

(This is a sample cover image for this issue. The actual cover is not yet available at this time.)

This article appeared in a journal published by Elsevier. The attached copy is furnished to the author for internal non-commercial research and education use, including for instruction at the authors institution and sharing with colleagues.

Other uses, including reproduction and distribution, or selling or licensing copies, or posting to personal, institutional or third party websites are prohibited.

In most cases authors are permitted to post their version of the article (e.g. in Word or Tex form) to their personal website or institutional repository. Authors requiring further information regarding Elsevier's archiving and manuscript policies are encouraged to visit:

<http://www.elsevier.com/copyright>

Neural Correlates of the Development of Theory of Mind in Children with Autism Spectrum Disorders

Li Meng, S. Helen * 

Department of Psychology, Peking University, Beijing, 100871, PR China

ARTICLE INFO

Article history:

Accepted: 14 November 2012
Available online: 27 November 2012

Keywords:

EEG
Neuroimaging
Psychology
Sensory processing
Theory of mind

ABSTRACT

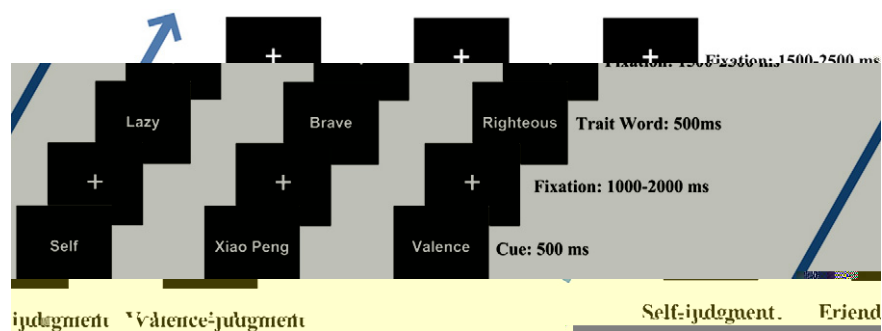
Theory of mind (ToM) is a set of skills that enable us to understand and predict the behavior of others based on their mental states. Children with autism spectrum disorders (ASD) have difficulties in ToM. This study aimed to investigate the neural correlates of ToM development in children with ASD. We used functional magnetic resonance imaging (fMRI) to measure brain activity during a ToM task. The results showed that children with ASD had reduced activation in the fusiform gyrus (FG) and the superior temporal sulcus (STS) compared to typically developing children. These findings suggest that the FG and STS are involved in ToM processing in children with ASD. The results also showed that children with ASD had increased activation in the superior frontal gyrus (SFG) and the inferior parietal lobule (IPL) compared to typically developing children. These findings suggest that the SFG and IPL are involved in ToM processing in children with ASD. The results also showed that children with ASD had increased activation in the superior temporal gyrus (STG) and the superior frontal gyrus (SFG) compared to typically developing children. These findings suggest that the STG and SFG are involved in ToM processing in children with ASD. The results also showed that children with ASD had increased activation in the superior temporal gyrus (STG) and the superior frontal gyrus (SFG) compared to typically developing children. These findings suggest that the STG and SFG are involved in ToM processing in children with ASD.

© 2012 Elsevier B.V. All rights reserved.

Introduction

Sensory processing (SP) is a set of skills that enable us to understand and predict the behavior of others based on their mental states. Children with autism spectrum disorders (ASD) have difficulties in SP. This study aimed to investigate the neural correlates of SP development in children with ASD. We used functional magnetic resonance imaging (fMRI) to measure brain activity during a SP task. The results showed that children with ASD had reduced activation in the fusiform gyrus (FG) and the superior temporal sulcus (STS) compared to typically developing children. These findings suggest that the FG and STS are involved in SP processing in children with ASD. The results also showed that children with ASD had increased activation in the superior frontal gyrus (SFG) and the inferior parietal lobule (IPL) compared to typically developing children. These findings suggest that the SFG and IPL are involved in SP processing in children with ASD. The results also showed that children with ASD had increased activation in the superior temporal gyrus (STG) and the superior frontal gyrus (SFG) compared to typically developing children. These findings suggest that the STG and SFG are involved in SP processing in children with ASD. The results also showed that children with ASD had increased activation in the superior temporal gyrus (STG) and the superior frontal gyrus (SFG) compared to typically developing children. These findings suggest that the STG and SFG are involved in SP processing in children with ASD.

N 6.999, 2009; H 2322T 14 () 2318() 16() 1 821 -1- 003-1.32 318(6 16()) 2() 22(-15((82 57(6 () 226() 21)-) 23() TJ/T123

[illegible]

Subjects

T 27 (13, 5, 18, 24, 19)
 E 2. A I T
 1. E 19

W 119.7 NCW 19.9 1.3 H 2 H . T 8.0 H 80 H . T TF fi - . T TF - -200 0 (P A , 1979). C 50 1000 . T TF 20 0 50 H 50 H C . T : (2-4 H), (5-7 H), 1 (8-10 H), 2 (11-13 H), (14-26 H), 1 (28-40 H), 2 (60-80 H), (M H , 2010). T TF , : : F , FC ; : C , CP : P , PO), (: F1, F3, F5, FC1, FC3, FC5; : F2, F4, F6, FC2, FC4, FC6), (: C1, C3, C5, CP1, CP3, CP5; : C2, C4, C6, CP2, CP4, CP6), (: P1, P3, P5, PO3, PO5, O1; : P2, P4, P6, PO4, PO6, O2). T TF (ANOVA) C (-) R (, -) H () . T ANOVA C (-) S ANOVA R /H () R / H TF / ANOVA S (/), T (/) R /H TF E 1 , ANOVA TF E 2 C (-) R - /H A P- ANOVA G -G .

Phase synchrony analysis

S (D , 2008; G , 2004; L , 1999; L , 2004; R , 1999), M (TFOI) fi - W (PLV) fi . T PLV j k t : j k t f N

PLV 0 1.0 j k. W 21 210 (21 20/2) (F3, F4, F), (FC3, FC4, FC), (C3, C4, C), (CP3, CP4, CP), (P3, P4, P), (PO3, PO4, PO), (O1, O2, O) . T . T -I P (K , 2004; M O , 2007). T PLV 1000 . T 1000 T , 1000 T . A 1000 T , 95 PLV T 95 (P<.05) fi .

Results

Behavioral performance

T ANOVA (RT) E 1 J(33) 7(15()-228() 21()15() (78-7 9()-0978-712 0()

$$PLV_{j,k,t} = N^{-1} \left| \sum_N i [\Phi_{j,f,t} - \Phi_{k,f,t}] \right|$$

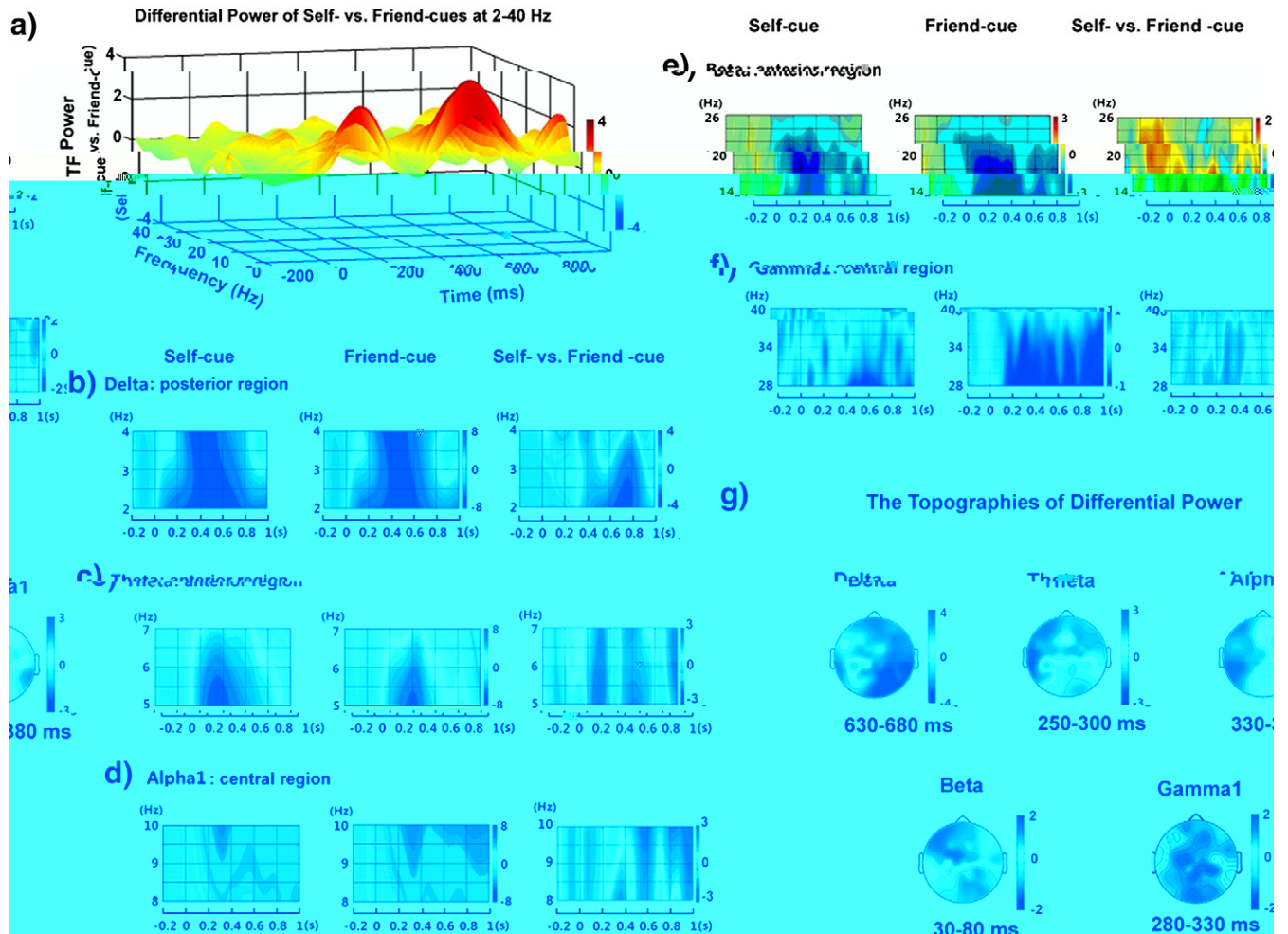


Fig. 2. T

F5

2–40 H

0 1000

F5.) A

1

F5.) G

50

P1.

CP3.

C1.) T

T

S

300–400

(F (2, 50) = 5.783, $P < .05$, $\eta^2 = .19$). P

(F (1, 25) = 5.32, $P < .05$, $\eta^2 = .18$)

(F (1, 25) = 5.55, $P < .05$, $\eta^2 = .18$). S

ANOVA

1000

(F (2, 50) = 8.61, $P < .01$, $\eta^2 = .24$). T

600–700

(F (1, 25) = 8.61, $P < .01$, $\eta^2 = .24$). T

700–900

(F (2, 50) = 4.86, $P < .05$, $\eta^2 = .15$)

800–900

(F (2, 50) = 7.15, $P < .05$, $\eta^2 = .20$). P

(F (1, 25) = 6.85, $P < .05$, $\eta^2 = .22$; P

F (1, 25) = 8.89, $P < .01$, $\eta^2 = .26$). N

(P > .05).

Desynchronous activity related to evaluation of one's own personality traits

N

1:

, F (1, 25) = 6.25, $P < .05$, $\eta^2 = .20$ 300–400 ;

, F (1, 25) = 6.58, $P < .05$, $\eta^2 = .21$ 300–400 ;

, F (1, 25) = 7.47, $P < .05$, $\eta^2 = .23$ 300–500 ;

, F (1, 25) = 7.79, $P < .01$, $\eta^2 = .24$ 200–500 ;

, F (1, 25) = 6.81, $P < .05$, $\eta^2 = .21$ 200–400 ;

, F (1, 25) = 6.32, $P < .05$, $\eta^2 = .20$ 200–300 ;

, F (1, 25) = 4.55, $P < .05$, $\eta^2 = .15$ 300–400 ,

F (1, 25) = 5.33, $P < .05$, $\eta^2 = .18$). ANOVA

(P > .05).

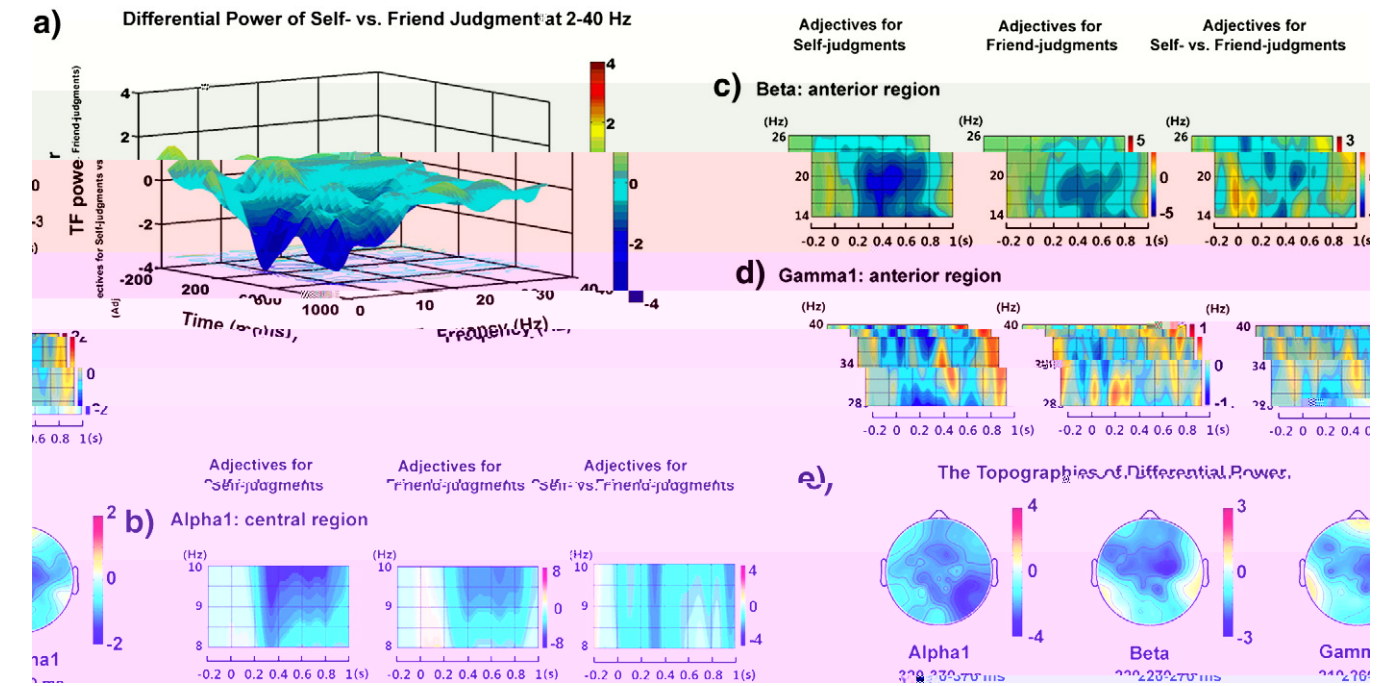


Fig. 3. T

R (300–400, $F(1, 25) = 5.69$, $P < .05$, $\eta^2 = .19$; 700–800, $F(1, 25) = 14.80$, $P < .01$, $\eta^2 = .37$) (300–400, $F(1, 25) = 6.64$, $P < .05$, $\eta^2 = .21$). N (P > .05).

Distinct patterns of neural oscillations to self-cue and self-related trait adjectives

ANOVA (S (F (1, 25) = 29.02, $P < .001$, $\eta^2 = .54$; 400–1000, $F(1, 25) = 46.86$, $P < .001$, $\eta^2 = .65$; 54.77, $P < .001$, $\eta^2 = .69$; 700–800, $F(1, 25) = 69.56$, $P < .001$, $\eta^2 = .74$), 900–1000, $F(1, 25) = 14.04$, $P < .001$, $\eta^2 = .36$; 800–900, $F(1, 25) = 4.66$, $P < .05$, $\eta^2 = .16$). M (300–400, $F(1, 25) = 5.42$, $P < .05$, $\eta^2 = .18$, $F(1, 4) = 1.4$), 300–1000, $F(1, 25) = 8.94$, $P < .01$, $\eta^2 = .26$; 50–100, $F(1, 25) = 9.48$, $P < .01$, $\eta^2 = .28$; 200–400, $F(1, 25) = 8.17$, $P < .01$, $\eta^2 = .25$, $F(1, 4) = 1.4$), (200–400, $F(1, 25) = 6.04$, $P < .05$, $\eta^2 = .20$), 100–200, $F(1, 25) = 4.09$, $P = .05$, $\eta^2 = .14$; 300–500, $F(1, 25) = 9.27$, $P < .01$, $\eta^2 = .27$, $F(1, 4) = 1.4$). T

P (300–400, $F(1, 25) = 31.92$, $P < .0001$, $\eta^2 = .56$), 1 (300–1000, $F(1, 25) = 14.84$, $P < .001$, $\eta^2 = .37$), (300–1000, $F(1, 25) = 14.64$, $P < .001$, $\eta^2 = .37$), (0–100, $F(1, 25) = 7.85$, $P < .01$, $\eta^2 = .24$; 200–300, $F(1, 25) = 4.62$, $P < .05$, $\eta^2 = .16$), (300–500, $F(1, 25) = 6.60$, $P < .05$, $\eta^2 = .21$). I (200–400, $F(1, 25) = 9.84$, $P < .01$, $\eta^2 = .28$), (200–400, $F(1, 25) = 5.23$, $P < .05$, $\eta^2 = .17$), (100–200, $F(1, 25) = 4.57$, $P < .05$, $\eta^2 = .16$). T (P > .05).

Phase synchrony of neural oscillations to self-cue

TFOI (300–400, $F(1, 25) = 3.08$, $P < .05$), 300–400, $F(1, 25) = 2.92$, $P < .05$. S

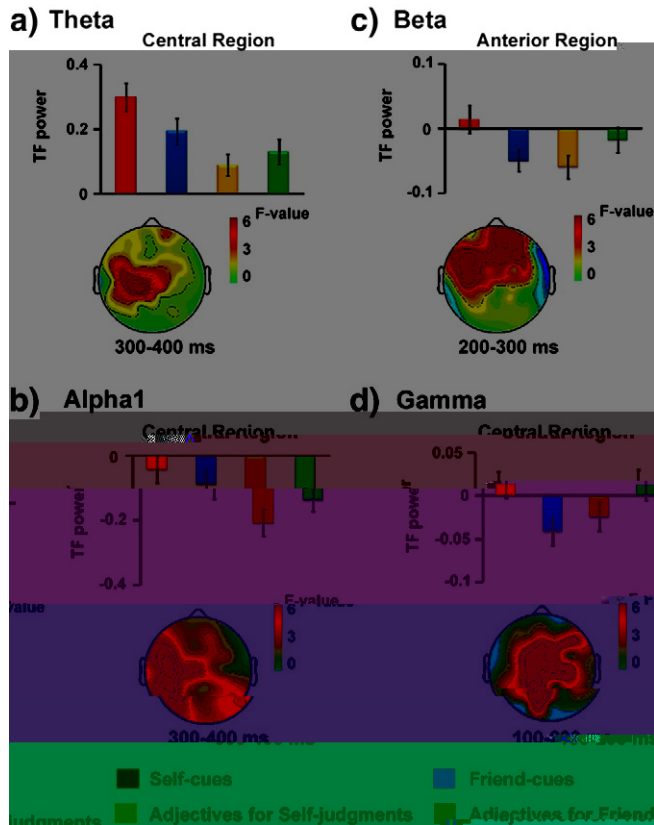


Fig. 4. TF power and F-value maps for four frequency bands across different time windows and regions. The figure is divided into four panels: a) Theta (Central Region, 300-400 ms), b) Alpha1 (Central Region, 300-400 ms), c) Beta (Anterior Region, 200-300 ms), and d) Gamma (Central Region, 100-200 ms). The legend indicates four conditions: Self-cues (red), Friend-cues (blue), Adjectives for Self-judgments (green), and Adjectives for Friend-judgments (orange).

400–500 (25) = 3.41, $P < .05$). H TFOI (P > .05).

Phase desynchrony of neural oscillations to evaluation of one's own personality traits

T TFOI 300–400 (25) = –3.22, $P < .05$ 1 300–400 (25) = –3.18, $P < .05$, $F(1, 5)$. TFOI (P > .05). W 400 (25) = 2.88, $P < .05$.

Non-phase-locked neural activity in Experiment 2

T TFOI 2, TF (P > .05). W 400–700 (F (1, 17) = 8.28, $P = .01$, $\eta^2 = .33$) (F (1, 17) = 8.53,

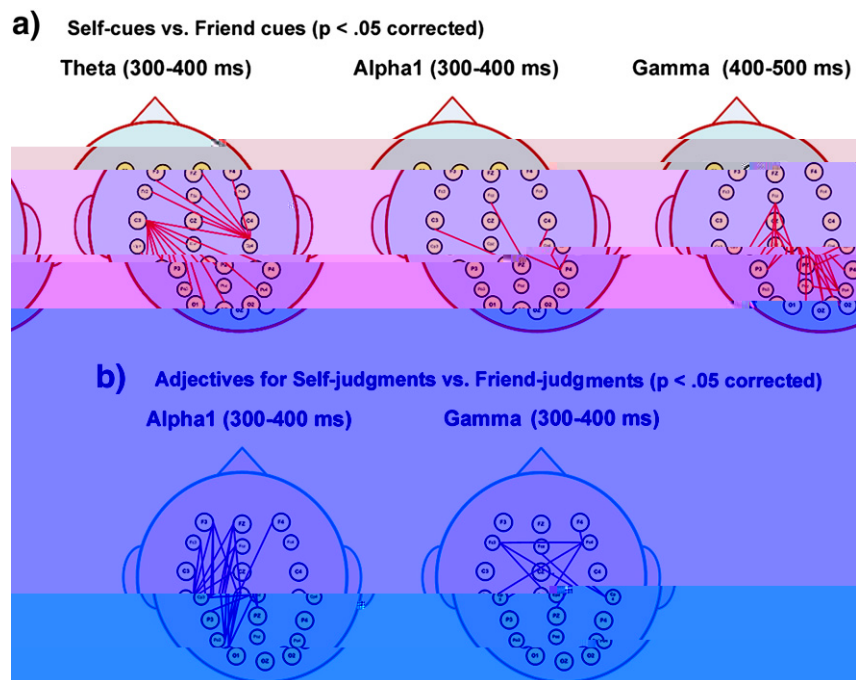


Fig. 5. Topographic maps of TF power for self-cues vs. friend cues and adjectives for self-judgments vs. friend-judgments. The figure is divided into two panels: a) Self-cues vs. Friend cues ($p < .05$ corrected) and b) Adjectives for Self-judgments vs. Friend-judgments ($p < .05$ corrected). Panel a) shows three maps for Theta (300-400 ms), Alpha1 (300-400 ms), and Gamma (400-500 ms). Panel b) shows two maps for Alpha1 (300-400 ms) and Gamma (300-400 ms).

$P < .01$, $\eta^2 = .33$) , $\eta^2 = .23$) (F (1, 17) = 5.20, $P < .05$, TFOI (F (1, 17) = 4.83, $P = .04$, $\eta^2 = .22$) . (P > .05).

Discussion

T . W (R ., 1977) . W . I . O . fi . fl .

Neural oscillations and self-related attentional orientation

I . W . K . (2002), . T . I . B . fi . fl . I . I . 1 . I . A . 1 . T . E . 2 . E . 2 . H .

2. T . P EEG . A . (F ., 1995; H ., 1996) . (L ., 2007). I . (C ., 2003; O ., 2001) . S . O . I . (. . (B ., 2000). S . (G ., 1999; H ., 2000), K ., 2001; M ., 2000), (H ., 2000), (B ., 2002; T .-B ., 2009). B . T .-B . . (1996, 1997) . O . (. ., R ., 1999). T . (V ., 2001). I . H . T . fl . U . -/ . -/ . B . (F . A ., 2011), .

Neural oscillations of self-related evaluation

T . fi . T . W . T . I .

(Muller, H., 2010). B. (V., 2001), F. (D., 2003). S. (H., 2004, 2004). T. (H., 2004, 2004). W. (Muller, H., 2010). (K., 2002). I. T. F. O. R. (F., A., 2011). F. (P., K., 2009). E. (G., 2001). I. T. (K., 2002).

Conclusion

T. N. EEG. W. H. O. N.

A. EEG. MRI. F. (H., 2009; H., 2009; M., K., 1991), N.

Acknowledgments

T. N. B. R. P. C. (973 P. 2010CB833903), N. N. S. F. C. (P. 30910103901, 91024032, 81161120539), C. P. S. F. (P. 2011M500171, 2012T50006). W. L.

References

- B., E., B., E., C., K., S., S., M., 2000. B. J. P. 35, 95–124.
- B., A.P., A., L., 2002. EEG. 46, 91–100.
- C., N.R., C., R.J., D., S.J.J., B., A.P., G., J.H., 2003. P. 65–74.
- D., S., H., C.S., K., C., G., D., E., A.K., 2003. T. 14, 683–686.
- D., A., M., S., 2004. EEGLAB: EEG. 134, 9–21.
- D., S.M., R., A.B., K., K., W., L.M., 2008. L. 18, 386–396.
- F., J., A., N., 2011. T. 12, 105–118.
- F., T., H., T., R., M., B., J., S., J., R., A., M., E., 1995. EEG. 94, 175–182.
- F., E.C., K., G.R., 2012. A. A. ERP. 62, 562–574.
- F., P., H., S.J., G., S.J., G., C., K., M.L., C., F., M., H., 2003. I. A. J. P. 160, 1938–1945.
- G., J., S., I., K., K., S., K., H., B., S., A., 2004. M. P. N. S. A. 101, 13050–13055.
- G., A., K., R., M., J., 1989. R. I. C. J.M., G., A., T., P. (E.), W., T., F., M., P. N. 2–20.
- G., T., M., M.M., K., A., E., T., 1999. S. EEG. C. N. 110, 2074–2085.
- G., T., K., A., M., M.M., 2001. M. N. L. 316, 29–32.
- H., C., B., T., C., R.J., W., M., G., J., 2000. G. (EEG). P. N. A. S. U. S. A. 97, 7645–7650.
- H., S., N., G., 2009. U. P. B. R. 178, 203–212.
- H., S., M., L., G., G., J., M., 2008. N. S. N. 3, 1–15.
- H., S., G., M., L., G., J., W., G., M., 2010. N. S. C. B. S. C. A. N. 5, 332–339.
- H., S., N., G., V., K., W., B.E., K., S., V., M.E.W., A. R. P.

- H, T., F, T., S, J., B, J., D, L., R, A., M, E., R, M., R, M., 1996. EEG . I . J. P . 24, 161–171.
- H, T.F., 2011. N . 62, 363–390.
- H, T.F., W, C.L., M, C.N., D, K.E., D, B.T., K, W.M., 2006. M . S . C . A . N . 1, 18–25.
- H, C.S., K, R.T., 2001. M . R . 25, 465–476.
- H, C.S., L, D., J, S., B, N.A., M, B., 2004. M . BMC N . 5, 13.
- H, C.S., M, M.H.J., E, A.K., 2004. C . N . 8, 347–355.
- K, J., B, M., W., 2004. M . N . I . 23, 551–560.
- K, W.M., M, C.N., W, C.L., C, S., I, S., H, T.F., 2002. F . A . MRI . J. C . N . 14, 785–794.
- K, S.B., C, L., T, J., C, S., 2002. D . R . 109, 306–329.
- K, M, R., M, J., G, A., 1987. A . I . J. P . R . 1, 273–302.
- L, J.P., R, E., M, J., V, F.J., 1999. M . H . B . 8, 194–208.
- L, U, K., H, E., T, H., U, S., O, T., N, H., 2007. G . N . R . 65, 44–52.
- L, A., 1990. M . L . C . F . W . F . N . P . B . A . G, L.L., R, N.B., R, M., D, R.J., 2004. L . P . N . A . S . U. S. A. 101, 16369–16373.
- M, H, S., 2011. N . B . 134, 235–246.
- M, B, D., W, C., A, M., F, C., R, A., H, S., S . S . C . A . N . M, C.N., M, J.M., H, T.F., B, J.F., K, W.M., 2004. M . C . C . 14, 647–654.
- M, E., A, K., 2007. S . P . S . 18, 672–677.
- M, E., O, R., 2007. N . EEG- . MEG- . J. N . M . 164, 177–190.
- M, H.R., K, S., 1991. C . R . 98, 224–253.
- M, N., M, D., S, L., B, R., P, A., V, N., M, L, G, A., 2012. T . EEG . N . I . 60, 922–932.
- M, J.M., M, C.N., H, T.F., W, C.L., K, W.M., 2006. N . J. C . N . 18, 1586–1594.
- M, H, S., 2010. N . N . I . 53, 757–768.
- M, M.M., G, T., K, A., 2000. M . EEG . P . 38, 283–299.
- N, G., H, A., G, M., B, F., D, H., P, J., 2006. N . I . 31, 440–457.
- O, E.V., S, T.A., P, I.N., 2001. A . C . N . 112, 740–749.
- P, L., K, J., 2009. C . B . R . 1247, 126–132.
- P, G., 1992. E . (ERS): . C . N . 83, 62–69.
- P, G., A, A., 1979. E . (ERD) . E . C . N . 46, 138–146.
- P, G., I, S, F.H., 1999. E . EEG/MEG . C . N . 110, 1842–1857.
- P, G., S, A, J., A., N, C., 1996. E . : . I . J. P . 24, 39–46.
- R, E., G, N., L, J.P., M, J., R, B., V, F.J., 1999. P . : . N . 397, 391–393.
- R, T.B., K, N.A., K, W.S., 1977. S . J. P . S . P . 35, 677–688.
- S, J., P, H., R, P., S, G.L., S, A., 1998. S . P . N . A . S . U. S. A. 95, 7092–7096.
- S, A., D, P.J., 2010. A . A . J. P . 167, 536–544.
- S, M., L, R., 1988. T . P . R . 68, 649–742.
- T, B, C., 2009. T . F . B . 14, 321–332.
- T, B, C., B, O., D, C., P, J., 1996. S . J. N . 16, 4240–4249.
- T, B, C., B, O., D, C., P, J., 1997. O . (30–70 H) . J. N . 17, 722–734.
- V, F., L, J.P., R, E., M, J., 2001. T . N . R . N . 2, 229–239.
- W, G., M, L., M, C., J., L, W, J., W, H., S., 2012. N . 222–229.
- W, L.A., D, B., 2007. S . B . R . 1152, 106–110.
- W, C, L, H, S., D., 2007. B . N . I . 35, 1654–1662.
- , L., F, J., H, S., 2007. N . I . 34, 1310–1316.
- , S., H, O., F, E., C, D., 2002. T . MRI . N . I . 15, 983–991.