was associated with prolonged RT, with a super additive surprise effect. ** $P < 0.01$; Error bars: ±SEM.

T PPI , % % TPJ. W % % - % - (–) PPI , – %) PPI

ROI and correlation analyses

U , ROI % 6 . A % % RT (– – %) PPI

Dynamic causal modeling (DCM)

D PPI , % - DCM TPJ % . DCM : ROI, - % , - F ., 2003 . DCM ( ) SPM S ., 2007 . T ROI, % ROI

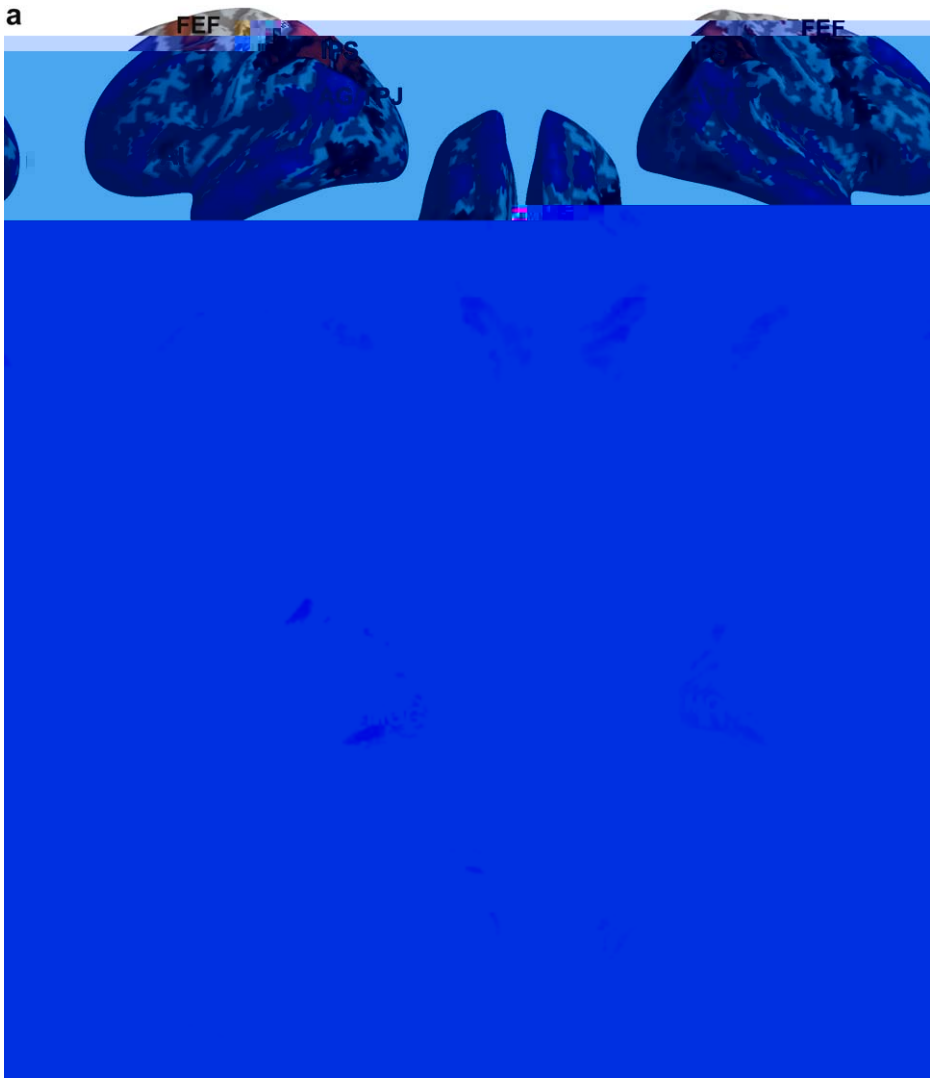

Figure 3.

Main effects of top-down and bottom-up processes. (**a**) Regions associated with the recruitment of top-down attentional process (main effect of cognitive load, high load - low load). (**b**) Regions associated with the recruitment of bottom-up attentional process (main effect of stimulus surprise level, oddball - standard). Red

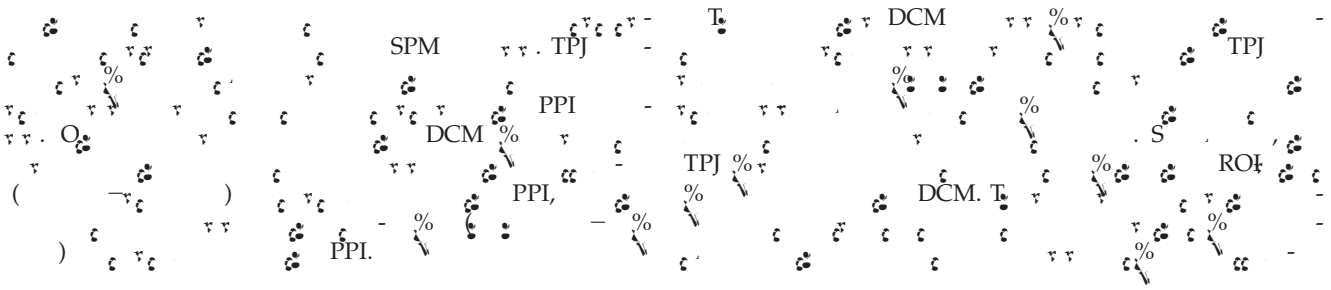

TABLE I. Activation and deactivation of brain regions involved in top-down attentional processes

R	L/R	BA	MNI			*T*	*Z*	*k*
			x	*y*	*z*			
P								
M (IPS)	R	19	30	−63	36	9.76	6.69	1633
SPL	R	7	18	−72	57	9.33	6.53	
P	R	2	45	−36	45	7.74	5.84	
SPL	R	40	39	−48	57	7.55	5.75	
I	R	40	36	−45	45	7.49	5.72	
SPL (IPS)	L	7	−24	−63	57	9.6	6.63	3829
I	L	40	−36	−51	54	8.07	5.99	
I	L	37	−48	−66	−3	7.08	5.51	
C I	L		−33	−60	−30	6.56	5.24	
M	L	19	−27	−72	30	6.47	5.19	
P	L	2	−51	−30	45	6.1	4.98	
C VI	L		−24	−63	−27	5.89	4.85	
C II	L		−3	−81	−27	5.85	4.83	
F	R	37	54	−54	−15	5.76	4.78	
C II	R		6	−78	−39	5.36	4.53	
C VIIB	L		−6	−75	−39	5.32	4.51	
C I	R		39	−57	−30	4.98	4.28	
C VIII	L		−30	−69	−−51	4.54	3.98	
I	R	19	48	−69	−9	4.5	3.96	
C I	R		48	−54	−27	4.46	3.93	
C VI	R		27	−63	−27	4.33	3.83	
C VIII	R		15	−72	−48	4.32	3.83	
C X	R		27	−36	−45	3.54	3.24	
V			3	−48	−12	3.36	3.1	
C IX	L		−18	−45	−54	3.13	2.92	
M	R	6	30	3	63	7.8	5.87	811
P	R	4	42	6	30	5.9	4.86	
I	R	44	51	12	27	5.51	4.62	
P	R	6	54	6	45	4.52	3.97	
S	L	6	−57	9	39	6.36	5.12	600
P	L	6	−36	−3	60	6.27	5.08	
S	R	6	3	12	54	6.27	5.08	277
A	R	32	9	24	39	3.68	3.35	
T	R		18	−9	18	5.36	4.53	212
A	R		33	27	0	5.26	4.47	144
T	L		−15	−12	15	4.48	3.95	183
A	L		−33	24	6	4.07	3.65	64
N								
O	R	11	3	45	−6	10.56	6.99	13565
A	R	39	51	−66	33	9.52	6.6	
P	R	23	3	−39	36	9.08	6.43	
M	L	19	−39	−78	42	8.96	6.38	
P	L	23	0	−57	27	8.89	6.35	
M	R	10	6	57	30	8.57	6.21	
S	R	9	24	33	48	8.52	6.19	
C	L	17	−12	−60	18	8.36	6.12	
M	L	23	0	−21	45	7.88	5.9	
M	L	10	0	60	15	7.63	5.78	
I	L	20	−63	−18	−24	7.44	5.69	
M	L	21	−69	−42	−3	6.95	5.44	
L	R	19	9	−51	6	6.71	5.32	
M	R	21	60	−9	−21	6.67	5.3	
M	R	8	9	36	63	6.61	5.27	
S	L	9	−21	30	48	6.61	5.26	

TABLE I. (continued).

R	L/R	BA	MNI			T	Z	k
			x	y	z			
S	R	19	15	−96	30	6.24	5.06	
M	L	9	−3	45	51	6.09	4.98	
T	R	38	42	12	−39	5.95	4.89	
I	R	20	54	−3	−33	5.8	4.8	
T	L	38	−30	18	−30	5.74	4.77	
S	L	19	−63	−57	27	5.7	4.74	
M	L	8	−6	27	63	5.7	4.74	
I	L	47	−36	36	−18	5.57	4.66	
P	R	36	18	0	−24	5.51	4.62	
M	L	9	−18	51	30	5.36	4.53	
M	R	23	6	−6	39	5.11	4.37	
P	L	36	−33	0	−24	5.03	4.32	
M	R	37	66	−45	−6	5.03	4.32	
P	L	34	−15	0	−18	4.33	3.84	
T	R		15	−30	0	4.32	3.83	
I	R	18	27	−102	0	4.29	3.81	
I	L	18	−24	−105	3	4.28	3.8	
V	L		−18	6	−12	4.27	3.79	
S	R	42	42	−30	15	4.24	3.77	
O	L	11	−18	27	−15	4.08	3.65	
P	R		33	−9	−3	3.94	3.55	
I	L	45	−51	33	6	3.91	3.53	
P	L	27	−15	−36	−3	3.82	3.46	
P	L	4	−6	−21	72	3.81	3.45	
I	R	45	57	36	6	3.7	3.37	
P	R	30	24	−27	−21	3.65	3.33	
F	R	37	30	−36	−15	3.43	3.15	
F	L	30	−18	−39	−15	3.43	3.15	
S	L	40	−66	−33	21	3.38	3.12	
H	R		18	−24	−9	3.28	3.03	
C II	R		24	−84	−36	6.34	5.11	263
C II	L		−30	−78	−36	5.86	4.84	168

(—) PPI, %

T. %

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RT, ($F_{(1,34)} = 10.49$, $P < 0.01$), ($F_{(1,34)} = 1.27$, $P > 0.20$). P RT ($F_{(1,34)} = 11.40$, $P < 0.01$), ($F < 1$). T.

%

. T.

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RESULTS

Behavioral Results of the fMRI Experiment

O MFT % 490 ± 83 (M ± SD) RT 92.3 ± 3.5% . P % % (2:1) % (3:0; F . 2). R - ANOVA RT % % RT ($F_{(1,34)} = 1004.15$, $P < 0.001$ $F_{(1,34)} = 155.63$, $P < 0.001$,). W RT, ($F_{(1,34)} = 8.25$, $P < 0.01$), % %

Statistic Parametric Mapping Results

Main effects of top-down and bottom-up control processes

F - % (— % -),

TABLE II. Activation and deactivation of brain regions involved in bottom-up attentional processes

R	L/R	BA	MNI			*T*	*Z*	*k*
			x	*y*	*z*			
P								
F	L	37	−45	−54	−15	5.6	4.68	703
I	L	37	−48	−66	−12	5.27	4.47	
C VI	L		−39	−51	−24	5.12	4.38	
I	L	18	−36	−90	6	3.5	3.21	
M	L	19	−33	−90	−3	3.39	3.12	
P	L	2	−48	−36	57	5.32	4.51	183
M	R	19	39	−81	6	5.19	4.43	1092
I	R	37	48	−57	−12	4.98	4.28	
I	R	19	42	−78	−6	4.76	4.14	
M	R	37	42	−69	12	4.11	3.68	
F	R	19	36	−66	−15	4.1	3.67	
M	R	39	39	−72	21	3.82	3.46	
S	R	7	27	−66	39	3.81	3.45	
C VI	R		21	−60	−18	3.75	3.41	
M	L	19	−30	−66	33	3.9	3.52	63
N								
C	L		−12	18	−3	4.76	4.14	390
C	R		6	−3	3	4.22	3.76	
V	L		−18	9	−18	3.8	3.45	
C	L		−18	3	18	3.36	3.1	
T	L		−9	−3	0	3.07	2.86	
O	R	11	9	36	−18	4.58	4.02	51
M	R	6	9	−9	75	3.47	3.19	70
M	L	6	−3	−15	72	3.27	3.03	

(FEF), (SPL), (IPS) (F . 3 , T I), %

. I - G V , 2013 . T BOLD

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TPJ (F . 3 , T I).

F - , -

SPL (F . 3 , T II). A -

TPJ (F . 4), % BOLD (%)

TPJ (F . 4). T TPJ TPJ (TPJ): 51, −52, 24; TPJ (TPJ): −48, −54, 24 % - TPJ

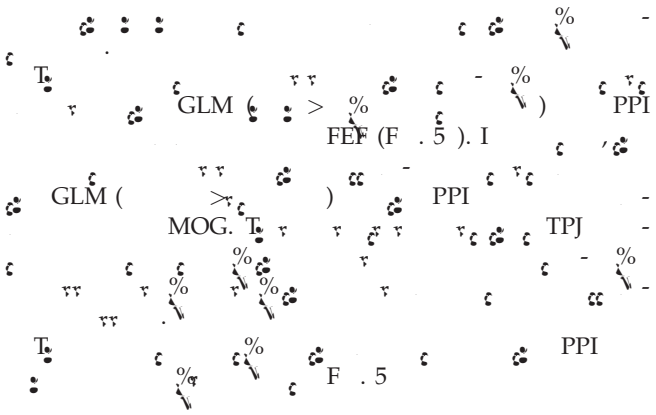
TPJ (TPJ: $t_{(34)} = -3.24$, $P < 0.01$; TPJ: $t_{(34)} = -4.33$, $P < 0.001$), % (TPJ: $t_{(34)} = 2.57$, $P < 0.05$; TPJ: $t_{(34)} = 1.0$, $P > 0.1$). W % - % . T TPJ

Interaction between top-down and bottom-up processes

W % % (− %). T -

PPI Results

W PPI % TPJ (MOG), % TPJ (FEF), % % % - (F . 5 , T III). T TPJ MOG FEF,



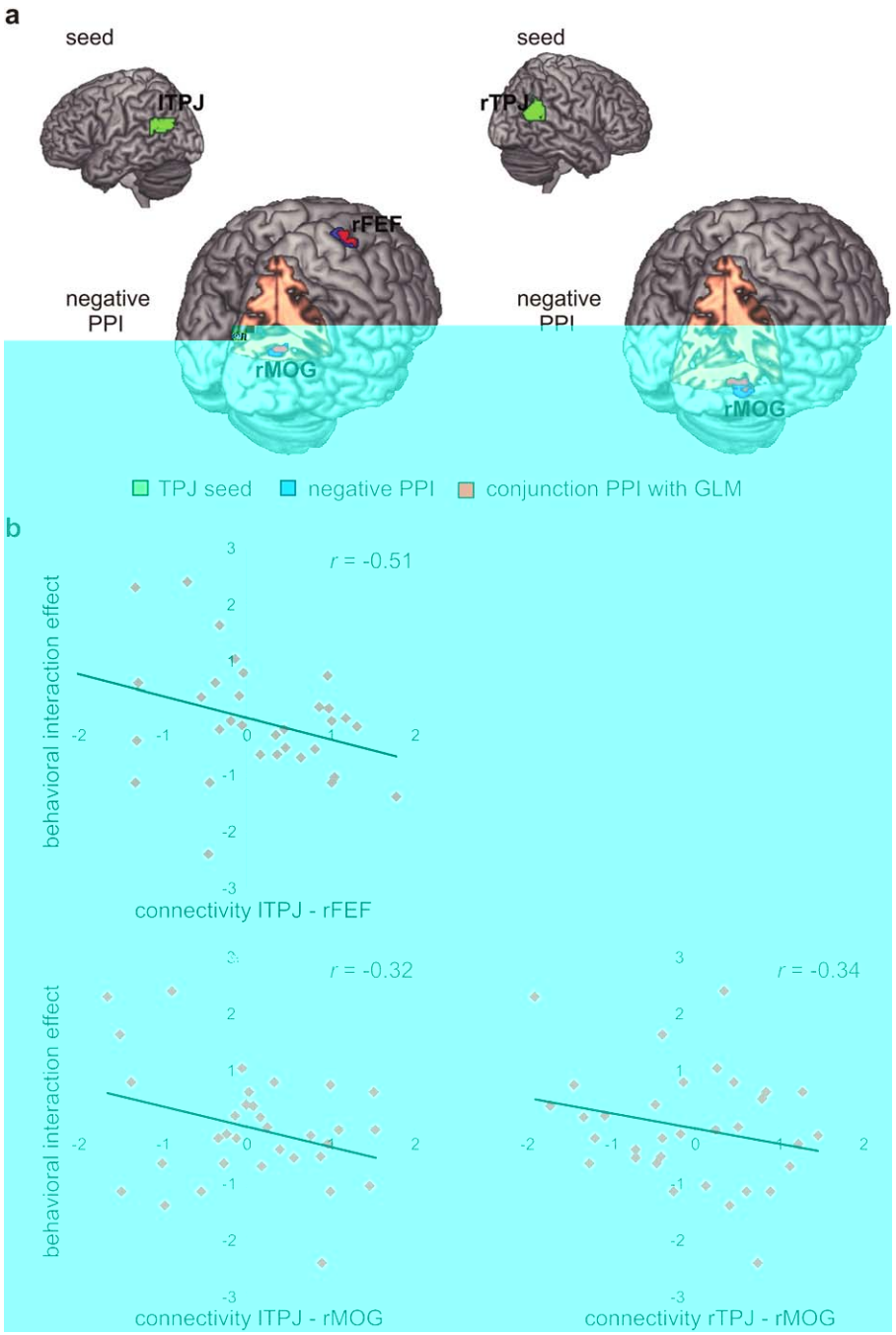


Figure 5.

PPI and ROI results. (**a**) PPI results. Top row: seed regions of left and right TPJ for PPI analysis. Bottom row: regions showed negative associations with left or right TPJ modulated by the interaction between experimental manipulations. Decreased activity in the left TPJ was associated with increased activity in the rFEF and rMOG, while decreased activity in the right TPJ was associated with increased activity only in the rMOG. Green color indicates the seed regions of the bilateral TPJ. Blue color indicates regions showing negative PPIs with the TPJ. Red color indicates conjunction regions of bottom-up contrast image of the GLM (oddball > standard) and the PPI image, and the conjunction of top-down (high cognitive load − low cognitive load) contrast image and the PPI. (**b**) ROI and correlation results. The PPI between the lTPJ and rFEF was negatively correlated with behavioral interaction effect. The PPI between the bilateral TPJ and rMOG was marginally correlated with behavioral interaction effect.

TABLE III. Negative PPI

R	L/R	BA	MNI			T	Z	k
			x	y	z			
L TPJ								
M	R	39	33	−69	18	3.92	3.53	114
S	R	6	21	−9	75	3.61	3.29	57
R TPJ								
M	R	19	36	−72	−3	4.55	3.98	69

($F < 1$). T % -% ANOVA RT DCS ($F_{(1,17)} = 32.16$, $P < 0.001$ $F_{(1,17)} = 6.13$, $P < 0.05$, ; F . 7 ,). H % , DCS % ($F < 1$; F . 7). T B % 1/3 (B = 0.22), . T DCS TPJ

T ., 2005 . T TPJ . I , TPJ % % , % % % MRI , TPJ % % A ., 2010; S ., 2003, 2007 . W %

DISCUSSION

W % - % , % % - TPJ: % RT TPJ % . I , TPJ % PPI % MOG - - - % % % FEF - % . T TPJ % DCM TPJ MOG % . I , DCS TPJ - T , TPJ - % % - . B TPJ , % %

A Filter Model of the TPJ

A TPJ S ., 2003, 2007 . I , TPJ . F , % TPJ, % C ., 2008; D Q G , 2011 . U % , . T TPJ - %

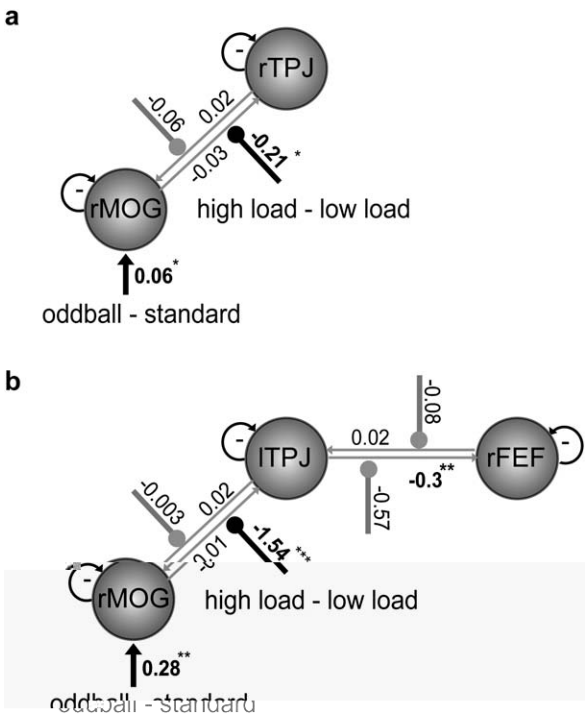


Figure 6.
DCM models and results. (**a**) DCM model of the rTPJ and rMOG. (**b**) DCM model of the lTPJ, rMOG, and rFEF. Bold arrows indicate the driving input (oddball − standard). Arrows with circle in the end indicate the modulatory effect (high load − low load), with significant modulation in black and nonsignificant modulation in gray. Significant parameters are indicated by the asterisk (* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$).

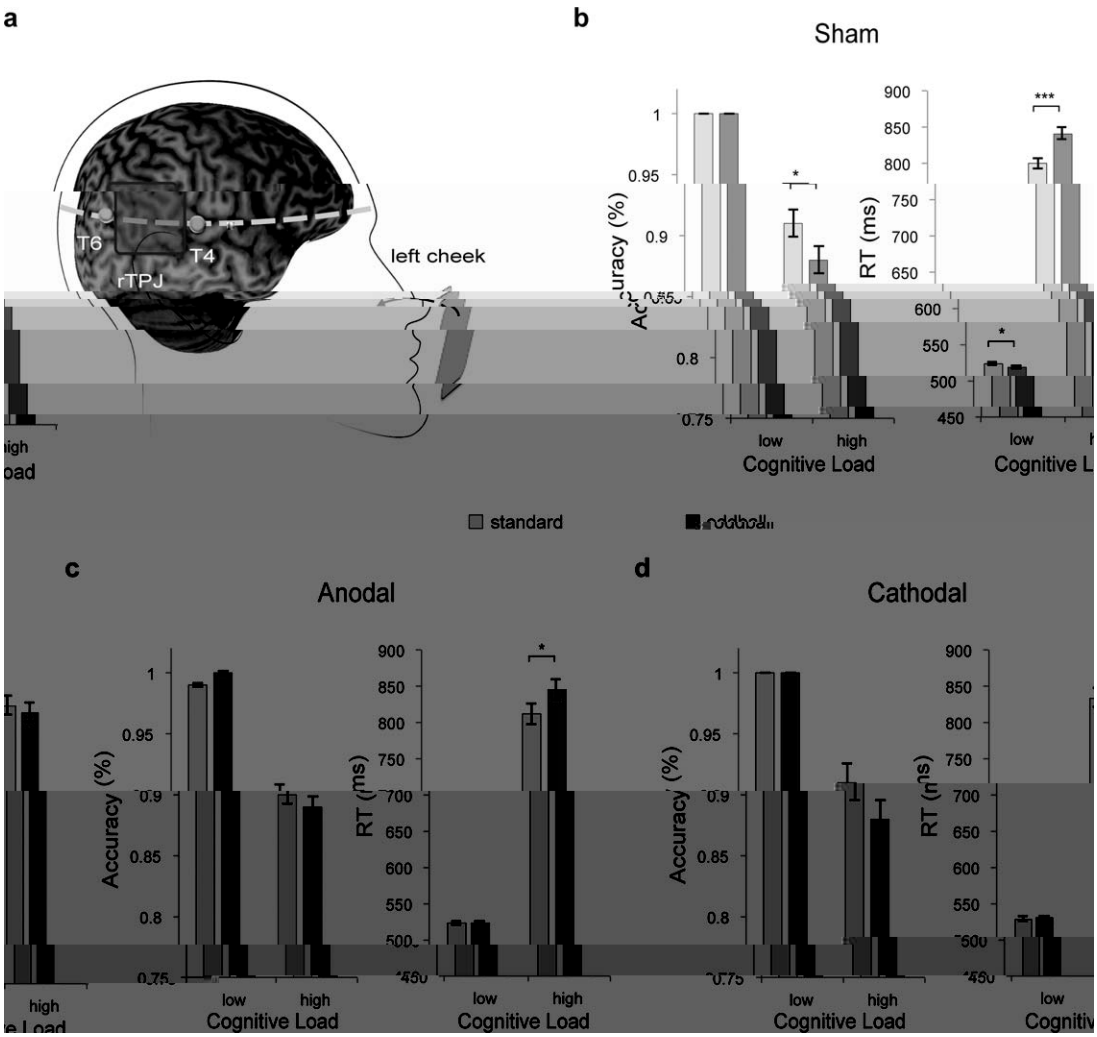


Figure 7.
tDCS results. (**a**) schematic representation of the locations of the tDCS. (**b**−**d**) results of Sham, anodal, and cathodal tDCS. Significance is indicated by the asterisk (* $P < 0.05$; *** $P < 0.001$).

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TPJ as a Sensor of Bottom-Up Information

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ACKNOWLEDGMENTS

T D . X L . T D . T L , J L V , M -A M

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A A, R G, S GL, B DM (2010): W : TPJ . N 49:2638 2648.

A CL, T JJ, S AP, M R (2010): A - . N N 13:507 512.

A E, B AV, T J (2012): T - :A T C S 16:437 443.

B PM, S -C V, G N, D J, H M (2010): I - . J N 30: 5968 5978.

C R, C E, M M (2012): C - : A . T C S 16:338 352.

G C-F, H T-Y, T P, L W-K, T OJL, H DL, J C-H (2013): R - . H B M 34:869 877.

G AB, B P, V -C A (2011): D - . J N 31:8143 8149.

G YC, Y S (2009): A - : S . J N 29:3930 3938.

C M, K JM, O JM, M A MP, S GL (2000): V . N N 3:292 297.

C M, P G, S GL (2008): T : F . N 58:306 324.

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