No Change in Emotion Recognition, Self-Other Distinction, or Set-Shifting Following Transcranial Direct Current Stimulation of the Right Temporoparietal Junction

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Abstract

Transcranial direct current stimulation (tDCS) is used as an experimental tool to establish how brain activity relates to cognition and behaviour by altering how specific brain areas function. The right temporoparietal junction (rTPJ) has been implicated in Theory of Mind processes, and tDCS studies have demonstrated this with a variety of different social cognition tasks. However, it is unclear what cognitive processes are being altered by tDCS due to inconsistent findings, and whether complex social effects are underlied by modulation of simple cognitive activities like set-shifting. This study used anodal, cathodal, and sham tDCS conditions to modulate the rTPJ whilst participants performed the Reading the Mind in the Eyes Task, a shape association self-other distinction task, and the Wisconsin Card Sorting Test in an effort to understand whether tDCS alters both basic and complex cognitive function originating in the rTPJ. Results showed no significant differences between anodal, cathodal, and sham tDCS conditions, as well as no significant differences between accuracy on the three tasks ($p = .05$). The efficacy of tDCS in typical individuals is therefore called into question, and there is exploration of a potential file-drawer problem which may be driving the overall positive research view of tDCS.

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Humans live highly complex social lives, where even the most straightforward interactions, such as greeting a friend, require many interconnected cognitive processes to occur very rapidly. When we interact with other people we are aware of the fact that they have thoughts, feelings, and desires that are different to our own, and we use this knowledge to inform how we communicate on a second by second basis. This highly adaptive and selective ability to impute the mental states of others is known as Theory of Mind (ToM), and it plays a key role in socialisation. Deficits in ToM, as shown by a reduced ability to imagine or predict how others' minds are working, can lead to frustrating and fruitless communication with others. Reduced ToM abilities are thought to contribute to social deficits in a wide range of disorders, and understanding the neural basis for ToM is important in helping people with deficits experience less distress from asynchronous social interactions.

Theory of Mind: in research and in the brain

In their seminal paper on chimpanzees' social abilities, Premack and Woodruff (1978) found that chimps were able to infer another chimp's purpose and beliefs about problem solving tasks, and termed this ToM. This investigation of social expertise led to a rise in behavioural research and theoretical work investigating how these skills work, what other cognitive processes they are associated with, and when these skills arise during development. Wimmer and Perner (1983) developed a new paradigm to study ToM abilities in children, termed a false-belief task,. This task required children to identify that a character in a story would in fact have a different view to the one the child expects, allowing the subject to accurately impute that character with a

belief. At age 5, over 90% of children were accurate in their assessment of the character's understanding. At age 6, all typically developing children were identified as correctly completing the task (Baron-Cohen, Leslie, & Frith, 1985). Autistic children, however, struggle with tasks where ToM is a key skill. The term 'second order representations' describes the ability to impute mental states on others by drawing from cues in their behaviour and presentation to imagine their emotional and cognitive states, a skill described as forming the basis for ToM (Baron-Cohen et al., 1985). Second order representations were shown to begin developing around age 2 in typical infants (Leslie, 1984). In autistic infants, these skills remain underdeveloped or not developed at all. This conclusion was identified by studies using false belief tasks, indicating that autistic children impute characters with their own beliefs, rather than understanding that the character did not have information available to them which would lead to them holding the child's own belief (Surian & Leslie, 1999). In addition to autism, those with attention deficit hyperactivity disorder, schizophrenia, and frontal brain damage have been investigated and repeatedly shown to have reduced ToM abilities, which can lead to dysfunctional and stressful social interactions as individuals cannot correctly identify beliefs and emotions (Duval, Piolino, Bejanin, Eustache, & Desgranges, 2011; Horat et al., 2018; Hughes & Leekam, 2004; Schaafsma, Pfaff, Spunt, & Adolphs, 2015; Zelazo & Müller, 2007).

Functional brain imaging has been used to isolate the neural basis of ToM. Functions theorised to be involved in the complex cognitive mechanisms of ToM include the ability to jointly share attention by observing and following someone else's gaze, the ability to distinguish between living and non-living objects, the ability to differentiate between the self and others, and the ability to represent goal-directed actions. In evidence of this, (Gallagher & Frith, 2003)

performed a systematic review with many functional neuroimaging studies, concluding that several distinct brain areas, reflecting the varied processes that go into ToM, were involved in ToM processing. The anterior paracingulate cortex, superior temporal sulcus, and the temporal poles were all strongly associated with complex, cooperative, and highly socially demanding ToM tasks. The orbitofrontal cortex and the amygdala also appear to be involved in these tasks, but it is possible that these areas are performing underlying processes that enable ToM processes to occur.

In addition to these findings, acquired deficits in ToM following brain damage in adulthood has given valuable insights. Frontal lobe (Bach, Happe, Fleminger, & Powell, 2000; Channon & Crawford, 2000; Rowe, Bullock, Polkey, & Morris, 2001) and amygdala damage (Shaw et al., 2004) have been shown to lead to impairments in ToM related tasks. Damage to these regions in both adulthood and childhood lead to worse performance on tasks relating to emotion recognition and social faux pas identification (Stone & Gerrans, 2006). Similarly, patients with behavioural variant frontotemporal dementia performed poorly on a task requiring participants to identify a social faux pas. Failure to identify these events indicated that degeneration of the anterior medial and orbital prefrontal cortex appears to reduce abilities to concretely imagine the mental states of others (Giovagnoli, Bell, Erbetta, Paterlini, & Bugiani, 2019). These findings, in combination with those from functional neuroimaging studies, demonstrate the variety of brain areas that are active and implicated in ToM processes.

One area that has been continually shown to play a role in ToM is the temporoparietal junction (TPJ). When neuroimaging studies originally looked at areas associated with ToM, the TPJ was discounted because its activity was high during false belief stories, in which ToM has to

be engaged to realise the other person holds different beliefs, as well as non ToM stories, which describe actions based on another person's beliefs that are the same as the participant's (Gallagher & Frith, 2003; Saxe & Kanwisher, 2003). However, this distinction does not take into account the fact that both stories require thinking about another person's mental states, and as such the TPJ has shown consistent involvement in tasks requiring ToM (Mars et al., 2012). The TPJ appears to not be involved in false representations in non-social stories, showing that it is directly involved in the false beliefs that other people hold rather than false notions that are separate from people's beliefs. This evidence, alongside further work showing the TPJ is involved specifically in thinking about the mental states of others as opposed to their physical states or the states of non-human objects, demonstrates the specific role that the TPJ has in the reasoning about the mental states of others (Saxe & Kanwisher, 2003). The role of the TPJ in ToM is now well established, with activity being related specifically to imputing others with mental states in a variety of paradigms (Mars et al., 2012; Wang, Callaghan, Gooding-Williams, McAllister, & Kessler, 2016).

However, the specific role of the TPJ continues to be contentious. It has been implicated in processes as varied as attention (Corbetta & Shulman, 2002), episodic memory retrieval (Vilberg & Rugg, 2008; Wagner, Shannon, Kahn, & Buckner, 2005), temporal processing (Davis, Christie, & Rorden, 2009), language and speech (Graves, Binder, Desai, Conant, & Seidenberg, 2010), resting state activity (Buckner et al., 2005; Greicius, Krasnow, Reiss, & Menon, 2003), vestibular function (Ventre-Dominey, 2014), alongside the evidence of its involvement in ToM. Attention and social cognition have drawn the most research attention, specifically in the right side (rTPJ) as activity here seems to be most strongly correlated with

these functions. Bottom-up and top-down attentional processes have both been linked with rTPJ activity (Decety & Lamm, 2007), as well as attention deficits on the left side of space (Ptak & Schnider, 2011). In other studies focused on social cognition substantial rTPJ activity is also seen (Gallagher & Frith, 2003; Saxe & Kanwisher, 2003) as well as in interrelated but distinct social constructs such as attribution of beliefs to others (Moran et al., 2011), imitation and control of imitation in social settings (Sowden & Catmur, 2015), and moral processing (Greene, Nystrom, Engell, Darley, & Cohen, 2004). Related functions such as self-other distinction and bodily-awareness processing have also been seen to activate the rTPJ (van der Meer, Groenewold, Nolen, Pijnenborg, & Aleman, 2011; Vogeley et al., 2001). From this broad range of cognitive processes it is clear that the rTPJ is not just involved in ToM, and in fact seems to play a range of roles, or perhaps has an underlying, more basic, function which enables its involvement in all of these processes.

tDCS and the rTPJ

Brain stimulation methods have been used more frequently over the last decade as a way of establishing a more causal link between neural activation and social abilities. This modulation of activity, often via transcranial direct current stimulation (tDCS), has further demonstrated that the rTPJ plays an active role in ToM abilities, both when accuracy on social tasks is improved with anodal stimulation (Santiesteban, Banissy, Catmur, & Bird, 2012) and when abilities are reduced with cathodal stimulation (Mai et al., 2016). tDCS work has also demonstrated that the rTPJ is involved in several of the aforementioned interrelated processes. One recent study looking at perspective taking, an important part of reasoning the mental states of others, identified that attentional processing is key, rather than implicit ToM ability, thus the rTPJ is

enabling for perspective taking to occur (Santiesteban, Kaur, Bird, & Catmur, 2017). This research has demonstrated that rTPJ contributes to social cognition specifically when perceivers must infer the beliefs of another person, and it has neglected substantial and crucial evidence that this region may also subserve a set of attentional processes that are not specific to social contexts. Increased rTPJ activity has also been noted when participants become distracted by stimuli that share a salient feature with a target, suggesting that this region selectively shifts attention away from stimuli that possess task-relevant features (Serences et al., 2005). In other research, the rTPJ seems to be involved more in shifting attention towards information relating to the self or others, rather than being involved in self other distinction as a whole (Hogeveen et al., 2015). These studies demonstrate further that rTPJ is not selective for ToM processes.

The role of tDCS in TPJ activation began as a purely experimental exploit and has developed quickly into a clinical tool for altering cognition in a variety of settings. tDCS has been extensively used to attempt to treat anxiety and depression, with varying degrees of success (Palm, Hasan, Strube, & Padberg, 2016), and is also now being investigated as a potential tool for altering and improving social function in autistic adults. The neuroanatomical differences that exist in autistic individuals when compared to typical individuals are characterised by significant localized grey matter reductions within fronto-striatal and parietal networks, decreases in ventral and superior temporal grey matter, and reduced white matter in the cerebellum, left internal capsule and fornices, reflecting anatomical differences in areas relating to social cognition (Hadjikhani, Joseph, Snyder, & Tager-Flusberg, 2006; McAlonan et al., 2005). These structural differences seem to reflect the functional difficulties that autistic people experience, and the potential for tDCS to improve social cognition through function alteration is an exciting one for

many. One case study of an 18 year old autistic man showed improvement in social function and in mood over 6 months after completing just 8 sessions of tDCS stimulation over the right TPJ, which has shown more involvement in ToM than the left (Esse Wilson, Quinn, Wilson, Garcia, & Tesche, 2017). While the authors are clear that this is merely a first step into the use of tDCS as a treatment for autism, many others have taken these results, and other corroborating studies, to propose that a straightforward, easily accessible, relatively low risk form of neuromodulation could be effective in ameliorating one of the key cognitive difficulties that autistic people face (Strang et al., 2012).

Despite this enthusiasm, the true effect of this form of stimulation on social and non-social taskis still unclear. Various studies have found it difficult to replicate findings that stimulation of the TPJ improves ToM abilities when studied using complex social tasks, as opposed to improving a broad range of attentional and self-other distinction processes that contribute to ToM (Andrew K. Martin, Huang, & Meinzer, 2018; Mitchell, 2008; Schuwerk, Schurz, Müller, Rupprecht, & Sommer, 2017). One study showed tDCS applied over the rTPJ improved perspective taking and imitation inhibition abilities but did not improve autism quotient score (Nobusako et al., 2017) and others show improvements in set-shifting, where participants have to simply change between operations or mental sets, as well as complex social tasks (Mitchell, 2008),. Yet there is limited consensus on how tDCS affects the rTPJ's ability to contribute to ToM, social engagement, and to the basic cognitive processes that underlie these abilities. This may be as a result of studies looking individually at either complex ToM tasks that involve emotional, social, and verbal reasoning to work together, or at simple, set-shifting tasks when stimulating the rTPJ when attempting to discover its role. There appears to be a gap in the

investigations of the intermediary stage of rTPJ function, particularly the social but not socially complex task of self-other distinction, in studies aiming to modulate the function of the rTPJ with tDCS. This incomplete investigation may, in part, be driving the incomplete and often highly varied results seen in this field.

The current work addresses this by including three different tasks, the Reading the Mind in the Eyes Task (Baron-Cohen, Wheelwright, Hill, Raste, & Plumb, 2001), a self-other distinction task (Sui, He, & Humphreys, 2012), and the Wisconsin Card Sorting Test (Barceló, Muñoz-Céspedes, Pozo, & Rubia, 2000). In this way it will be possible to compare the effects of tDCS between the three related but separate cognitive processes that the rTPJ is known to be instrumental in, and address the issue of inconsistent research findings when studies investigate just one of these three components, or look at only the most complex and the most simple. By incorporating three levels of complexity, and three interrelated by separate cognitive processes that contribute to social abilities, it will be possible to gain a nuanced understanding of the effect of tDCS on the rTPJ..

The main aim of the current study was to use tDCS to test the role of the rTPJ in a ToM related task, a less social and less complex task, and then a simple set-shifting task to assess to what degree tDCS modulates processes that the rTPJ is involved in. In doing so, two hypotheses will be investigated:

1. There will be a difference in task accuracy between the three stimulation types: anodal, cathodal, and sham.
2. There will be a difference in task accuracy across the three tasks: ToM, self-other distinction, and set-shifting.

Methods

Participants

The sample consisted of 54 adults between the ages of 18 and 33 participated in the study (mean age = 22; 23 females, no exclusions were made). Participants were recruited via posters in the University of Bath Psychology department, advertisements on the electronic notice board for staff and students and additionally via a snowball method. As participants were recruited, they were assigned in order to either the anodal, cathodal, or sham groups. The first participant was assigned to the anodal group, the second to the cathodal group, and so on, with 18 participants in each group (anodal: age range 18 to 33; mean age = 23; 8 females; cathodal: age range 19 to 32; mean age = 22; 9 females; sham: age range 19 to 33; mean age = 22; 6 females). They were all naive with respect to experimental hypotheses and remained unaware of what type of stimulation they received until after the experiment had ended.

Participants were asked to complete a safety assessment form (Appendix B) prior to signing a consent form. Extensive exclusion criteria were listed on this form to minimise risks associated with tDCS. Participants were not able to participate if they had undergone a neurosurgical procedure; if they had ever been diagnosed with epilepsy, experienced fainting spells, or had febrile convulsions in infancy; if they had a heart pacemaker, a cochlear implant, a medication pump, or a surgical clip; or if there was any chance they could be pregnant. A number of other questions were asked about medication, family history, personal history, and recent consumption of alcohol or drugs. Two participants taking medication to treat psychiatric conditions (sertraline; citalopram and propranolol) were included as there were no other

contraindications to participation indicated on their assessment forms. Three participants were included who had psychiatric conditions (depression and anxiety) that were well controlled and deemed not to be a confounding factor in the efficacy of tDCS.

The experimental procedures received full ethical approval from the University of Bath Department of Psychology Research Ethics Committee. Participants provided written informed consent after completion of the safety assessment form and read the study's information sheet, and provided a signature to show they had been fully debriefed once they completed the experiment prior to receiving payment of £8. These materials are available in the appendices (Appendix A-D).

Stimuli

Reading the mind in the eyes task (RMET, (Baron-Cohen, Wheelwright, Hill, Raste, & Plumb, 2001). The RMET consists of 36 black and white photographs of the eye region of faces taken from magazine photos. Each photograph was the same size (15 cm x 6 cm) and shows from the eyebrows down to midway along the bridge of the nose to ensure each picture is similar in composition. Participants are required to make a forced choice between four words, one correct answer and three distractors, that describe what the person in the photograph may be feeling.

For this study, to avoid practise effects, the RMET was split in half and administered as two separate parts. To ensure that these were as similar as possible an equal number of positive, neutral, and negative photographs were included in both parts. This emotional valence classification was taken from a pilot study which asked 12 undergraduate women from Queen's

University, Canada to rank the stimuli for emotional valence on a 7 point scale (Harkness, Sabbagh, Jacobson, Chowdrey, & Chen, 2005).

The size of the stimuli was altered to represent a similar area on screen (14.5 x 5.5cm) as was taken up on paper, with the four words resized to be the same composition as when on paper. Numbers 1 to 4 were assigned to each of the four words in a clockwise manner, and each number was placed directly before each word when appearing on the screen. Participants had 10 seconds in which to indicate their answer by pressing the relevant number on the keyboard in front of them. If they did not respond within this time frame the task moved on to the next picture. The task was run on a PC using E-Prime 2.0 software (Psychological Software Tools) by downloading the RMET stimuli pages (Baron-Cohen, Wheelwright, Hill, Raste, & Plumb, 2001).

Self-other distinction task (SOD, Sui et al., 201). The SOD was completed as a measure of self-other distinction using a shape association task. Using the procedure from Sui et al. (2012), participants were presented with a shape paired with a label on screen for 100ms, which may or may not have corresponded with the correct association shown at the beginning of the task. They were then shown a blank pale grey screen for a variable time, between 800 and 1200ms, in which time they responded by pressing one of the two response buttons (m and n, counterbalanced) as quickly and accurately as possible. Feedback (correct or incorrect) was presented on screen for 500ms at the end of each trial. Participants were informed of their overall accuracy at the end of each block, completing a total of three blocks of 120 trials after 12 practice. Throughout these trials, self, friend, and stranger occurred equally often.

On a pale grey background, three white geometric shapes (triangle, circle, and square, each 3.8 degrees x 3.8 degrees) were alternately presented. Below this, a white fixation cross (0.8

degrees x 0.8 degrees) was presented at the centre of the screen. Three white words ("you", "friend", and "stranger"; each 3.1 degrees/3.6 degrees x 1.6 degrees) were alternately presented below this. For each iteration of the task the correct associations were counterbalanced and presented to the participant on screen prior to the practice trial. The experiment was run on a PC using E-Prime 2.0 software (Psychological Software Tools).

Wisconsin card sorting test (WCST Computerised; Stoet, 2010, 2017). The WCST consists of four static category cards and a pile of stimulus cards. All of the cards are multidimensional, according to colour (C), shape (S), and number (N), with each of these dimensions acting as a matching rule. The participant is asked to match each stimulus card as it appears with one of the four category cards. They are required to use trial and error to discover the preordained matching rule based on feedback. After 10 consecutive correct matches, the matching rule changes to one of the other two dimensions. Participants have up to six attempts to derive a rule, providing five rule shifts (C-S-N-C-S-N), with each rule attainment referred to as 'completing a category'.

Stimuli were presented on a black screen (25cm x 20cm). Each new card was presented for 10 seconds, in which participants selected their chosen category card from the four available by using the left click on the computer mouse. After each selection, a black screen with the feedback word ("Correct" or "Incorrect") was displayed, in tandem with a high pitched sound when correct and a short low tone indicating incorrect respectively. If the participant did not select a card within the time frame, they were shown feedback as if they selected an incorrect option. The task was completed when all 128 cards are sorted, irrespective of accuracy and

completion of rule shifts. This version was downloaded from the psytookit online testing resource (Stoet, 2010, 2017).

tDCS Stimulation

Simulation of electrical current. A computer generated simulation of how tDCS would affect the brain with electrodes on different points of the skull was completed prior to deciding which area to put the secondary electrode. CP6 was chosen as the placement for the electrode stimulating the rTPJ, but the placement of the second electrode varies from vertex to left cheek, deltoid, and others (Ferrucci et al., 2008; Friedrich et al., 2019; Tremblay et al., 2014). Placement of the second electrode is important, as avoiding stimulating other structures involved in high level cortical function could impact performance by enabling areas other than the rTPJ to perform more effectively.

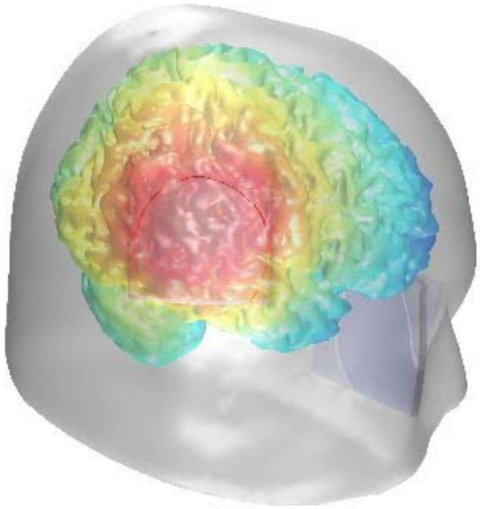

Figure 1. COMETS generated simulation of current density with 2ma when anodal electrode is at CP6 and cathodal electrode is on the left cheek.

The MatLab program COMETS (Jung, Kim, & Im, 2013) was used to simulate the electrical field of two versions of tDCS stimulation: vertex and left cheek (deltoid was not possible in this program). The results of these simulations (Figure 1) indicated that placing the secondary electrode on the left cheek meant the current density was focused over CP6, which was the target location intended to be stimulated. It also indicated that electrical field did not extended to cover the whole motor cortex as vertex simulations had done, making this a preferable location to minimise stimulation that may interfere with task performance. Therefore, the left cheek was chosen as the secondary electrode location for this study.

Equipment and preparation. A DC-Stimulator Plus was used with a battery-driven tDCS Equipment Electrode Set (NeuroConn GmbH, Ilmenau, Germany) to generate the stimulation. The electrode set consisted of two electrode cables to connect the tDCS stimulator to the electrodes and two 5cm² conductive rubber electrodes which were inserted into corresponding 5cm² sponges. The sponge-electrodes were soaked in saline solution until very moist, then secured to the head using a wide, elasticated headband under the chin and over the top of the head.

The electrodes were positioned according to the International 10-20 system for EEG electrode placement (Herwig, Satrapi, & Schönfeldt-Lecuona, 2003). The vertex was found and marked with a non-permanent marker to ensure that the orientation of the cap was correct prior to establishing the electrode location. A blank EEG cap was used to mark out the position of CP6, the location to stimulate the rTPJ in many studies (Santiesteban et al., 2017), before placing an electrode over it. In the anodal and sham conditions, the anodal electrode was placed over

CP6 and the cathodal electrode was placed on the left cheek. In the cathodal condition, this was reversed.

Stimulation protocol. In the anodal and cathodal stimulation conditions, a current strength of 2mA was applied over 1200 seconds (20 minutes) with a ramp-up and ramp-down period of 15 seconds. The stimulation began when the participant completed the first round of tasks, and was carried out for 5 minutes prior to beginning the second round of tasks. The entire second round was typically complete immediately prior to the stimulation ending.

In the sham stimulation condition, the same protocol was followed but the ramp-up period was immediately followed by a ramp-down period, with only 30 seconds total of the device being active. This was to produce the initial feeling of stimulation but not invoke any cortical changes.

At the start of each tDCS stimulation session the small display window on the stimulator was checked to ensure that the device was working correctly. The stimulator is designed to cut out at 26 V, making a loud beep sound and turning off immediately if this threshold is reached. If the threshold was reached, more saline solution was applied under the electrode to ensure stimulation could take place uninterrupted through the entire study.

Procedure

Upon arrival, participants were provided with an information sheet on tDCS, completed a safety assessment form, and provided written informed consent. They were told they would be receiving brain stimulation and were not told about the possibility of a sham condition. Any questions about the type of stimulation they were going to receive were deferred until after the task. They were then seated 60 cm away from the computer screen. The tDCS equipment was

then set up by attaching the active electrode (anodal or cathodal in line with condition, anodal for sham condition) over the CP6 region of the skull and the second electrode to the left cheek with a wide hair band, ensuring that the participant was comfortable before continuing.

Participants were then given an instructional sheet and verbal instructions on what each of the three tasks consisted of, and completed each of them once. Between each task they were free to ask questions about what the next task would entail. They were then all told that the tDCS equipment would be switched on, and reminded that they may feel some tingling or itching sensations on their head and this would quickly dissipate. If the voltage limit was reached, further saline solution was added to ensure good contact of the electrodes. Participants then had a five minute break, in which they stayed seated and were free to chat with the experimenter or read the information sheet further. They then completed the three tasks again, with the second set of RMET stimuli and counterbalanced versions of the other tasks. Once this was complete, participants received a debrief sheet and payment of £8. They were then able to ask further questions about the aim of the research or about tDCS.

Results

Data Treatment

For the final accuracy scores, a difference score was computed by subtracting task accuracy before stimulation from task accuracy during stimulation. Due to the mixed between-within groups design of the present study, a mixed analysis of variance was carried out after the appropriate statistical assumptions were proven to be met.

Histograms revealed that the data consistently followed a normal distribution within variables, suggesting the assumption of normality had been met. Levene's test of equality of

error variances, used to establish homogeneity of variance, was non significant for the computed RMET (p = .721), SOD (p = .241), and WCST accuracy difference scores (p = .385). This suggests the data was gathered from populations with equal variances, therefore meeting the assumption of homogeneity of variance across groups. The significance of the test of equality of the variance-covariance matrices (Box's M) was non-significant (p = .718) meaning the assumptions for the planned mixed between-within subjects analysis of variance were not violated. Gender was included as a covariate due to findings suggesting it may influence ToM abilities in tDCS tasks (A. K. Martin, Huang, Hunold, & Meinzer, 2017)**.**

Inferential Statistics

A 3x3 (stimulation type x task) mixed between-within subjects analysis of variance was conducted to assess the impact of three different stimulation types (anodal, cathodal, and sham) on participants' performance on three tasks (RMET, SOD, and WCST) tested to a significance level of $p < .05$. Results showed there was no significant interaction between task and gender, a covariate, (Wilks Lambda = .949, $F(2, 49) = 1.328$, p = .274, partial eta squared = .051) or between task and stimulation type (Wilks Lambda = .894, $F(4,98) = 1.415$, p = .235, partial eta squared = .055). Moreover, there were no main effects regarding task (Wilks Lambda = .91, $F(2, 49) = 2.286$, p = .112, partial eta squared = .085), stimulation type ($F(2, 50) = 1.404$, p = .255, partial eta squared = .053), and gender ($F(1, 50) = .421$, p = .520, partial eta squared = .008). This indicates that no form of stimulation altered task performance, and there was no difference in task performance as a consequence of that stimulation (descriptive statistics seen in Table 1). The first hypothesis, that there will be a difference in task accuracy between stimulation types, should therefore be rejected in favour of the null hypotheses.

Table 1

Average Difference Score Across Stimulation Type And Task

	Task								
	RMET			SOD			WCST		
Stimulation type	n	M	SD	n	M	SD	n	M	SD
Anodal	18	.056	.119	18	-.029	.091	18	-.039	.060
Cathodal	18	.040	.112	18	.024	.089	18	-.007	.059
Sham	18	.037	.121	18	-.055	.135	18	-.010	.046

The between-groups test in the mixed ANOVA transformed the three accuracy difference scores from each of the three tasks into one transformed difference score when investigating the effect of stimulation type on task accuracy, thus failing to take into account that the three tasks measured three conceptually different characteristics and therefore three independent effects. As such, a one way ANOVA was administered to investigate the effect of stimulation type on task accuracy to give an analysis of each task independently as opposed to the holistic analysis provided by the mixed ANOVA.

There was no significant difference between groups on the RMET ($F(2,53) = .129$, $p = .880$, eta squared = .005), SOD ($F(2,53) = 2.591$, $p = .085$, eta squared = .092), or the WCST ($F(2,53) = 1.829$, $p = .171$, eta squared = .067). This indicates that there was no effect of stimulation on task performance even when the accuracy scores remained untransformed and the third hypothesis should also be rejected in favour of the null. However, a high F score on the between-subjects effect of stimulation on SOD performance does indicate that there is a potential effect here, if the present study had greater statistical power. Despite this mild trend, there are no

significant results from any of the conducted analyses and the experimental hypotheses should both be rejected.

Discussion

The aim of this study was to incorporate three levels of complexity when investigating ToM and related processes to understand in more detail the effect of rTPJ stimulation by way of tDCS. In this study anodal, cathodal, and sham tDCS stimulation were used to modulate task performance on three different tasks addressing related but separate cognitive processes associated with ToM. The study was designed to provide answers to two hypotheses: There will be a difference in task accuracy between the three stimulation types: anodal, cathodal, and sham; there will be a difference in task accuracy across the three tasks: ToM, self-other distinction, and set-shifting.

In this instance, within this population, there were no statistical findings to suggest that any differences were present. These findings fall into line with recent work which did not demonstrate a measurable change in various forms of cognition following tDCS (Blair-West, Hoy, Hall, Fitzgerald, & Fitzgibbon, 2018; Claus, Klimaj, Chavez, Martinez, & Clark, 2019.; Friedrich et al., 2019; Jacoby & Lavidor, 2018; Westwood & Romani, 2018). The current results show that stimulating the rTPJ may not be an effective method for altering social cognition or executive functioning in typical individuals, and add to mixed results of tDCS efficacy in the literature.

Discussion of Null Results

As discussed above, no significant differences were found and neither of the hypotheses can be accepted. Firstly, no differences were found in task accuracy between the three

stimulation types: anodal, cathodal, and sham. The study used three forms of stimulation to provide a full picture of the ways in which tDCS can affect participants, especially in the context of highly varied findings with regard to whether anodal, cathodal, or neither active forms of stimulation provided any change in cognition. The existing literature provides a dim view on the consistency of tDCS effects, as findings have been difficult to replicate and an inability to produce improved ToM skills in typical people for some research groups has proved no issue for others (Blair-West et al., 2018; Friedrich et al., 2019; A. K. Martin et al., 2017; Westwood & Romani, 2018). Further exploration in the form of a one way ANOVA did show a small trend indicating a statistically significant difference in performance between stimulation types may have been attainable with a larger sample size. However, sample sizes in this paper matched those of recent, similar studies, and a much larger group would have risked overpowering the study and producing results indicating an effect exists where there is none (Santiesteban et al., 2017; Westwood & Romani, 2018).

The second hypothesis, that there would be a difference in task accuracy across the three tasks: ToM, self-other distinction, and set-shifting, was also unsupported by the results. This is a particularly surprising finding as the tasks measure demonstrably different cognitive processes (Channon & Crawford, 2000; Lamm C., Bukowski H., & Silani G., 2016; Nakahara, Hayashi, Konishi, & Miyashita, 2002). However, findings of this nature are not unheard of, and as participants moved quickly from one task to another they may have been more influenced by their state of mind, overall cognitive abilities, and motivation towards task performance leading to a non significant difference. The tasks were also specifically chosen as interrelated and

varying in complexity but ultimately orienting towards the same cognitive processes, so the lack of significant difference here may be as a result of other factors.

tDCS mechanisms. The findings of this study give rise to several questions about how tDCS work is represented in the literature. There is a sense, in some instances, that the process by which stimulation enters and modulates neural states is thoroughly understood, but there is no one agreed upon explanation for how the current impacts cognition. A broad range of models have been outlined to explain the in/efficacy of tDCS in studies and clinical practice (Fertonani & Miniussi, 2017). Some studies show anodal improving task performance, cathodal reducing it, and sham doing nothing to performance at all, fitting the commonly used anodal excitation cathodal inhibition model of tDCS. While this model may be the case in some studies, it is also frequently reported that cathodal stimulation improves cognition just as much, if not more, than anodal stimulation (Antal, Kincses, Nitsche, Bartfai, & Paulus, 2004; Antal, Kriener, Lang, Boros, & Paulus, 2011), instead fitting the stochastic-resonance approach which predicts that an addition of noise to nonlinear systems may enhance or worsen the signal detection depending on the relations between the state of the signal. Likewise, cathodal has been seen to reduce activation in a certain area but anodal not improve activation in the same study (Nikolin, Lauf, Loo, & Martin, 2019). The competing theories for how tDCS affects the brain all attempt to explain why seemingly conflicting results are frequently found, but ultimately none of them are falsifiable with current technology. One should recall that it would be very unexpected that the stimulation of a complex system (i.e., a self-organizing, non-linear, and dynamic system) such as the human brain would result in simple, predictable behavioral outcomes. The ineffectiveness of tDCS in the current study may reflect an interaction between study design and tDCS mechanics

that is not well understood, resulting in null findings when an alternative design may have yielded significant results.

In addition, there does not seem to be consistency across brain area on how stimulation impacts cognition, and there are studies using very similar procedures which show that different forms of stimulation significantly modulated cognition (Esse Wilson, Trumbo, Wilson, & Tesche, 2018; Mai et al., 2016; Andrew K. Martin et al., 2018). Fertonani and Miniussi's paper on tDCS mechanisms reveals that very little is known about how far ranging, impactful, and consistent tDCS is (2017). The broad range of results found when stimulating just one brain area bring to the fore the concept that tDCS produces effects that are not well understood. The current study's null findings could be a result of an overgeneralisation of tDCS methods to be used on brain areas that do not respond simplistically to stimulation.

Publication bias and HARKing. If these findings are indeed valid, taking into account the possible limiting factors, then it is pertinent to address the fact that there are very few published studies with null findings. It is impossible to tell where these findings sit within the wider picture of tDCS and social cognition and to establish the efficacy of tDCS on the TPJ if the vast majority of papers published have highly significant effects, representing just a portion of the results that exist from papers worldwide. The results here may be a more realistic depiction of tDCS over the TPJ than previously thought when examining the extant literature. According to the range of possible outcomes when an effect is present, at least 5% of studies conducted on an effect will show nothing. This is not proportional to the number of studies published concerning null effects. When a literature search was conducted on PubMed using the terms "tDCS null", "tDCS no", and "tDCS does not" to find tDCS studies that reported null findings,

only 78 papers were found. While this is not an exhaustive search, and a true literature review driven meta-analysis would provide a clearer understanding, it would not be unusual for this field to be subject to the file drawer problem seen in vast swathes of psychological and clinical research journals. The study may be one of many which is affected by unpublished, well designed studies which could be building a more accurate understanding of the efficacy of tDCS, but instead remain unseen.

rTPJ subregion function. Three discernible areas seem to be functionally linked to other regions of the brain, and perform slightly different cognitive processes. A dorsal area in the middle part of the inferior parietal lobule has shown resting-state functional connectivity with, among other areas, the lateral anterior prefrontal cortex. Ventrally, an anterior TPJ cluster interacts with ventral prefrontal cortex and anterior insula, while a posterior TPJ cluster interacted with posterior cingulate, temporal pole, and anterior medial prefrontal cortex. These results indicate that TPJ can be subdivided into subregions on the basis of its structural and functional connectivity (Mars et al., 2012). However, due to a lack of spatial specificity, when tDCS is performed over this region it is unclear whether all regions are being activated equally, or whether the activity of some take precedence over others.

The large area stimulated when tDCS is applied means that several subsections of the TPJ may be being activated simultaneously. The anterior portion of the rTPJ has been identified as dominating set-shifting, and the posterior rTPJ is involved in social interaction capabilities, but they rarely work in isolation (Mars et al., 2012). This implies that ToM may be rooted in attention shifting, and that this link between the two processes seem in development, where children with strong attentional capacities at an early age tend to have high level social cognition

at a later age, is functionally as well as structurally present (Jones, Gliga, Bedford, Charman, & Johnson, 2014; Rothbart, Sheese, Rueda, & Posner, 2011). It is possible that no significant differences were found between tasks because all subregions of the rTPJ were simultaneously stimulated.

Possible Limitations

Study design. The current study varies somewhat from existing ToM stimulation work. Instead of using a straightforward between groups design, where each of the three participant groups received one form of stimulation with no non-stimulation condition, this study used a between-within groups design. This was chosen so a difference score could be generated using the baseline measure of competence in these ToM related tasks, so that the magnitude of the efficacy of tDCS as a cognitive modulation tool could be investigated. In an ideal situation, this would have been reflected in two separate sessions for each participant, separated by at least a week to reduce practise effects from the tasks.

Due to time constraints, both the non-stimulation and stimulation conditions were performed in the same session with just a five minute period of stimulation prior to beginning the second round of tasks, and ten minutes of stimulation ongoing throughout the second round. Five minutes of stimulation has been shown to cause a large degree of cognitive modulation, so this was deemed an appropriate length of time to ensure that testing sessions remained under 1 hour long (Nitsche et al., 2003). Although the typical length of stimulation is 15-30 minutes prior to task completion to ensure that the brain area targeted is still under the effects of stimulation throughout the entire task, the three tasks took less than 15 minutes to complete and required a much smaller time frame for stimulation effects to be taking place. It is possible that this short

stimulation time is responsible for the lack of significant results, but this seems unlikely as other work stimulating the TPJ has used similarly short stimulation protocols (Paulus, 2011). The length of stimulation time, as long as it is over 5 minutes, does not seem to impact the magnitude with which a brain area is stimulated, only impacting the length of time the stimulation lasts (Nitsche et al., 2003). For this reason it seems unlikely that this study design impacted the outcome and caused the null findings.

Reading the mind in the eyes task. There is some suggestion that the RMET may not be the most effective measure of ToM abilities. The RMET requires participants to read emotional states by detecting subtle facial cues, an ability more frequently used to investigate emotion recognition. This poses a problem for alexithymic participants who may have considerable ToM ability but are simply unable to interpret and understand facial cues, especially in isolation as static images. The task also requires high levels of verbal ability, as those who were unable to understand one or more of the adjectives available to them were unable to give informed responses. A recent study demonstrated that alexithymia, but not autism diagnosis, influenced RMET performance but did not affect performance on a ToM measure which did not require emotion recognition (Oakley, Brewer, Bird, & Catmur, 2016). These findings call into question whether the RMET is a true ToM test, and instead posit that it investigates emotion recognition instead. The majority of other ToM measures require contextual information or dynamic behavioural cues to be used when making judgements about others, a distinctly different method which may yield a more ecologically valid result (Baron-Cohen, Jolliffe, Mortimore, & Robertson, 1997; Dziobek et al., 2006). Therefore, the ToM measure used in the current study

may have not measured in the most appropriate way, and one with more ecological validity would have allowed for a more appropriate assessment of participants ToM abilities.

However, even as an emotion recognition measure the RMET still provides insight into the dissociable roles of the rTPJ when under tDCS stimulation. The SOD task represented a very distinct form of social processing to the RMET, and the WCST a strong measure of attentional and set-shifting abilities. While there may have been preferable alternatives to the RMET that do not involve emotion recognition or high verbal ability, including the Movie for the Assessment of Social Cognition (Dziobek et al., 2006), the time constraints of this study meant that a brief task was much better suited. The types of cognitive processes required for each of the three tasks were still broadly related to ToM and did not overlap with one another, providing the detailed investigation that this study aimed to carry out.

Ceiling effect. Finally, the tasks chosen may have simply been too straightforward for the participants, thus creating a ceiling effect whereby any stimulation they received would not have positively impacted their performance and created a difference between non-stimulation to stimulation conditions. This is a strong possibility as the mean accuracy for each of the three tasks in the first round was around 70-80% (RMET = 74%, SO = 69%, WCST = 82%). This level of performance may make any further improvement difficult to ascertain as the increase in accuracy may be negligible due to having very few inaccuracies to improve upon, and ceiling effects in tDCS studies have been noted before (Furuya, Klaus, Nitsche, Paulus, & Altenmüller, 2014).

However, in similar research using tDCS to improve social cognition, with significant results and high effect sizes, accuracy levels are not substantially different from the ones seen

here, ranging around 75-90% (Mai et al., 2016). It is possible that the ceiling effect was present partly due to the nature of the population studied, as all participants were either students or staff members at an academically highly ranked university. Despite this, much statistically significant work has come out of universities using similar recruitment methods who also rank as highly as the University of Bath, such as Cambridge University, so this seems an unlikely source of the null effect (Santiesteban et al., 2012, 2017). It seems as though the accuracy scores being particularly high at the non-stimulation condition may have contributed somewhat, but it is still important to note that there were no differences between anodal, cathodal, and sham conditions. If a ceiling effect were present then it is possible there would likely have been a drop in performance in the cathodal condition and a small, even if non-significant, rise in performance in the anodal condition. This was not the case, implying further that the lack of significance was not a result of the participants' task accuracy.

Conclusion

The current study had no significant findings to suggest that tDCS over the rTPJ modulated social cognition and related cognitive processes. In addition, anodal, cathodal, and sham stimulation were all as ineffective in producing a change in task accuracy as one another, calling into question the efficacy of tDCS as a cognitive modulation tool. These findings provide insight into conditions where tDCS may not be a useful experimental or clinical tool to bring about change in neural processing.

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Appendix A

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Ethical approval code PREC 18-290

Effects of tDCS on rTPJ function on theory of mind and related tasks

You are being invited to volunteer in a research study which involves transcranial direct current stimulation (tDCS). Before you decide to take part in this study, it is important for you to understand what the research will involve. Please do not hesitate to ask us if there is anything that is not clear or if you would like any more information. You are free to withdraw from the study if you decide you do not want to participate.

What is involved in this study
This research aims to understand more about how one area of the brain, the right temporoparietal junction (rTPJ) is involved in thinking about ourselves and other people. You will be asked to complete a set of computer based tasks two times, once normally and once with the brain stimulation equipment switched on. The tasks will involve straightforward questions or situations that you will see on the computer screen. The study will last approximately one hour.

What is tDCS
Transcranial direct current stimulation, known as tDCS, is a non-invasive, safe, painless technique for stimulating the brain. It involves delivering a small electrical current (below 2mA) through an electrode placed on the scalp, with a second electrode on the cheek as a reference point. It is a reliable technique used in universities and hospitals around the world to investigate and improve brain function, and is considered safe for use in neurologically healthy individuals.

What are the risks
The most common side effects are brief tingling or light itching sensations. These effects typically occur at the beginning of the stimulation and disappear quickly. Sometimes people experience a low level, short headache. In rare cases tDCS might lead to nausea or dizziness. If you feel pain, nausea, or other discomfort during the procedure please alert the experimenter immediately so that testing can be stopped. tDCS does not cause epileptic seizures and does not make them more likely to happen in most people. It is important that you inform the researcher if you have ever had a seizure. A short questionnaire will determine if you have any of the other known risk factors.

Your data
All information collected about you during this research will be kept strictly confidential. There is no record that links the data collected from you with personal data from which you could be identified (i.e. the signed consent form).

If you decide to take part
You will be asked to sign a safety assessment form and a consent form. You are still free to withdraw from the study at any point up until the end of the testing sessions, as your data will be anonymous after this. If you decide to withdraw at any time during the testing you do not have to give a reason and there will be no repercussions. Upon completion of the sessions we will reimburse you £8 for taking part in the research, and you can ask any remaining questions you may have.

If you would like to take part in the study or if have any questions about it, please contact:
Zoë Freeman - zclf20@bath.ac.uk

If you have any concerns related to the ethics of this study please direct them to the Psychology Research Ethics Committee.
Email: psychology-ethics@bath.ac.uk
Telephone: 01225 384322

Appendix B

Transcranial Current Stimulation (TCS)
Safety Assessment Form

Department of Psychology | UNIVERSITY OF BATH

To be completed BEFORE signing the consent form

Participant ID: Date:

Screening Researcher:

1	Have you ever suffered from epilepsy, febrile convulsions in infancy or had recurrent fainting spells?	Yes	No
2	Have you ever undergone a neurosurgical procedure (including eye surgery)? **If YES please give details**	Yes	No
3	Do you currently have any of the following fitted to your body? (please circle) Heart pacemaker Cochlear implant Medication pump Surgical clips	Yes	No
4	Is there any chance you might be pregnant?	Yes	No
5	Have you ever suffered from any neurological or psychiatric conditions? **If YES please give details (nature of condition, duration, etc).**	Yes	No
6	Are you currently taking any unprescribed or prescribed medication, including antimalarial treatment? **If YES please give details.**	Yes	No
7	Does anyone in your immediate or distant family suffer from epilepsy? **If YES please state your relationship to the affected family member.**	Yes	No
8	Have you drunk more than 3 units of alcohol in the last 24 hours?	Yes	No
9	Have you drunk alcohol already today?	Yes	No
10	Have you had more than one cup of coffee, or other sources of caffeine in the last hour?	Yes	No
11	Have you used recreational drugs in the last 24 hours?	Yes	No
12	Have you already participated in a tDCS experiment in the last week?	Yes	No

Appendix C

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UNIVERSITY OF BATH

CONSENT FORM

Effects of tDCS on rTPJ function on theory of mind and related tasks

Please answer the following questions to the best of your knowledge

Are you aged 17 or over?	YES	NO
Have you been given information explaining the study?	YES	NO
Have you had an opportunity to ask questions and discuss this study?	YES	NO
Have you received satisfactory answers to all your questions?	YES	NO
Have you received enough information about the study for you to make a decision about your participation?	YES	NO
Do you understand that you are free to withdraw from the study at any time during the session and are free to withdraw your data prior to final consent?	YES	NO
Do you understand that you can withdraw without having to give a reason?	YES	NO

I hereby fully and freely consent to my participation in this study

I understand the nature and purpose of the procedures involved in this study. These have been communicated to me on the information sheet accompanying this form.
I understand and acknowledge that the investigation is designed to promote scientific knowledge and that the University of Bath will use the data I provide for no purpose other than research.
I understand the data I provide will be **anonymous**. No link will be made between my name or other identifying information and my study data.
I understand that the University of Bath may use the data collected for this study in a future research project but that the conditions on this form under which I have provided the data will still apply.

Participant's signature: _____ Date: _____

Name in BLOCK Letters: _____

If you have any concerns related to the ethics of this study please direct them to the Psychology Research Ethics Committee.
Email: psychology-ethics@bath.ac.uk
Telephone: 01225 384322

Appendix D

Debriefing Information

Thank you for taking part in this project which has been investigating the effect of tDCS on social and non-social tasks regarding the self and others.

We are aware that some of the people who take part in this project may find information about tDCS and its effects useful. Below is a list of organisations and websites that may contain information useful to you.

For information on tDCS - https://www.frontiersin.org/articles/10.3389/fnins.2017.00641/full

For papers regarding brain stimulation - http://www.brainstimjrnl.com/

Thank you again for participating. If you would like to speak to us or ask us any questions about the project please get in touch.

Researcher - Zoë Freeman

Email – zclf20@bath.ac.uk

Project supervisor - Dr Chris Ashwin

Email – c.ashwin@bath.ac.uk Telephone – 01225 383502

Address: Department of Psychology, University of Bath, Claverton Down, Bath, BA2 7AY

……

I confirm I have received £8 for participating in the University of Bath project 'Effects of tDCS on rTPJ function on theory of mind and related tasks'.

Signed……

Date……

Researcher's signature……

Date……

If you have any concerns related to the ethics of this study please direct them to the Psychology Research Ethics Committee.
Email: psychology-ethics@bath.ac.uk
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