



Using tDCS to Explore the Role of the Right Temporo-Parietal Junction in Theory of Mind and Cognitive Empathy

Xiaoqin Mai¹, Wenli Zhang¹, Xinmu Hu¹, Zhen Zhen², Zhenhua Xu¹, Jing Zhang¹ and Chao Liu^{2*}

¹ Department of Psychology, Renmin University of China, Beijing, China, ² State Key Laboratory of Cognitive Neuroscience and Learning, Beijing Normal University, Beijing, China

OPEN ACCESS

Edited by:

Roberta Sellaro,
Leiden University, Netherlands

Reviewed by:

Lara Bardi,
University of Gent, Belgium
Sandy Overgaauw,
Leiden University, Netherlands

*Correspondence:

Chao Liu
liuchao@bnu.edu.cn

Specialty section:

This article was submitted to
Cognition,
a section of the journal
Frontiers in Psychology

Received: 12 November 2015

Accepted: 03 March 2016

Published: 15 March 2016

Citation:

Mai X, Zhang W, Hu X, Zhen Z, Xu Z, Zhang J and Liu C (2016) Using tDCS to Explore the Role of the Right Temporo-Parietal Junction in Theory of Mind and Cognitive Empathy. *Front. Psychol.* 7:380. doi: 10.3389/fpsyg.2016.00380

The right temporo-parietal junction (rTPJ) is thought to be closely related to theory of mind (ToM) and cognitive empathy. In the present study, we investigated whether these socio-cognitive abilities could be modulated with non-invasive transcranial direct current stimulation (tDCS) of the rTPJ. Participants received anodal (excitatory), cathodal (inhibitory), or sham stimulation before performing a social cognitive task which included inferring other's intention (the ToM condition) and inferring other's emotion (the cognitive empathy condition). Our results showed that the accuracy of both ToM and cognitive empathy decreased after receiving the cathodal stimulation, suggesting that altering the cortical excitability in the rTPJ could influence human's socio-cognitive abilities. The results of this study emphasize the critical role of the rTPJ in ToM and cognitive empathy and demonstrate that these socio-cognitive abilities could be modulated by the tDCS.

Keywords: social cognition, theory of mind, cognitive empathy, temporo-parietal junction (TPJ), transcranial direct current stimulation (tDCS)

INTRODUCTION

Successful human social interaction mostly depends on the understanding of others' mental states, which are built on the social abilities such as theory of mind (ToM) and cognitive empathy. ToM is the central function of human social cognition, referring to the ability to attribute other's mental states, such as beliefs and intentions (Frith and Frith, 1999). It can help us understand observable actions by inferring agents' mental representations. Affective empathy is the ability to share the emotional experience of others ("I feel what you feel"). It is different from cognitive empathy which is the capacity to understand other's perspective or mental states (Preston and de Waal, 2002; Shamay-Tsoory et al., 2009; Schnell et al., 2011). Cognitive empathy emphasizes inferring other's affective mental state ("I understand what you feel") but not necessarily sharing this feeling (de Waal, 2008). Many researchers believe that cognitive empathy is related to ToM (Eslinger, 1998; Shamay-Tsoory et al., 2003). Walter (2012) proposes that cognitive empathy is the emotional part of ToM. Blair (2005) even equates cognitive empathy with ToM. Since ToM and cognitive empathy have an overlap in concept, they might recruit common brain regions.

Functional magnetic resonance imaging (fMRI) studies have demonstrated the involvement of temporo-parietal junction (TPJ) in the attribution of mental states (Vogeley et al., 2001; Saxe and Kanwisher, 2003; Saxe and Wexler, 2005; Spengler et al., 2009; Schurz and Perner, 2015). For example, Saxe and Kanwisher (2003) used false belief tasks and found the greater activity in the

TPJ when participants read stories about a person's belief than the stories describing a physical process, such as melting or rusting, suggesting the important role of the TPJ in understanding other's mental states. Some studies also suggest that the TPJ is involved in cognitive empathy (Rankin et al., 2005; Shamay-Tsoory et al., 2005; Vollm et al., 2006). Vollm et al. (2006) designed an experimental paradigm to directly compare the neural correlates of ToM and cognitive empathy using fMRI, in which participants were asked to make inferences about the emotional or the intentional states of the protagonists in a visual cartoon task. The results showed that both ToM and cognitive empathy activated the TPJ, medial prefrontal cortex, and temporal poles, though they also recruited other distinct brain regions. They concluded that the overlapping network of ToM and cognitive empathy is related to inferring others' internal states. Using the same cartoon task, Atique et al. (2011) also found that both ToM and cognitive empathy (in their paper, they use the term "intention mentalizing" and "emotion mentalizing", respectively) activated the TPJ, though different subregions. These findings suggest that ToM and cognitive empathy are closely related and the TPJ is engaged in both of them.

In recent years, non-invasive brain stimulation techniques, such as transcranial magnetic stimulation (TMS) and transcranial direct current stimulation (tDCS), have been used to explore the role of the TPJ, especially the right TPJ (rTPJ), in social cognition. Costa et al. (2008) reported that the application of repetitive TMS over the rTPJ significantly worsened accuracy and response times (RTs) in both false belief and faux-pas written story tasks, confirming the important role of the rTPJ in ToM performance. Some studies have also found that applying the TMS over the rTPJ disrupted the capacity to use mental states in moral decision making (Young et al., 2010; Jeurissen et al., 2014). Moreover, Young et al. (2010) revealed that using TMS over the rTPJ led participants rely less on the actor's mental states when making moral judgments.

More recently, using tDCS, several studies reported that the application of anodal or cathodal stimulation over the rTPJ could modulate the belief attribution (Sellaro et al., 2015; Sowden et al., 2015; Ye et al., 2015). Sellaro et al. (2015) found that participants who received anodal stimulation assigned less blame to accidental harms compared to participants who received cathodal or sham stimulation, emphasizing the role of rTPJ in mediating the belief attribution for moral judgements. Ye et al. (2015) reported that inhibiting the rTPJ of typical adults with cathodal stimulation decreased the role of beliefs in moral judgments and increased the dependence on the action's outcomes when making moral judgment.

However, Santiesteban et al. (2012) did not find the effects of anodal or cathodal stimulation of the rTPJ when participants were asked to make mental judgments about themselves or others (ToM), though they did observe that anodal stimulation of the rTPJ improved the on-line control of self and other representations in the imitation and perspective-taking tasks which involve low-level sociocognitive processes. In their latest study (Santiesteban et al., 2015), they applied anodal stimulation over the rTPJ or left TPJ (lTPJ) and observed the bilateral TPJ involvement in the perspective-taking and imitation inhibition,

while they still found no effect on the ToM task in which participants watched a movie and were asked to infer the mental state of characters. The possible reason for no tDCS effects on ToM in their studies might be that the ToM tasks they used are insensitive to the performance variation induced by stimulation in typical adults (Santiesteban et al., 2015).

The present study aimed to use the non-invasive tDCS to examine whether both ToM and cognitive empathy depends causally on the neural activity in the rTPJ that has previously identified through fMRI (Vollm et al., 2006; Atique et al., 2011). Therefore, in the present study, we used the cartoon task derived from Vollm et al. (2006) to validate the crucial role of rTPJ in these sociocognitive abilities through elevating or inhibiting the cortical excitability. Many fMRI studies of ToM reported the activity in the rTPJ or bilateral TPJ, while a few studies reported the unilateral activation of the left TPJ (see meta-analysis by Van Overwalle, 2009). In addition, most previous TMS and tDCS studies of ToM stimulate the rTPJ (e.g., Costa et al., 2008; Santiesteban et al., 2012). In order to make our study comparable to previous studies, we focused on the rTPJ instead of lTPJ. Based on the previous studies, we hypothesized that anodal stimulation could enhance the abilities of ToM and cognitive empathy, while the cathodal could have the opposite effect. As to our knowledge, this is the first study to explore whether both ToM and cognitive empathy could be modulated by the tDCS of the rTPJ.

There are several reasons for why we are interested in ToM in adults. First, although the ToM ability is already fully developed at the age of 4–5 years, its specific neural mechanisms remain unclear. Second, the ToM ability is closely correlated with neurodevelopmental disorders, such as autism. Third, some socio-cognitive abilities, such as moral judgment, and lie detection, also rely on ToM (Sellaro et al., 2015; Sowden et al., 2015; Ye et al., 2015; Young et al., 2010). Therefore, investigating ToM in adults could help us understand not only ToM itself but also neural models of other socio-cognitive abilities, as well as help individuals with neurodevelopmental disorders.

MATERIALS AND METHODS

Participants

Sixty-eight right-handed adults (mean age 22.8 ± 2.6 years, 35 females) participated in the study. They were randomly assigned to three groups: the anodal ($n = 21$), the cathodal ($n = 23$), or the control "sham" ($n = 24$). Two additional participants, one in the anodal group and another in the cathodal group, withdrew from the study because they reported to be afraid of receiving the tDCS. None of the participants reported a history of neurological or psychiatric disorders. All participants were paid for their participation and gave their informed consent. The study was approved by the Institutional Review Board of Department of Psychology at Renmin University of China.

tDCS Protocol

Transcranial direct current stimulation was administered through a specially battery-driven constant current stimulator

(DC-Stimulator Plus, NeuroConn GmbH, Germany). The stimulation was induced through a saline-soaked pair of surface sponge electrodes (35 cm² in size). To stimulate the rTPJ, the anodal or cathodal electrode was placed between CP6 and C6 according to the international 10–20 EEG system and previous fMRI studies (Jurcak et al., 2007) (see **Figure 1**). This area covers the MNI coordinates [54, –59, 22] of the rTPJ reported in previous fMRI studies (Young et al., 2007; Young and Saxe, 2009). The reference electrode was placed over the left cheek.

As in previous studies, to assure the target cortex to be activated completely (Jurcak et al., 2007; Cerruti and Schlaug, 2009), a relatively weak current (1.5 mA) was constantly delivered for 20 min. For the sham group, although the electrode was placed over the rTPJ for 20 min, the stimulation only lasted for 15 s. At the onset of each condition (anodal, cathodal, or sham), the fade in and fade out time were both 15 s (Cerruti and Schlaug, 2009; Holland et al., 2011; Keeser et al., 2011). Participants felt the current as itching sensation at the beginning of the stimulation.

Experimental Procedure

All participants filled in the Interpersonal Reactivity Index (IRI) questionnaire (Davis, 1980) to assess empathy before receiving the stimulation. The IRI is a self-report questionnaire that includes four subscales, perspective-taking, fantasy, empathic concern, and personal distress. Each subscale is comprised of seven questions, which constitutes the total 28 items. The perspective-taking and fantasy subscales are two cognitive scales, while the empathic concern and personal distress subscales are two affective scales (Davis, 1983). We focused our analysis on the perspective-taking and fantasy subscales, because we only interested in cognitive empathy. The perspective-taking scale measures the tendency to accept spontaneously others' point of view (e.g., "I sometimes try to understand my friends better by imagining how things looks from their perspective"); while the fantasy scale measures the tendency to transfer oneself into fictional situations (e.g., "When I am reading an interesting story or novel I imagine how I would feel if the events in the story were happening to me"). Responses are on a 5-point Likert scale ranging from 0 (does not describe me well) to 4 (describe me very well). The Cronbach's alpha was 0.81 for the perspective-taking scale and 0.79 for the fantasy scales.

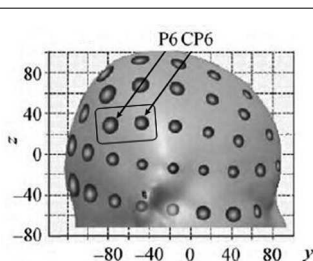


FIGURE 1 | The location of the anodal or cathodal electrode was placed in the MNI coordinates (adapted from Jurcak et al., 2007).

After the stimulation, participant performed the task derived from Vollm et al. (2006) on the computer. The task consists of four conditions: ToM, Cognitive empathy, Physical 1, and Physical 2. The Physical 1 and Physical 2 are the control of the ToM and Cognitive empathy, respectively. **Figure 2** shows examples of stimuli from each condition. In the ToM and Cognitive empathy conditions, participants were asked to infer the character's intention or emotion, respectively. In the other two conditions, they had to make inferences based on physical causalities. The stories of ToM and Physical 1 described one character only while Cognitive empathy and Physical 2 described two characters.

A total of 40 comic strips each depicting a short story were presented in eight blocks, with each block comprising of five comic strips belonging to the same condition. Thus each condition was showed twice and each strip was showed only once. The sequence of blocks and comic strips in each block were counterbalanced.

Each block began with an introductory question for 6 s which indicated the required type of inference (ToM condition: "What will the main character do next?"; Cognitive empathy condition: "What will make the main character feel better?"; Physical 1 and Physical 2 conditions: "What is most likely to happen next?"). Each strip cartoon was presented for 6 s, and then another two cartoons showing the possible outcome were imposed on the bottom of the screen for 4.5 s. Participants were required to make a choice between the two possible outcomes of the stories by pressing the button as soon as possible. Accuracy and RTs were recorded for all cartoons. A score of one referred to a correct answer while a score of 0 was assigned to be wrong.

Data Analysis

Analyses were done with SPSS statistical software (version 22, Chicago, IL, USA). Accuracy and RTs in each condition (ToM, Cognitive empathy, Physical 1, and Physical 2) were analyzed using one-way analysis of variance (ANOVA) with Group as a between-subjects factor (i.e., anodal, sham, and cathodal). Further *Post hoc* analyses were conducted using the Tukey's honestly significant difference (HSD) test when appropriate.

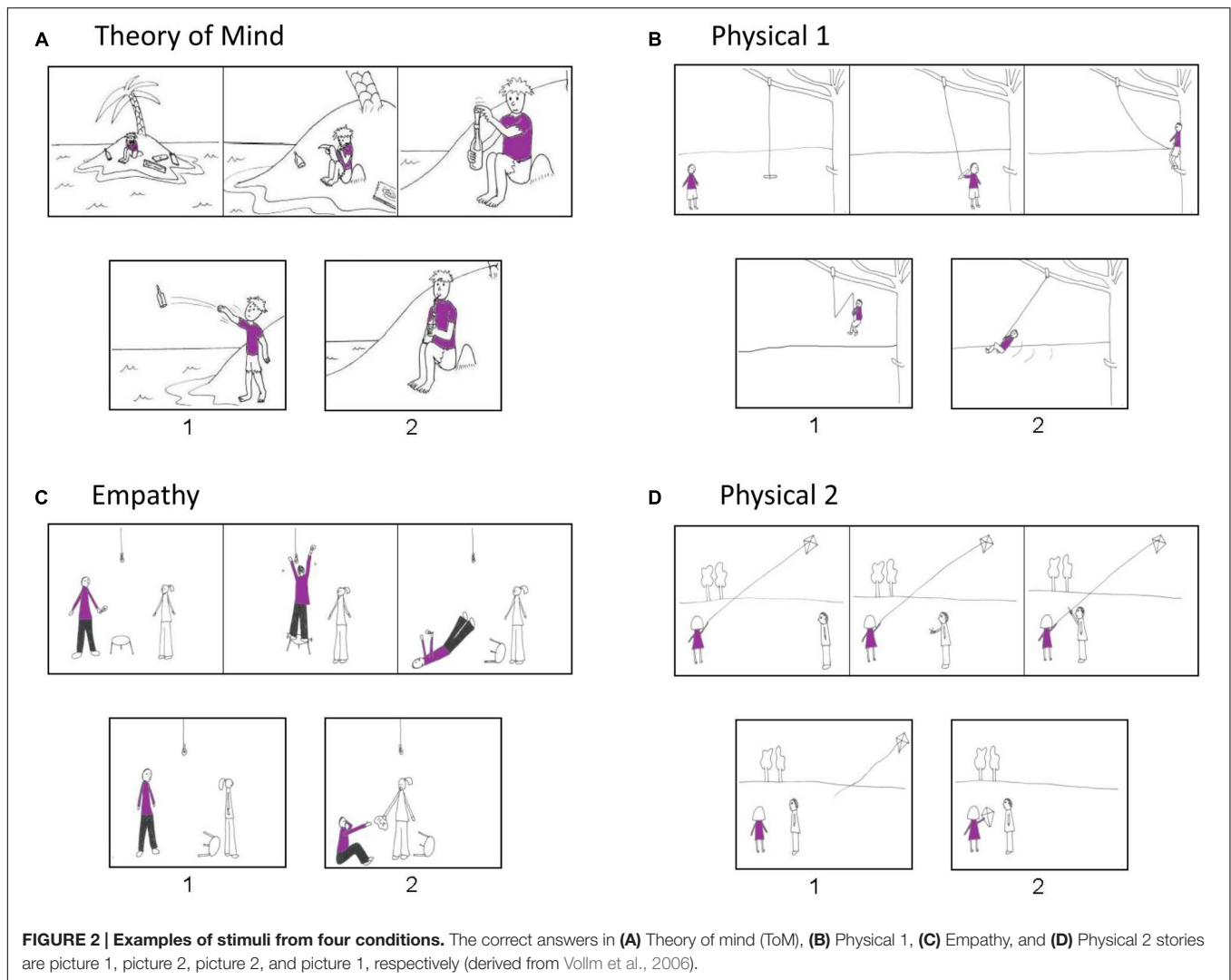
RESULTS

IRI score

The scores for the perspective-taking and fantasy subscales which measure cognitive empathy were analyzed using a one-way ANOVA with Group as a between-subjects factor (i.e., anodal, sham, and cathodal). No significant differences were found for scores of both perspective-taking (mean \pm SD, 17.9 \pm 3.2, 17.9 \pm 3.1, and 18.8 \pm 4.5) and fantasy (15.2 \pm 5.0, 15.4 \pm 5.8, and 14.0 \pm 6.4) among the Anodal, Cathodal, and Sham groups before stimulation, indicating that there were no group differences in cognitive empathy before receiving the tDCS.

Accuracy

Figure 3 shows accuracy in four conditions for three stimulation groups. In the ToM condition, there was a reliable main effect



of Group, $F(2,65) = 3.76, p = 0.028$. *Post hoc* analyses revealed that the difference between Cathodal and Sham groups reached significance ($p = 0.040$) but no differences were found between Anodal and Shame groups ($p = 0.980$) and between Anodal and Cathodal groups ($p = 0.075$), indicating that compared with the the Sham group, participants in the Cathodal group were less accurate in inferring the character's intention. In the Physical 1 condition which is the control of the ToM condition, no differences were found between stimulation groups.

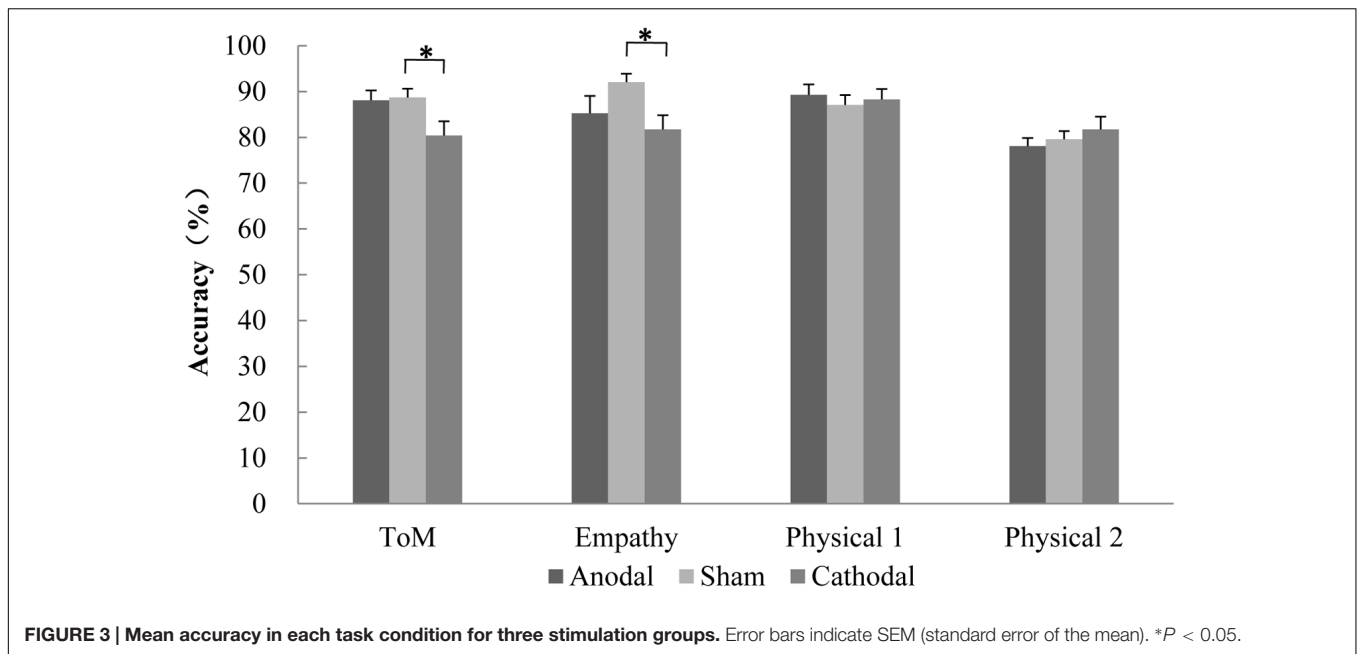
In the cognitive empathy condition, there was also a reliable main effect of Group, $F(2,65) = 3.35, p = 0.041$. *Post hoc* analyses showed that the difference between Cathodal and Sham groups reached significance ($p = 0.035$) but no differences were found between Anodal and Shame groups ($p = 0.236$) and between Anodal and Cathodal groups ($p = 0.685$), indicating that compared with the Sham group, participants were less accurate in inferring the character's emotion after receiving the cathodal stimulation. In the Physical 2 conditions which is the control of the cognitive empathy condition, no differences were found between stimulation groups.

Response Times

Response times were recorded for all 40 trials and the trials failing to respond within 4.5 s were excluded from the analysis. **Table 1** shows RTs in four conditions for three stimulation groups. For each condition, the one-way ANOVA did not find any significant between-group effects, indicating that the tDCS over the rTPJ did not significantly affect RTs.

DISCUSSION

The present study assessed the potential effect of the tDCS of the rTPJ on ToM and cognitive empathy. Our findings indicate that the accuracy of both ToM and cognitive empathy decreased after receiving the cathodal stimulation, suggesting that altering the cortical excitability in the rTPJ could influence human's socio-cognitive abilities. More specifically, the inhibition of cortical excitability by the tDCS in the rTPJ could impair human's ability in inferring others' mental states or emotional states. Therefore, the results of this study



emphasize the critical role of the rTPJ in ToM and cognitive empathy.

The results of the present study are in line with the findings of previous fMRI studies in which they have found that the rTPJ is closely related to both ToM and cognitive empathy (Vogeley et al., 2001; Saxe and Kanwisher, 2003; Vollm et al., 2006; Spengler et al., 2009; Atique et al., 2011). They are also consistent with the TMS study by Costa et al. (2008) in which they reported that the application of the rTMS over the rTPJ could worsen ToM performances, as well as the tDCS study of Ye et al. (2015) in which they observed that the inhibition of the rTPJ with cathodal stimulation decreased the role of beliefs in moral judgments. Together with previous studies, our findings suggest that ToM and cognitive empathy could be related to the neural activity in the rTPJ.

However, Santiesteban et al. (2012) did not observe the inhibition effect of cathodal stimulation in the rTPJ on ToM. One likely reason of the discrepancy is that the reaction time, which is the only behavioral measure of the ToM test in their study, might not be a sensitive behavioral index of ToM performance. In our study, both accuracy and reaction times were measured in the ToM task and the cathodal-inhibition effects were shown only in accuracy data but not reaction times. In both studies of Santiesteban et al. (2012) and ours, participants' reaction times are more than 2000 ms. Such slow reaction times might

be insensitive to measuring the variation of the ToM ability. More recently, Santiesteban et al. (2015) further examined the bilateral TPJ involvement in ToM using tDCS and accuracy was measured in the ToM task. Unfortunately, they only applied anodal stimulation but did not use cathodal stimulation and thus the effect of cathodal stimulation of TPJ on ToM is unknown in their study.

In addition, we did not validate our hypothesis that anodal stimulation might enhance the performance of ToM and cognitive empathy. Santiesteban et al. (2012, 2015) did not find any reliable effect of anodal stimulation of the rTPJ on ToM either. The possible explanation is that the tasks in their studies and ours are so easy for healthy adults that their performances (accuracy and RTs) of the ToM and cognitive empathy were already good enough when without any stimulation and thus could not be improved with anodal stimulation. This interpretation should be tested in the future studies by investigating individuals with ToM impairment, such as people with autism spectrum disorders and schizophrenia.

In the present study, we used a between-subject design and found that tDCS of the rTPJ had effects on ToM and cognitive empathy. It should acknowledge that our argument that stimulation makes a difference would be stronger if we use a within-subject design. However, the task we used in the present study is not appropriate for the within-subject design. For the within-subject design, there should be two tests, one before stimulation and another after stimulation. But there was only 10 trials in each condition in our task and there would not be enough trials for each test if we split 10 trials into two tests, i.e., pre-stimulation and after-stimulation tests. In addition, there might be learning and priming effects if the task is repeated after stimulation.

TABLE 1 | Response times (ms) in each task condition for three stimulation groups (M ± SD).

| | ToM | Empathy | Physical 1 | Physical 2 |
|----------|------------|------------|------------|------------|
| Anodal | 2161 ± 363 | 2197 ± 446 | 2162 ± 459 | 2286 ± 418 |
| Sham | 2098 ± 374 | 2178 ± 386 | 2180 ± 452 | 2375 ± 403 |
| Cathodal | 2085 ± 433 | 2177 ± 400 | 2137 ± 585 | 2273 ± 586 |

It has to be acknowledged that there are several limitations of the present study. First, the findings are based on one study in which the experimental materials and task came from the study of Vollm et al. (2006). However, some evidence shows that brain areas related to ToM differ for different tasks and stimuli (see the review by Schurz and Perner, 2015). Therefore, our results may not be generalizable to other ToM tasks with different stimuli. Moreover, the task might be too easy for healthy adults to validate the enhancement of anodal stimulation on ToM and cognitive empathy. Third, although previous studies have confirmed that the tDCS could induce excitability changes of the cortex (Jaberzadeh and Zoghi, 2013), we must admit that the tDCS does not have the spatial specificity and thus it is impossible to distinguish different functions of subdivisions of the TPJ. Also, different brain areas might be involved in the different types of ToM tasks (see the review by Schurz and Perner, 2015). Therefore, in the future studies, more tasks should be tried and the role of the different subregions of the TPJ should be explored through combining other neuroimaging techniques. Despite these limitations, the findings of this study still could help us understand the relationship between the rTPJ and some socio-cognitive abilities, such as ToM and cognitive empathy, and also highlight the potential contribution of the tDCS to the field of social cognition.

The tDCS technique is mainly used in clinical treatment and rehabilitation (Nair et al., 2011; Schlaug et al., 2011), while the results of the present study also show the significant value of this technology in the normal group. Some other socio-cognitive abilities also rely on ToM, such as moral judgment and lie detection (Sellaro et al., 2015; Sowden et al., 2015; Ye et al., 2015). Therefore, investigating the neural mechanisms of ToM in adults could help us understand not only ToM itself but also other socio-cognitive abilities. In addition, depression, anti-social personality disorder and stroke patients have been characterized by local

changes in the brain structure and function (Grefkes and Fink, 2011; Palazidou, 2012) and thus most of them may have problems in understanding others' intentions and emotion. The tDCS, as a non-invasive stimulation, has a wide application prospect in the improvement of such disabled patients. Future studies should also address how such clinical diseases can be modulated by the tDCS.

As far as we know, this is the first study to explore tDCS effects on both ToM and cognitive empathy by controlling the cerebral cortex excitability of the rTPJ. Future research can continuously investigate the anodal effect of tDCS over the rTPJ on ToM and cognitive empathy or apply tDCS over the left temporal area, the frontal area, and other brain areas related to social cognitive processing.

AUTHOR CONTRIBUTIONS

XM, CL, and WZ designed the study. WZ, ZZ, and ZX performed data collection and analysis. XM, WZ, XH, CL, and JZ wrote the paper. All authors approved the final version of the paper for submission.

ACKNOWLEDGMENTS

This work was supported by grants from the National Natural Science Foundation of China (31170971, 61210010, 31200845, 31400888), the Major Project of the National Social Science Foundation (12&ZD228, 13&ZD155), Humanities and social science projects supported by Ministry of Education (13YJA190007), State Key Laboratory of Cognitive Neuroscience and Learning at Beijing Normal University (CNLYB1212), and the Fundamental Research Funds for the Central Universities and the Research Funds of Renmin University of China (15XNLQ05).

REFERENCES

- Atique, B., Erb, M., Gharabaghi, A., Grodd, W., and Anders, S. (2011). Task-specific activity and connectivity within the mentalizing network during emotion and intention mentalizing. *Neuroimage* 55, 1899–1911. doi: 10.1016/j.neuroimage.2010.12.036
- Blair, R. J. R. (2005). Responding to the emotions of others: dissociating forms of empathy through the study of typical and psychiatric populations. *Conscious. Cogn.* 14, 698–718. doi: 10.1016/j.concog.2005.06.004
- Cerruti, C., and Schlaug, G. (2009). Anodal transcranial direct current stimulation of the prefrontal cortex enhances complex verbal associative thought. *J. Cogn. Neurosci.* 21, 1980–1987. doi: 10.1162/jocn.2008.21143
- Costa, A., Torriero, S., Oliveri, M., and Caltagirone, C. (2008). Prefrontal and temporo-parietal involvement in taking others' perspective: TMS evidence. *Behav. Neurol.* 19, 71–74. doi: 10.1155/2008/694632
- Davis, M. H. (1980). A multidimensional approach to individual differences in empathy. *JSAS Catalog Sel. Doc. Psychol.* 10, 85.
- Davis, M. H. (1983). Measuring individual differences in empathy-evidence for a multidimensional approach. *J. Pers. Soc. Psychol.* 44, 113–126. doi: 10.1037/0022-3514.44.1.113
- de Waal, F. B. M. (2008). Putting the altruism back into altruism: the evolution of empathy. *Annu. Rev. Psychol.* 59, 279–300. doi: 10.1146/annurev.psych.59.103006.093625
- Eslinger, P. J. (1998). Neurological and neuropsychological bases of empathy. *Eur. Neurol.* 39, 193–199. doi: 10.1159/000007933
- Frith, C. D., and Frith, U. (1999). Cognitive psychology – Interacting minds – A biological basis. *Science* 286, 1692–1695. doi: 10.1126/science.286.5445.1692
- Grefkes, C., and Fink, G. R. (2011). Reorganization of cerebral networks after stroke: new insights from neuroimaging with connectivity approaches. *Brain* 134, 1264–1276. doi: 10.1093/brain/awr033
- Holland, R., Leff, A. P., Josephs, O., Galea, J. M., Desikan, M., Price, C. J., et al. (2011). Speech facilitation by left inferior frontal cortex stimulation. *Curr. Biol.* 21, 1403–1407. doi: 10.1016/j.cub.2011.07.021
- Jaberzadeh, S., and Zoghi, M. (2013). Non-invasive brain stimulation for enhancement of corticospinal excitability and motor performance. *Basic Clin. Neurosci.* 4, 257–265.
- Jourissen, D., Sack, A. T., Roebroeck, A., Russ, B. E., and Pascual-Leone, A. (2014). TMS affects moral judgment, showing the role of DLPFC and TPJ in cognitive and emotional processing. *Front. Neurosci.* 8:18. doi: 10.3389/fnins.2014.00018
- Jurcak, V., Tsuzuki, D., and Dan, I. (2007). 10/20, 10/10, and 10/5 systems revisited: their validity as relative head-surface-based positioning systems. *Neuroimage* 34, 1600–1611. doi: 10.1016/j.neuroimage.2006.09.024
- Keiser, D., Meindl, T., Bor, J., Palm, U., Pogarell, O., Mulert, C., et al. (2011). Prefrontal transcranial direct current stimulation changes connectivity

- of resting-state networks during fMRI. *J. Neurosci.* 31, 15284–15293. doi: 10.1523/JNEUROSCI.0542-11.2011
- Nair, D. G., Renga, V., Lindenberg, R., Zhu, L., and Schlaug, G. (2011). Optimizing recovery potential through simultaneous occupational therapy and non-invasive brain-stimulation using tDCS. *Restor. Neurol. Neurosci.* 29, 411–420. doi: 10.3233/RNN-2011-0612
- Palazidou, E. (2012). The neurobiology of depression. *Br. Med. Bull.* 101, 127–145. doi: 10.1093/bmb/lds004
- Preston, S. D., and de Waal, F. B. M. (2002). Empathy: its ultimate and proximate bases. *Behav. Brain Sci.* 25, 1–72.
- Rankin, K. P., Kramer, J. H., and Miller, B. L. (2005). Patterns of cognitive and emotional empathy in frontotemporal lobar degeneration. *Cogn. Behav. Neurol.* 18, 28–36. doi: 10.1097/01.wnn.0000152225.05377.ab
- Santiesteban, I., Banissy, M. J., Catmur, C., and Bird, G. (2012). Enhancing social ability by stimulating right temporoparietal junction. *Curr. Biol.* 22, 2274–2277. doi: 10.1016/j.cub.2012.10.018
- Santiesteban, I., Banissy, M. J., Catmur, C., and Bird, G. (2015). Functional lateralization of temporoparietal junction – imitation inhibition, visual perspective-taking and theory of mind. *Eur. J. Neurosci.* 42, 2527–2533. doi: 10.1111/ejn.13036
- Saxe, R., and Kanwisher, N. (2003). People thinking about thinking people: the role of the temporo-parietal junction in “theory of mind”. *Neuroimage* 19, 1835–1842. doi: 10.1016/S1053-8119(03)00230-1
- Saxe, R., and Wexler, A. (2005). Making sense of another mind: the role of the right temporo-parietal junction. *Neuropsychologia* 43, 1391–1399. doi: 10.1016/j.neuropsychologia.2005.02.013
- Schlaug, G., Marchina, S., and Wan, C. Y. (2011). The use of non-invasive brain stimulation techniques to facilitate recovery from post-stroke aphasia. *Neuropsychol. Rev.* 21, 288–301. doi: 10.1007/s11065-011-9181-y
- Schnell, K., Bluschke, S., Konradt, B., and Walter, H. (2011). Functional relations of empathy and mentalizing: an fMRI study on the neural basis of cognitive empathy. *Neuroimage* 54, 1743–1754. doi: 10.1016/j.neuroimage.2010.08.024
- Schurz, M., and Perner, J. (2015). An evaluation of neurocognitive models of theory of mind. *Front. Psychol.* 6:1610. doi: 10.3389/fpsyg.2015.01610
- Sellaro, R., Guroglu, B., Nitsche, M. A., van den Wildenberg, W. P. M., Massaro, V., Durieux, J., et al. (2015). Increasing the role of belief information in moral judgments by stimulating the right temporoparietal junction. *Neuropsychologia* 77, 400–408. doi: 10.1016/j.neuropsychologia.2015.09.016
- Shamay-Tsoory, S. G., Aharon-Peretz, J., and Perry, D. (2009). Two systems for empathy: a double dissociation between emotional and cognitive empathy in inferior frontal gyrus versus ventromedial prefrontal lesions. *Brain* 132, 617–627. doi: 10.1093/brain/awn279
- Shamay-Tsoory, S. G., Tomer, R., Berger, B. D., and Aharon-Peretz, J. (2003). Characterization of empathy deficits following prefrontal brain damage: the role of the right ventromedial prefrontal cortex. *J. Cogn. Neurosci.* 15, 324–337. doi: 10.1162/089892903321593063
- Shamay-Tsoory, S. G., Tomer, R., and Aharon-Peretz, J. (2005). The neuroanatomical basis of understanding sarcasm and its relationship to social cognition. *Neuropsychology* 19, 288–300. doi: 10.1037/0894-4105.19.3.288
- Sowden, S., Wright, G. R. T., Banissy, M. J., Catmur, C., and Bird, G. (2015). Transcranial current stimulation of the temporoparietal junction improves lie detection. *Curr. Biol.* 25, 2447–2451. doi: 10.1016/j.cub.2015.08.014
- Spengler, S., von Cramon, D. Y., and Brass, M. (2009). Control of shared representations relies on key processes involved in mental state attribution. *Hum. Brain Mapp.* 30, 3704–3718. doi: 10.1002/hbm.20800
- Van Overwalle, F. (2009). Social cognition and the brain: a meta-analysis. *Hum. Brain Mapp.* 30, 829–858. doi: 10.1002/hbm.20547
- Vogeley, K., Bussfeld, P., Newen, A., Herrmann, S., Happe, F., Falkai, P., et al. (2001). Mind reading: neural mechanisms of theory of mind and self-perspective. *Neuroimage* 14, 170–181. doi: 10.1006/nimg.2001.0789
- Vollm, B. A., Taylor, A. N. W., Richardson, P., Corcoran, R., Stirling, J., McKie, S., et al. (2006). Neuronal correlates of theory of mind and empathy: a functional magnetic resonance imaging study in a nonverbal task. *Neuroimage* 29, 90–98. doi: 10.1016/j.neuroimage.2005.07.022
- Walter, H. (2012). Social cognitive neuroscience of empathy: concepts, circuits, and genes. *Emot. Rev.* 4, 9–17. doi: 10.1177/1754073911421379
- Ye, H., Chen, S., Huang, D., Zheng, H., Jia, Y., and Luo, J. (2015). Modulation of neural activity in the temporoparietal junction with transcranial direct current stimulation changes the role of beliefs in moral judgment. *Front. Hum. Neurosci.* 9:659. doi: 10.3389/fnhum.2015.00659
- Young, L., Camprodon, J. A., Hauser, M., Pascual-Leone, A., and Saxe, R. (2010). Disruption of the right temporoparietal junction with transcranial magnetic stimulation reduces the role of beliefs in moral judgments. *Proc. Natl. Acad. Sci. U.S.A.* 107, 6753–6758. doi: 10.1073/pnas.0914826107
- Young, L., Cushman, F., Hauser, M., and Saxe, R. (2007). The neural basis of the interaction between theory of mind and moral judgment. *Proc. Natl. Acad. Sci. U.S.A.* 104, 8235–8240. doi: 10.1073/pnas.0701408104
- Young, L., and Saxe, R. (2009). An fMRI investigation of spontaneous mental state inference for moral judgment. *J. Cogn. Neurosci.* 21, 1396–1405. doi: 10.1162/jocn.2009.21137

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The reviewer SO and handling Editor declared their shared affiliation, and the handling Editor states that the process nevertheless met the standards of a fair and objective review.

Copyright © 2016 Mai, Zhang, Hu, Zhen, Xu, Zhang and Liu. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) or licensor are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.