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Trans direct cranial stimulation; tempro- parietal junction (rTPJ) role in visuospatial perception , perspective taking, and mind reading

Mohammad ebrahim hokmabadi*, Psychiatry and Behavioral Sciences Research Center, Mashhad University of Medical Sciences, Mashhad, Iran, ebi.hokmabady@gmail.com
Roza salehian, Psychiatry and Behavioral Sciences Research Center, Mashhad University of Medical Sciences, Mashhad, Iran
Hamid zolfaghari, Phd student of Psychology ,Ferdowsi University of mashhad,mashhad,iran
Tarlan tavakoli, Department of Psychology, Neyshabur Branch, Islamic Azad University, Neyshabur, Iran
Roghayeh rajabi doki, Department of Psychology, Roudehen Branch, Islamic Azad University, Roudehen, Iran

Abstract:
Back ground and purpose: Right tempro- parietal junction (rTPJ), as a supramodal associative area of the brain, plays an important role in visuao spatial functions and social cognition. The current study aims to evaluate the role of rTPJ in mental rotation, perspective taking and mind reading.
Method: Thirty healthy male subjects received both anodal and cathodal transcranial direct current stimulation of 2 mA intensity over the rTPJ for 20 min in two separate sessions with 24-hours interval. During stimulation, participants had to perform mental rotation test, picture test, and reading mind from eyes test for evaluation of mental rotation, perspective taking and mindreading in orderly. Three repeated-measure analysis of variance were used for analysis using SPSS 24.
Results: Findings showed the performance of mental rotation and perspective taking significantly improved under anodal stimulation over the rTPJ. The performance of mind reading was similar in both anodal and cathodal stimulation over the rTPJ.
Conclusion: The rTPJ is a common neural correlate of mental rotation and perspective taking. These two functions are structurally and functionally interwoven. The rTPJ is not an only decisive neural component of mind reading from eyes.

Key words: **Mental rotation, perspective taking and mind reading, rTPJ, tDCS**

I. Introduction:

Functional neuroanatomy and neuroimaging of TPJ

The temporo-parieto junction (TPJ) is a mosaic area of the brain located at the border of temporal and parietal areas, surrounding the posterior end of the Sylvian fissure (De Benedictis et al., 2014). TPJ refers to several areas in both parietal and temporal lobes including posterior inferior parietal lobule, angular, supramarginal, and posterior superior temporal gyri (Mars et al., 2011).

TPJ, as a supramodal association area, receives several sensory modalities such as somatosensory, visual, vestibular and auditory. During lateralization, the right TPJ (rTPJ) becomes larger that correspond with the visuospatial specialization of the right hemisphere. This area is in the dorsal visual stream and the intermodal mixing nature of its connectivity arms it for controlling spatially guided behaviors (Kolb & Whishaw, 2009).

Neuroimaging studies, with different methods, attribute a variety of functions to the TPJ in health and disease. For instance, fMRI studies found different roles for TPJ in healthy subjects such as, numerical cognition (Holloway, Price, & Ansari, 2010; Zarnhofer et al., 2012), autobiographic memory (Steinvorth, Corkin, & Halgren, 2006), working memory (Deprez et al., 2013), face and object recognition (Tavor et al., 2014; Zhen, Fang, & Liu, 2013), mind reading (Molenberghs, Johnson, Henry, & Mattingley, 2016), sense of agency (Farrer et al., 2003) and evaluation of prosocial traits (van der Cruijsen, Peters, & Crone, 2017).

In psychopathology, fMRI studies showed the role of TPJ in word generation in schizophrenia (John, Halahalli, Vasudev, Jayakumar, & Jain, 2011), self-other distinctions in both schizophrenia and Tourette syndrome (Eddy, 2017)

More, lesion studies have revealed impairment in calculation in patient with left TPJ (lTPJ) hemorrhage (Lampl, Eshel, Gilad, & Sarova-Pinhas, 1994) and impairment in writing and reading in left angular and supramarginal gyrus hemmorrhage. Furthermore, impairment in visuospatial recognition and prospagnosia have been reported in lesion of rTPJ (Sakurai, Hamada, Tsugawa, & Sugimoto, 2016). Furthermore, rTPJ lesion in stroke leads to visual neglect (Vallar & Perani, 1986).

Furthermore, intraoperational mapping via direct electrical stimulation in low grade glioma of temporal lobe shows the role of rTPJ in visuao spatiaol abilities (de Schotten et al., 2005; Duffau, Velut, Mitchell, Gatignol, & Capelle, 2004).
The transcranial direct current stimulation (tDCS) over the rTPJ leads to reducing smoking behavior (Meng, Liu, Yu, & Ma, 2014), attenuating cue- induced craving for heroin (Y. Wang et al., 2016), and enhancing judgment of agency (Nahab et al., 2010).
In sum, the variety of findings in different studies about the role of TPJ makes it difficult to consider a unique role for this are.

Non -invasive brain stimulation techniques in neuroimaging:
Non -invasive brain stimulation (NIBS) techniques provide a situation to target and modulate the brain areas directly (Monte-Silva et al., 2013) and are thus introduced as promising methods for the study of cognitive functions (Nitsche & Paulus, 2000, 2001).
Two widely used NIBS techniques are transcranial electrical stimulation (tES) and transcranial magnetic stimulation (TMS). TMS, with putting a coil on the scalp, induces a magnetic field in the target regions of the brain and leads to depolarization of targeted cortical neurons (Walsh & Pascual-Leone, 2003). TES, with 2 scalp electrodes, applies an electrical current to the brain that causes cortical excitability under anodal electrode and cortical hypoactivity under cathodal electrode (Nitsche & Paulus, 2000). In compare to TMS, TES has a better potential for clinical applications because of feasibility in clinical environment.
In tDCS, a weak (0.5–2 mA) direct current is applied over the scalp via two or more anodal and cathodal electrodes. In this way, tDCS alters neuronal resting membrane potentials, and - depending on the stimulation polarity, enhances or reduces excitability of the cortical target at a macroscopic level (Nitsche et al., 2008). Beyond these acute effects, sufficiently long stimulation (for some minutes) results in after-effects lasting for more than 1h after stimulation, which resemble long term potentiation, and depression (Nitsche & Paulus, 2001; Rroji, van Kuyck, Nuttin, & Wenderoth, 2015).
These potential let us to study the function of cortical areas under hypoactive and hyperactive conditions.

Neural correlate of mental rotation, perspective taking and mind reading:
Mental rotation, as a visuo spatial ability, is the ability of judging objects in different orientations (Shepard & Metzler, 1971). Neuroimaging studies illustrate the mental rotation direct mainly by the posterior parietal lobes (Jordan, Heinze, Lutz, Kanowski, & Jäncke, 2001; Milivojevic, Hamm, & Corballis, 2009; Podzebenko, Egan, & Watson, 2002). More precisely, mental rotation could be divided into two separate components including object recognition and spatial processing. The ventral occipital–temporal pathway or the 'what' visual system is involved in former and the dorsal occipital-parietal pathway or the 'where' visual system is involved in latter (Booth et al., 2000; Koshino, Carpenter, Keller, & Just, 2005).
Perspective taking, as another visuo spatial ability, is the ability of understanding others' visuospatial experiences and views to the scene from their perspectives (A. Surtees, I. Apperly, & D. Samson, 2013). Perspective taking process differentiates first and third perspective and usually consider as underpinning of "cognitive empathy" or "mentalizing" (Davis, Conklin, Smith, & Luce, 1996; Lamm, Batson, & Decety, 2007). Functional neuroimaging studies have identified several brain areas as a network that are involved in perspective taking including the medial prefrontal cortex (mPFC), posterior superior temporal sulcus (pSTS/TPJ), and temporal poles/amygdala (Rameson, Morelli, & Lieberman, 2012; Ruby & Decety, 2004; Völlm et al., 2006) Lesion studies, in individuals with dementia, have found the role of medial and ventromedial prefrontal cortex (vmPFC) as well as regions in the posterior TPJ in perspective taking (Rankin et al., 2006)
Mind reading is the ability to infer and predict the desires, intentions, intuitions, thoughts, reactions, plans and beliefs of other people (U. Frith & Frith, 2010). Mind reading could be considered as two domain including *representation* and *deployment or attribution* of the mental state to self and/or other (Abu-Akel & Shamay-Tsoory, 2011). Mind reading enables individuals to understand and interact with each other (C. D. Frith & Frith, 2008). Neuroimaging studies have found mind reading is controlled by different brain areas such as bilateral TPJ, medial prefrontal cortex (MPFC), anterior cingulate cortex (ACC), posterior cingulate cortex (PCC), precuneus, superior temporal sulcus (STS), inferior frontal gyrus (IFG) (Amodio & Frith, 2006; Kana, Libero, Hu, Deshpande, & Colburn, 2012; Kana et al., 2015; Saxe & Powell, 2006; Schurz, Radua, Aichhorn, Richlan, & Perner, 2014). Based on meta- analysis studies, the main common brain areas in the different paradigms and tasks of mind reading are TPJ and MPFC (Molenberghs et al., 2016; Schurz et al., 2014)
In light of above mentioned findings, we can consider these three cognitive functions in a spectrum extend from mental rotation as a physical/ perceptual end to mind reading as emotional/ conceptual end.

In sum, we aim to evaluate the role of inhibition and excitation of rTPJ area via cathodal and anodal tDCS during performing three main supposed cognitive functions including mental rotation, perspective taking and mind reading.

II. METHOD AND MATERIALS:

Participants. Thirty healthy male participants aged from 20-40 years old (Mean=23.66 , SD= 5.60) volunteered to join to the study. All participants were student of **** university (23 psychology student and 7 other majors), native speakers, right handed, with normal or corrected-to-normal vision. The inclusion criteria were: to be aged from 20 to 40, no previous history of head trauma, psychiatric or neurological disorder, and drug addiction. Helsinki ethical standards were considered for the study and the proposal approved by Ethical Committee of the ***** University.

Materials.

Mental rotation test (MRT) (Vandenberg & Kuse, 1978). This task contains some cubes drawing rotated in different angles in different items. The cubes redrawn by Peters et al (Peters et al., 1995). In each item, five cubes exist in a row, the left one is the target and the two of four remained stimuli are identical with the target with a depth rotation. The task includes 24 experimental items and 3 training items for familiarization. The participant had to mark the 12 first answer in 3 minutes, then there was a short break, and they had to complete the last 12 items in 3 minutes. A point was given if both stimuli were marked correctly (figure 1).

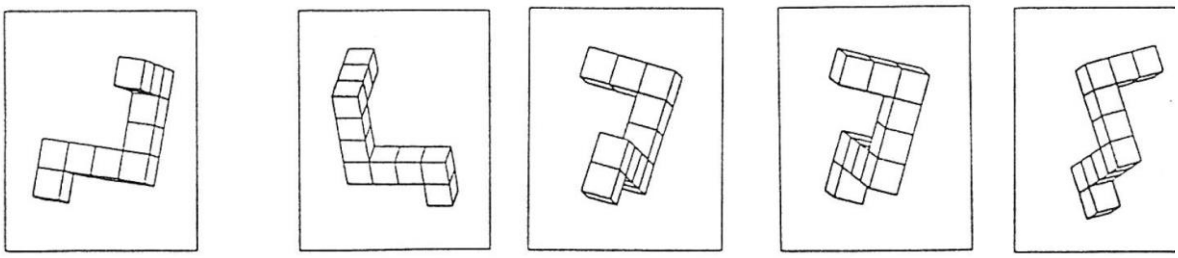

Figure 2. sample question of MRT

Pictures test (PT). In the pictures test, a picture is presented to examinee that illustrate three individuals with different perspective are taking photos of some objects. After viewing this picture, three photos were presented to participants and they had to find the photographer of each photo. In the present study, we used a modified version, easier to perform, that only one photographer exists in the picture and participant had to select one related photo from three choices (Hegarty & Waller, 2004). (figure 2).

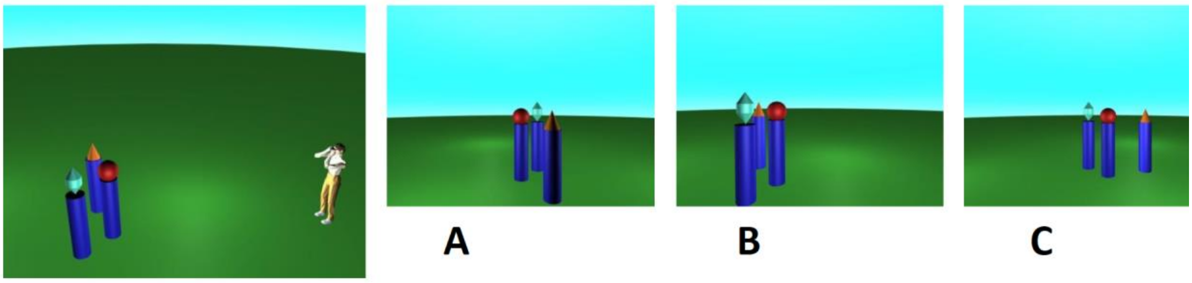

Figure 2. sample question of PT

Reading mind from eyes test (RMET). The RMET includes 36 photographs of eyes region (in both genders equally) expressing a complex mental state. Four word about different mental states are presented as choices below the image and examinee should circle the correct answer (figure 3). An example is used for familiarization. The sum of correct answers is considered as mind reading score (Baron-Cohen, Wheelwright, Hill, Raste, & Plumb, 2001) Test-retest reliability of the Persian version is 0.735 with a 95 % CI of (0.514, 0.855) (Khorashad et al., 2015)

Figure 3. sample question of RMET

Procedure. After checking inclusion criteria and an explanation about the procedure of study, participants fill out a written consent form and learn about the tasks. All participants received 20-min of anodal or cathodal stimulation by one of authors (HZ), with a single blind, counterbalance and random situation, in a quiet room. There was a 24-hr interval between the sessions to prevent transfer and confounding effect of stimulation. Five minutes after the starting of stimulation, participants performed the three task of MRT, PT, and RMET lasting around 15 minutes while they received electrical stimulation. Based on a side-effect survey, no adverse effects were reported in participants. Participants have received financial incentive for their participation.

The tDCS device in use was "ActivaDose Iontophoresis" manufactured by Activa Tek, battery-driven with a 9-volt battery as its source. Electrical direct current of 1.5 mA generated by the stimulator was applied through a pair of saline-soaked sponge electrodes with size of 25 cm2 (5×5) for 20 min (with 15 s ramp up and 15 s ramp down). We had two tDCS conditions according to the 10–20 EEG international system in this study: (a) anodal rTPJ / cathodal on the left arm (b) cathodal rTPJ / anodal on left arm.

Data Analysis. Three repeated measures one way ANOVA were conducted for dependent variables (MRT, PT, and RMET) with tDCS conditions (anodal and cathodal) as the within-subject factor using SPSS 24.

III. RESULTS

Mental rotation

Regarding the analysis of the MRT, repeated-measures analysis of variance showed a significant main effects of "type of stimulation", $F(1,29) = 26.515$, $p <.001$, partial $\eta 2 =478$. The performance in the MRT was higher in the anodal stimulation ($M = 18.93$, $SD = 3.57$) compared to the cathodal stimulation ($M = 16.83$, $SD = 4.16$).

Perspective taking

Regarding the analysis of the PT, a repeated-measures analysis of variance showed a significant main effect of "type of stimulation", $F(1,29) = 7.373$, $p = .011$, partial $\eta 2 = .203$. The performance in the PT was higher in the anodal stimulation ($M = 10.13$, $SD = 2.27$) compared to the cathodal stimulation ($M = 9.13$, $SD = 3.17$).

Mind reading

Regarding the analysis of the RMET, a repeated-measures analysis of variance showed a non significant main effect of "type of stimulation", $F(1,29) = 3.343$, $p = .078$, partial $\eta 2 = .103$. Although performance in the RMET was higher in the anodal stimulation ($M = 20.03$, $SD = 2.56$) compared to the cathodal stimulation ($M = 18.83$, $SD = 3.09$).

IV. CONCLUSION:

The result revealed the rTPJ has a decisive role in perspective taking and mental rotation. The role of rTPJ in mind reading is not crucial. The similar result in perspective taking and mental rotation keep it in mind that the rTPJ is a common neural correlate of these two visuospatial functions. These two functions are correlated functionally. Functionally, perspective taking is explained by three possible mechanisms. First, embodied egocentric transformation that is transformation of the self to the others place and taking their views as self rotation. Second, rotation of others visual world view to the self view. Third, as view point rotation, the environmental cues are considered for perspectives' matching (A. D. R. Surtees, I. A. Apperly, & D. Samson, 2013). In other words, mental rotation, for the self, other or the environment, is the core function of perspective taking.

The role of rTPJ in mental rotation

Our result shows the role of rTPJ in mental rotation. Although the majority of fMRI studies have reported the posterior parietal cortex as the main brain area that is involved in mental rotation, the complexity of tasks is the matter. As firstly Shepard and Metzler (1971) pointed, an increase in angle of rotation in the mental rotation task makes it more difficult (Shepard & Metzler, 1971). This differences originate from different involved brain areas in the way that greater superior, than inferior, parietal cortex activation with increasing angle of rotation are involved (Gogos et al., 2010). Furthermore, a typical mental rotation task per se encompasses several components including: visual recognition, representation of rotation, memorizing of rotated representation, and decision making between choices (Booth et al., 2000). The rTPJ can play a role in both visual recognition and representation of rotation as visuospatial constructs. More, the strategy of performing a mental rotation task can influence the neural correlate. In a mental rotation task, individual should shift between two perspectives that may attribute one of them to the self and another to the other, or self in another situation. This shifting process should be used several time during performing a mental rotation task, related to it's difficulty, and a successful shifting requires a discrimination between self and others that is one well- known role of the rTPJ (Uddin, Molnar-Szakacs, Zaidel, & Iacoboni, 2006). In other words, using and shifting between self or another person perspective during representation of rotation as a frame of reference requires the activity of rTPJ.

Furthermore, for comparing two objects, original and rotated representation, we can consider self as a center of experience in two different position. Locating the center of experience out of the body called out of body experience (OBE) that rTPJ is involved in (Blanke, Ortigue, Landis, & Seeck, 2002).

An OBE includes several folds including: (a) moving self, as the center of experience, out of the physical body (disembodiment), (b) taking an extracorporeal egocentric perspective, and (c) impression of seeing one's own body, or autoscopy, from a elevated perspective (Blanke et al., 2002).

An un intentional OBE considers as a lesion of rTPJ in schizophernia (Thakkar, Nichols, McIntosh, & Park, 2011) and dissociative disorder (Blanke & Mohr, 2005). However, OBE has been reported in 10 percent of non clinical population and could be learned and performed intentionally via spiritual experiences (Blanke et al., 2005; Wilde & Murray, 2009). In a typical mental rotation task, all of above mentioned OBE stages are occurred with an object instead of the self physical body.

Role of rTPJ in perspective taking

Perspective taking govern by rTPJ based on our tDCS stimulations. This finding is in line with the TMS study as another neurostimulation modality. Similarly, acceleration and deceleration of perspective taking are reported by theta frequency (6 Hz) and alpha (10 Hz) of TMS in orderly (Gooding-Williams, Wang, & Kessler, 2017). Further, magnetoencephalography revealed right posterior TPJ is involved in the cognitive effort of perspective-taking (amount of angular disparity between self vs. other's viewpoint) and embodied processing (posture congruence) (Wang, Callaghan, Gooding-Williams, McAllister, & Kessler, 2016). Furthermore, Seymour et al with magnetoencephalography state that rTPJ plays a role such a "hub" in perspective taking (Seymour, Wang, Rippon, & Kessler, 2018).

Role of rTPJ in mind reading

Based on our findings, TPJ has not a significant role in mind reading from eyes. As mentioned earlier, mind reading is controlled by different cortical areas. One decisive factor in this variety of neural correlate is the disparity of paradigms and tasks used for the assessment of mind reading. The variety of brain areas is obvious even in the single task. For instance; in the RMET, used in our study, fMRI studies have been reported the inferior frontal gyrus (IFG), middle temporal gyrus extending and posterior superior temporal sulcus (pSTS) are involved (Thye, Murdaugh, & Kana, 2018) In another fMRI study, pSTS and IFG are reported as the main involved structures (Gunther Moor et al., 2011). Although the TPJ is exist in both mentioned study, but there are some common region such as IFG that play an essential role. Lesion study in traumatic brain injury revealed that individuals with left IFG injury have a poorer performance in RMET (Dal Monte et al., 2014).

Meta -analytic studies, included different neuroimaging studies with different mind reading tasks, have found there are two core and task free regions in mind reading including bilateral posterior TPJ and MPFC (Molenberghs et al., 2016; Schurz et al., 2014). In sum, there are at least two main cortical areas that handle reading mind from eyes and hyperactivation or hypoactivation of TPJ, as one of them, can not influence the performance of mind reading from eyes.

Santiesteban et al have found applying an inhibitory TMS over rTPJ impaired the performance of perspective taking, regardless of the mentalistic/non-mentalistic nature of the task (Santiesteban, Kaur, Bird, & Catmur, 2017). We can consider that mind reading tasks have two components of mentalizing and perspective taking that only the perspective taking component is handled by rTPJ.

In sum, we can conclude that rTPJ has an essential role in both mental rotation and perspective taking as visuospatial tasks. The perspective taking and mental rotation are interwoven functionally. In the way that mental rotation is required for perspective taking and some strategies of perspective taking are used for mental rotation tasks. For the mind reading, we can not found any significant role for the rTPG and we conclude that there is another main decisive region for mind reading from the eyes. One limitation of our study is the task type used for evaluation of mind reading. It seems that if we used another mind reading task, with high perspective taking demand like strange stories, we would find a better role for rTPJ in mind reading. We propose future studies use both strange stories and RMET with bipolar stimulation over rTPJ and vmPFC for the evaluation of neural correlate of mind reading.

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References:

1. Abu-Akel, A., & Shamay-Tsoory, S. (2011). Neuroanatomical and neurochemical bases of theory of mind. *Neuropsychologia, 49*(11), 2971-2984.
2. Amodio, D. M., & Frith, C. D. (2006). Meeting of minds: the medial frontal cortex and social cognition. *Nature Reviews Neuroscience, 7*(4), 268.
3. Baron-Cohen, S., Wheelwright, S., Hill, J., Raste, Y., & Plumb, I. (2001). The "Reading the Mind in the Eyes" test revised version: A study with normal adults, and adults with Asperger syndrome or high-functioning autism. *Journal of child psychology and psychiatry, 42*(2), 241-251.
4. Blanke, O., & Mohr, C. (2005). Out-of-body experience, heautoscopy, and autoscopic hallucination of neurological origin: Implications for neurocognitive mechanisms of corporeal awareness and self-consciousness. *Brain Research Reviews, 50*(1), 184-199.
5. Blanke, O., Mohr, C., Michel, C. M., Pascual-Leone, A., Brugger, P., Seeck, M., . . . Thut, G. (2005). Linking out-of-body experience and self processing to mental own-body imagery at the temporoparietal junction. *Journal of Neuroscience, 25*(3), 550-557.
6. Blanke, O., Ortigue, S., Landis, T., & Seeck, M. (2002). Neuropsychology: stimulating illusory own-body perceptions. *Nature, 419*(6904), 269.
7. Booth, J. R., MacWhinney, B., Thulborn, K. R., Sacco, K., Voyvodic, J. T., & Feldman, H. M. (2000). Developmental and lesion effects in brain activation during sentence comprehension and mental rotation. *Developmental neuropsychology, 18*(2), 139-169.
8. Dal Monte, O., Schintu, S., Pardini, M., Berti, A., Wassermann, E. M., Grafman, J., & Krueger, F. (2014). The left inferior frontal gyrus is crucial for reading the mind in the eyes: brain lesion evidence. *Cortex, 58*, 9-17.
9. Davis, M. H., Conklin, L., Smith, A., & Luce, C. (1996). Effect of perspective taking on the cognitive representation of persons: a merging of self and other. *Journal of personality and social psychology, 70*(4), 713.
10. De Benedictis, A., Duffau, H., Paradiso, B., Grandi, E., Balbi, S., Granieri, E., . . . Sarubbo, S. (2014). Anatomo-functional study of the temporo-parieto-occipital region: dissection, tractographic and brain mapping evidence from a neurosurgical perspective. *Journal of anatomy, 225*(2), 132-151.
11. de Schotten, M. T., Urbanski, M., Duffau, H., Volle, E., Lévy, R., Dubois, B., & Bartolomeo, P. (2005). Direct evidence for a parietal-frontal pathway subserving spatial awareness in humans. *Science, 309*(5744), 2226-2228.
12. Deprez, S., Vandenbulcke, M., Peeters, R., Emsell, L., Amant, F., & Sunaert, S. (2013). The functional neuroanatomy of multitasking: combining dual tasking with a short term memory task. *Neuropsychologia, 51*(11), 2251-2260.
13. Duffau, H., Velut, S., Mitchell, M.-C., Gatignol, P., & Capelle, L. (2004). Intra-operative mapping of the subcortical visual pathways using direct electrical stimulations. *Acta neurochirurgica, 146*(3), 265-270.
14. Eddy, C. M. (2017). Social cognition and self-other distinctions in neuropsychiatry: Insights from schizophrenia and Tourette syndrome. *Progress in Neuro-Psychopharmacology and Biological Psychiatry*.
15. Farrer, C., Franck, N., Georgieff, N., Frith, C. D., Decety, J., & Jeannerod, M. (2003). Modulating the experience of agency: a positron emission tomography study. *Neuroimage, 18*(2), 324-333.
16. Frith, C. D., & Frith, U. (2008). Implicit and explicit processes in social cognition. *Neuron, 60*(3), 503-510.

17. Frith, U., & Frith, C. (2010). The social brain: allowing humans to boldly go where no other species has been. *Philosophical Transactions of the Royal Society of London B: Biological Sciences, 365*(1537), 165-176.
18. Gogos, A., Gavrilescu, M., Davison, S., Searle, K., Adams, J., Rossell, S. L., . . . Egan, G. F. (2010). Greater superior than inferior parietal lobule activation with increasing rotation angle during mental rotation: an fMRI study. *Neuropsychologia, 48*(2), 529-535.
19. Gooding-Williams, G., Wang, H., & Kessler, K. (2017). THETA-Rhythm Makes the World Go Round: Dissociative Effects of TMS Theta Versus Alpha Entrainment of Right pTPJ on Embodied Perspective Transformations. *Brain topography, 30*(5), 561-564.
20. Gunther Moor, B., Op de Macks, Z. A., Güroğlu, B., Rombouts, S. A., Van der Molen, M. W., & Crone, E. A. (2011). Neurodevelopmental changes of reading the mind in the eyes. *Social cognitive and affective neuroscience, 7*(1), 44-52.
21. Hegarty, M., & Waller, D. (2004). A dissociation between mental rotation and perspective-taking spatial abilities. *Intelligence, 32*(2), 175-191.
22. Holloway, I. D., Price, G. R., & Ansari, D. (2010). Common and segregated neural pathways for the processing of symbolic and nonsymbolic numerical magnitude: An fMRI study. *Neuroimage, 49*(1), 1006-1017.
23. John, J. P., Halahalli, H. N., Vasudev, M. K., Jayakumar, P. N., & Jain, S. (2011). Regional brain activation/deactivation during word generation in schizophrenia: fMRI study. *The British Journal of Psychiatry, 198*(3), 213-222.
24. Jordan, K., Heinze, H.-J., Lutz, K., Kanowski, M., & Jäncke, L. (2001). Cortical activations during the mental rotation of different visual objects. *Neuroimage, 13*(1), 143-152.
25. Kana, R. K., Libero, L. E., Hu, C. P., Deshpande, H. D., & Colburn, J. S. (2012). Functional brain networks and white matter underlying theory-of-mind in autism. *Social cognitive and affective neuroscience, 9*(1), 98-105.
26. Kana, R. K., Maximo, J. O., Williams, D. L., Keller, T. A., Schipul, S. E., Cherkassky, V. L., . . . Just, M. A. (2015). Aberrant functioning of the theory-of-mind network in children and adolescents with autism. *Molecular autism, 6*(1), 59.
27. Khorashad, B. S., Baron-Cohen, S., Roshan, G. M., Kazemian, M., Khazai, L., Aghili, Z., . . . Afkhamizadeh, M. (2015). The "Reading the Mind in the Eyes" test: investigation of psychometric properties and test–retest reliability of the persian version. *Journal of autism and developmental disorders, 45*(9), 2651-2666.
28. Kolb, B., & Whishaw, I. Q. (2009). *Fundamentals of human neuropsychology*: Macmillan.
29. Koshino, H., Carpenter, P. A., Keller, T. A., & Just, M. A. (2005). Interactions between the dorsal and the ventral pathways in mental rotation: an fMRI study. *Cognitive, Affective, & Behavioral Neuroscience, 5*(1), 54-66.
30. Lamm, C., Batson, C. D., & Decety, J. (2007). The neural substrate of human empathy: effects of perspective-taking and cognitive appraisal. *Journal of cognitive neuroscience, 19*(1), 42-58.
31. Lampl, Y., Eshel, Y., Gilad, R., & Sarova-Pinhas, I. (1994). Selective acalculia with sparing of the subtraction process in a patient with left parietotemporal hemorrhage. *Neurology, 44*(9), 1759-1759.
32. Mars, R. B., Sallet, J., Schüffelgen, U., Jbabdi, S., Toni, I., & Rushworth, M. F. (2011). Connectivity-based subdivisions of the human right "temporoparietal junction area": evidence for different areas participating in different cortical networks. *Cerebral cortex, 22*(8), 1894-1903.
33. Meng, Z., Liu, C., Yu, C., & Ma, Y. (2014). Transcranial direct current stimulation of the frontal-parietal-temporal area attenuates smoking behavior. *Journal of psychiatric research, 54*, 19-25.
34. Milivojevic, B., Hamm, J. P., & Corballis, M. C. (2009). Functional neuroanatomy of mental rotation. *Journal of cognitive neuroscience, 21*(5), 945-959.
35. Molenberghs, P., Johnson, H., Henry, J. D., & Mattingley, J. B. (2016). Understanding the minds of others: A neuroimaging meta-analysis. *Neuroscience & Biobehavioral Reviews, 65*, 276-291.
36. Monte-Silva, K., Kuo, M.-F., Hessenthaler, S., Fresnoza, S., Liebetanz, D., Paulus, W., & Nitsche, M. A. (2013). Induction of late LTP-like plasticity in the human motor cortex by repeated non-invasive brain stimulation. *Brain stimulation, 6*(3), 424-432.
37. Nahab, F. B., Kundu, P., Gallea, C., Kakareka, J., Pursley, R., Pohida, T., . . . Hallett, M. (2010). The neural processes underlying self-agency. *Cerebral cortex, 21*(1), 48-55.
38. Nitsche, M. A., Cohen, L. G., Wassermann, E. M., Priori, A., Lang, N., Antal, A., . . . Fregni, F. (2008). Transcranial direct current stimulation: state of the art 2008. *Brain stimulation, 1*(3), 206-223.
39. Nitsche, M. A., & Paulus, W. (2000). Excitability changes induced in the human motor cortex by weak transcranial direct current stimulation. *The Journal of physiology, 527*(3), 633-639.

40. Nitsche, M. A., & Paulus, W. (2001). Sustained excitability elevations induced by transcranial DC motor cortex stimulation in humans. *Neurology, 57*(10), 1899-1901.
41. Peters, M., Laeng, B., Latham, K., Jackson, M., Zaiyouna, R., & Richardson, C. (1995). A redrawn Vandenberg and Kuse mental rotations test-different versions and factors that affect performance. *Brain and Cognition, 28*(1), 39-58.
42. Podzebenko, K., Egan, G. F., & Watson, J. D. (2002). Widespread dorsal stream activation during a parametric mental rotation task, revealed with functional magnetic resonance imaging. *Neuroimage, 15*(3), 547-558.
43. Rameson, L. T., Morelli, S. A., & Lieberman, M. D. (2012). The neural correlates of empathy: experience, automaticity, and prosocial behavior. *Journal of cognitive neuroscience, 24*(1), 235-245.
44. Rankin, K. P., Gorno-Tempini, M. L., Allison, S. C., Stanley, C. M., Glenn, S., Weiner, M. W., & Miller, B. L. (2006). Structural anatomy of empathy in neurodegenerative disease. *Brain, 129*(11), 2945-2956.
45. Rroji, O., van Kuyck, K., Nuttin, B., & Wenderoth, N. (2015). Anodal tDCS over the primary motor cortex facilitates long-term memory formation reflecting use-dependent plasticity. *PLoS One, 10*(5), e0127270.
46. Ruby, P., & Decety, J. (2004). How would you feel versus how do you think she would feel? A neuroimaging study of perspective-taking with social emotions. *Journal of cognitive neuroscience, 16*(6), 988-999.
47. Sakurai, Y., Hamada, K., Tsugawa, N., & Sugimoto, I. (2016). Ventral simultanagnosia and prosopagnosia for unfamiliar faces due to a right posterior superior temporal sulcus and angular gyrus lesion. *Neurocase, 22*(1), 122-129.
48. Santiesteban, I., Kaur, S., Bird, G., & Catmur, C. (2017). Attentional processes, not implicit mentalizing, mediate performance in a perspective-taking task: Evidence from stimulation of the temporoparietal junction. *Neuroimage, 155*, 305-311.
49. Saxe, R., & Powell, L. J. (2006). It's the thought that counts: specific brain regions for one component of theory of mind. *Psychological Science, 17*(8), 692-699.
50. Schurz, M., Radua, J., Aichhorn, M., Richlan, F., & Perner, J. (2014). Fractionating theory of mind: a meta-analysis of functional brain imaging studies. *Neuroscience & Biobehavioral Reviews, 42*, 9-34.
51. Seymour, R. A., Wang, H., Rippon, G., & Kessler, K. (2018). Oscillatory networks of high-level mental alignment: A perspective-taking MEG study. *Neuroimage, 177*, 98-107.
52. Shepard, R. N., & Metzler, J. (1971). Mental rotation of three-dimensional objects. *Science, 171*(3972), 701-703.
53. Steinvorth, S., Corkin, S., & Halgren, E. (2006). Ecphory of autobiographical memories: an fMRI study of recent and remote memory retrieval. *Neuroimage, 30*(1), 285-298.
54. Surtees, A., Apperly, I., & Samson, D. (2013). Similarities and differences in visual and spatial perspective-taking processes. *Cognition, 129*(2), 426-438.
55. Surtees, A. D. R., Apperly, I. A., & Samson, D. (2013). The use of embodied self-rotation for visual and spatial perspective-taking. *Frontiers in human neuroscience, 7*, 698.
56. Tavor, I., Yablonski, M., Mezer, A., Rom, S., Assaf, Y., & Yovel, G. (2014). Separate parts of occipito-temporal white matter fibers are associated with recognition of faces and places. *Neuroimage, 86*, 123-130.
57. Thakkar, K. N., Nichols, H. S., McIntosh, L. G., & Park, S. (2011). Disturbances in body ownership in schizophrenia: evidence from the rubber hand illusion and case study of a spontaneous out-of-body experience. *PLoS One, 6*(10), e27089.
58. Thye, M. D., Murdaugh, D. L., & Kana, R. K. (2018). Brain mechanisms underlying reading the mind from eyes, voice, and actions. *Neuroscience, 374*, 172-186.
59. Uddin, L. Q., Molnar-Szakacs, I., Zaidel, E., & Iacoboni, M. (2006). rTMS to the right inferior parietal lobule disrupts self–other discrimination. *Social cognitive and affective neuroscience, 1*(1), 65-71.
60. Vallar, G., & Perani, D. (1986). The anatomy of unilateral neglect after right-hemisphere stroke lesions. A clinical/CT-scan correlation study in man. *Neuropsychologia, 24*(5), 609-622.
61. van der Cruijsen, R., Peters, S., & Crone, E. (2017). Neural correlates of evaluating self and close-other in physical, academic and prosocial domains. *Brain and Cognition, 118*, 45-53.
62. Vandenberg, S. G., & Kuse, A. R. (1978). Mental rotations, a group test of three-dimensional spatial visualization. *Perceptual and motor skills, 47*(2), 599-604.
63. Völlm, B. A., Taylor, A. N., Richardson, P., Corcoran, R., Stirling, J., McKie, S., . . . Elliott, R. (2006). Neuronal correlates of theory of mind and empathy: a functional magnetic resonance imaging study in a nonverbal task. *Neuroimage, 29*(1), 90-98.
64. Walsh, V., & Pascual-Leone, A. (2003). *Transcranial magnetic stimulation: a neurochronometrics of mind*: MIT press.

65. Wang, H., Callaghan, E., Gooding-Williams, G., McAllister, C., & Kessler, K. (2016). Rhythm makes the world go round: An MEG-TMS study on the role of right TPJ theta oscillations in embodied perspective taking. *Cortex, 75*, 68-81.
66. Wang, Y., Shen, Y., Cao, X., Shan, C., Pan, J., He, H., . . . Yuan, T.-F. (2016). Transcranial direct current stimulation of the frontal-parietal-temporal area attenuates cue-induced craving for heroin. *Journal of psychiatric research, 79*, 1-3.
67. Wilde, D., & Murray, C. D. (2009). An interpretative phenomenological analysis of out-of-body experiences in two cases of novice meditators. *Australian Journal of Clinical and Experimental Hypnosis, 37*(2), 90-118.
68. Zarnhofer, S., Braunstein, V., Ebner, F., Koschutnig, K., Neuper, C., Reishofer, G., & Ischebeck, A. (2012). The influence of verbalization on the pattern of cortical activation during mental arithmetic. *Behavioral and Brain Functions, 8*(1), 13.
69. Zhen, Z., Fang, H., & Liu, J. (2013). The hierarchical brain network for face recognition. *PLoS One, 8*(3), e59886.