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The Role of the Right Temporoparietal Junction in Social Cognition: A Transcranial Direct Current Stimulation Study.

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Personal Statement

The control of imitation task was used in the form that was previously designed by Sophie Sowden and Caroline Catmur (2013). The time plan and procedures were carried out by Dr Geoff Bird and Sophie Sowden. The research was carried out by Katerina Capouskova and Sophie Sowden (participant recruitment, Transcranial Direct Current Stimulation and computerized task administration). Data analysis was done by Katerina Capouskova under the supervision of Sophie Sowden. The report was written by Katerina Capouskova with the support of Sophie Sowden.

Abstract

The ability to control the perspective of the self and the other is a fundamental process in social cognition. Previous studies declared that the right temporoparietal junction (rTPJ) is one underlying brain region responsible for this ability (Brass et al., 2000a, 2005a). Also, broadly debated is whether the control of self and other representations is a process specific for social situations or domain-general; also covering non-social situations. In this study (Mitchell, 2008) transcranial direct current stimulation (tDCS) was used to modulate activity in the rTPJ, and a mid-occipital control site, prior to the completion of a computerized task measuring the ability to control behaviour at a social (imitative) and non-social (spatial) level. Consequently, the task provides an estimation of whether the role of the rTPJ is domain-specific to social cognition or domain-general by calculating compatibility effects for imitative and spatial dimensions of the task. Spatial and imitative compatibility effects were observed in error and response time data, however no significant effect of stimulation was found. Nevertheless, numerical differences in both effects between rTPJ and MO stimulation tentatively support a domain-general account of rTPJ involvement in this pilot sample. This is contrary to previous research (Sowden and Catmur, 2013) and possible reasons for these contradictory findings are discussed.

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1 Introduction

Social cognition explains our ability to decode, process, and manipulate information gained from social interaction. In relation to human action, it is well established that the same neural cluster processes an action in our brain not only during the performance of an action, but also during the observation of the same action performed by another human creating shared representation. However, another basic aspect of social cognition is also the distinction and consecutive control of these shared representations: the self and the other (Iacoboni et al., 1999; Molenberghs et al., 2012). This distinction or switching mode between self and other neural representations is important in situations when we have to acquire another's perspective by inhibiting one's own representation or when we have to inhibit the other's representation in a situation that requires the enhancement of the self. Perspective taking is an 'either-or' situation when one has to choose between taking the perspective of the self or the other. This 'self-other' control serves as an ability necessary in social situations.

Theory-of-mind (ToM) tasks showed the necessity of ascribing mental states like beliefs and desires to the other inferred from their perspective rather than from one's own (Gopnik and Wellman, 1992). False belief tasks have proven that children are able to ascribe other people's propositional attitudes around the age of four (Flavell, 2004) when they are able to distinguish between their own perspective and the perspective of their peers. Another important ability in social interaction that is vital for the 'either-or' situation characteristic of perspective taking is the control of imitation. In order to perform one's own actions, we

must inhibit the motor representation held for the other[1] and enhance the representation for the self (Chartrand and Bargh, 1999; Bargh and Williams, 2006). The control of imitation functions as either inhibitory or excitatory (changing between) according to the needs of a specific social situation. Meaning, either the self-perspective is inhibited or excited with complementary excitation or inhibition of the other's action.

Even though social interaction is processed on many cognitive levels, evidence has shown that there might be this underlying lower-level process of switching between the representations of the self and the other (self-other control). This can happen in forms of visual, bodily, or mental/emotional states (Decety and Lamm, 2007; Cazzato et al., 2014; Luo et al., 2014), serving the needs of a specific social situation.

Previous evidence has shown that we possess a 'shared representational system', which activates the corresponding neurones when we observe an action and also when we execute that action (Prinz, 1997). The neural basis of the self-other distinction ability has been researched based on the 'shared representations', looking for the ability to control between one's motor representation and the representations triggered by the perception of others. The activation of the right temporoparietal junction (rTPJ), as the control mechanism, has been shown by many meta-analyses, particularly in ToM, empathy and perspective taking (Grèzes and Decety, 2001; Decety and Sommerville, 2003; Hasler and Northoff, 2011). Brass and his colleagues (Brass, Ruby, & Spengler, 2009; Brass, Ullsperger, Knoesche, von Cramon, & Phillips, 2005; Spengler, von Cramon, & Brass, 2009) investigated the self-other distinction

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[1] These automatically happen when we observe someone else in a state of nonconscious mimicry, for example.

and control of imitation using functional magnetic resonance imaging (fMRI). Participants performed imitation-inhibition task (Brass et al., 2005a), where they were instructed by numbers (1,2) to lift their index or middle finger placed on a keyboard while presented with a response irrelevant image (distractions) of either index finger lift or middle finger lift, resulting in compatible (imitative) or incompatible (nonimitative) responses. This task was performed during fMRI scanning session. The results of activated regions suggested that rTPJ and medial prefrontal cortex (mPFC) play a correlative role in this ability to control automatic imitative responses as they were activated during nonimitative reactions (Spengler et al., 2009). Accordingly, decreased activation was shown in rTPJ and mPFC in individuals with autism spectrum disorder, a disorder associated with poor social abilities and understanding (Spengler et al., 2010), and thus indicating the importance of these regions in typical social cognitive functioning.

The evidence derived from fMRI studies declares a correlation between the self-other control and activation of brain regions rTPJ and mPFC. The correlation of a neural activation and behavioural performance is established from the character of imaging methods when behavioural tasks are performed during brain scanning sessions. However, there is a lack of evidence showing a causative relation between rTPJ and mPFC activation and the behavioural ability of self-other control when behavioural testing succeeds a modulation of particular brain region. For example, Joseph, Fricker, and Keehn (2014) used a fMRI technique to measure visual responses with task-irrelevant stimuli presented by gaze (social) and arrow (non-social) cues. Either a gaze or an arrow was presented in four conditions (valid, invalid, neutral, and null). Successively, a target appeared left or right of the cue.

Participants were instructed to identify the position of the target. Gaze and arrow cues elicited nearly similar behavioural response times, however whole-brain analyses of invalid compared with valid cues demonstrated that TPJ and inferior parietal cortex were activated when the response required reorientation attention after invalid gaze cues. However, they were not activated when reorientation after invalid arrow cues was required. Yet, this finding can result in two possible interpretations. First, it is more demanding to interpret gaze than arrow cues, and therefore a response in rTPJ was found, as this imaging method is blood-oxygen-level dependent (BOLD)[2]. Second, rTPJ is domain specific and is activated only in 'social' situations. Hence, another method other than fMRI is needed to establish the causative role of rTPJ on self-other control. Also, the left TPJ has been proven to play an important role in social cognition in conjunction with rTPJ and mPFC (Wurm et al., 2011; Kestemont et al., 2014; Rochas et al., 2014), supporting the theory that TPJ activation is fundamental for all social tasks.

The stimulation techniques transcranial direct current stimulation (tDCS) and repetitive transcranial magnetic stimulation (rTMS) can indicate the **causal** connection between brain activation and the behavioural output in cognitive tasks. These techniques modulate cortical excitability in stimulated regions by changing resting membrane potentials at the neuronal level (Martin et al., 2014; Romero Lauro et al., 2014) and therefore modulate behavioural performance. Recently, some studies have used stimulation techniques to assess self-other control and its link to TPJ. The casual investigation of rTPJ in self-other control has been

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[2] The more particular task is cognitively demanding, the more oxygenated blood is needed to supply energy in the activated region.

carried out by applying rTMS in a study by Sowden and Catmur (2013), where participants were instructed to execute an index or middle finger lift according to colour cue while observing task-irrelevant stimuli in a form of image lifting either index or middle finger also with variation in spatial dimension. Either the task-irrelevant stimuli was on the right side or on the left side (providing variation by showing both left and right hands). Disruptive effects of rTMS to the rTPJ were observed in this study, reducing self-other control at the social level of the task (controlling imitative responses), but not at the non-social level (controlling spatially compatible responses).

Another study (Santiesteban et al., 2012) used excitatory tDCS applied to rTPJ and investigated its enhancing effects on self-other control in two tasks. First, a perspective taking task; where the self-perspective had to be inhibited and other's perspective enhanced. In this task, participants were instructed to move an object according to 'director' instructions in shelf that was placed between the participant's view and the director's view. Second, a task desigend to measure the control of imitation similar to Sowden and Catmur (2013) task; where the self-perspective had to become enhanced, and other's perspective inhibited (Santiesteban et al., 2012). Using opposite task requirements, these two studies have demonstrated complimentary results; whereby excitatory stimulation caused an improvement and a disruptive stimulation caused impairment of behavioural performance. Consequently, they both served as a basis for the present study with the use of tDCS and a task to measure the control of imitation (also termed imitation inhibition) to examine whether the rTPJ has a causal and domain specific role in the process of self-other control.

Above we have discussed the important involvement of the rTPJ in a number of social abilities, and therefore self-other control may be regarded as a domain specific process. However, the TPJ also has a well-known role in the process of attention (Corbetta & Shulman, 2002). Thus, it is possible that the ability to switch between two possible representations – the self and the other is a domain general process, meaning it is not specialized or unique for social situations. Rothmayr and colleagues (2011) reported activation in rTPJ not only during false belief attribution, but also during inhibitory control, using a Go/No-Go task. In the task, a sequence of picture, scrambled picture, and another picture was presented. The pictures had two possible set-ups with either one or two children depicted. The participant was instructed to press a button with index finger if the set-up (the number of children) in the presented picture was different from the set-up (number) in the previously presented picture. This is known as the 'Go' condition. While participant was instructed not to response when the number of children in the two consequent pictures remained unchanged, known as the 'No go' condition. This finding supports a domain general focus of rTPJ. This question has been highly debated in the literature (Mitchell, 2008; Scholz et al., 2009) and it has proved particularly demanding to design a task that measures specialized social cognitive and domain general ability at the same time.

A task is required that involves and measures both social cognition and domain general processing simultaneously, and where the task stimuli and demands are invariable. Many previously used tasks tested only one of these two kinds of the cognitive processing; either domain general or domain specific, or did not even place a question about generality or specificity (Grueneisen et al., 2014; Schneider et al., 2014a, 2014b). Sowden and Catmur

(2013) were the first to develop a task to measure these two abilities simultaneously during the same task.

Hence, this study employed a task measuring the control of imitation, which assesses response times (RT) and response errors to perform actions during the observation of task-irrelevant, distractor actions performed by another (Bertenthal, Longo, & Kosobud, 2006; Brass, Bekkering, & Prinz, 2001; Catmur & Heyes, 2011). The task used by Sowden and Catmur (2013) was designed to simultaneously measure not only the control of imitation, but also the control of non-social behaviour. The former is achieved by introducing imperative (instruction) cues which are compatible or incompatible with the required response (imitative compatibility) and the latter is achieved by implementing imperative cues located to be spatially compatible or incompatible (spatial compatibility) with the required response (Sowden and Catmur, 2013). As the cues appear simultaneously, their demands are the same for social - imitative and non-social - spatial facets of the task.

In the control of imitation task, participants view a resting hand on a computer screen. They are instructed to lift either the index or middle finger of their right hand according to cues that are presented on the screen in the form of coloured squares placed between index and middle fingers of the presented hand. Compatibility effects of imitation, in other words, the tendency to imitate, are measured by the calculation of the difference in RT to execute the instructed finger lift when observing the *imitatively incompatible image* compared to when observing the *imitatively compatible image* (both task-irrelevant stimuli) (Catmur and Heyes, 2011). Participants show slower responses when a middle finger lift is required during the observation of an index finger lift on the screen (imitatively incompatible) than during the

observation of a middle finger lift (imitatively compatible) on the screen. This is suggested to be because during incompatible trials, a neural representation of the 'other' is created which is opposing to the neural representation required for the participants own instructed action. Therefore this slows the production of the instructed action by the participant, as the representation of the 'other' must first be inhibited.

Spatial compatibility effects, in other words, the tendency to respond in accordance with the spatial location of the observed action, are measured by the calculation of the difference in RT to execute the instructed finger lift when performed on the opposite side of space, (spatially incompatible) versus the same side of space (spatially compatible) to the task-irrelevant stimulus (Sowden and Catmur, 2013). Participants show slower responses to lift their right index finger (left side of space) when the coloured cue is accompanied by an image of a finger lift on the right side of space compared to the situation when the coloured cue is accompanied by an image of a finger lift on the left side of space. This effect is often called the Simon effect (Simon, 1969) (Figure 2), whereby any response is speeded when it occurs in the same portion of space to an observed stimulus.

The control of imitation task (Sowden and Catmur, 2013) requires to not only control behaviour at an imitative level, but also at a spatial level (Cooper et al., 2013). There are four possible combinations of task-irrelevant stimuli presented: that are either imitative compatible or incompatible and either spatially compatible or incompatible (Figure 1). The task presented in the current experiment was also enriched with two well controlled (left and right) baseline trials (Wiggett et al., 2013). In the baseline trials, the coloured cue to lift

is accompanied by a pixelated image of the resting task-irrelevant hand stimulus. The incorporation of the two baseline trials serves as a suitable control task because these trials still require a finger lift response from participants as in the standard trials, yet without the bias of observed finger lifts. Therefore, they allow the computation of baseline RTs without an unnecessary impact of task-irrelevant activity. A baseline task is fundamental in demonstrating whether rTPJ stimulation has a causative effect on the ability to control response tendencies specifically.

In order to successfully control an imitative response we have to supress the motor representations that are activated when we observe an action. This happens when we see task-irrelevant stimuli executing an action creating the stimulus-response imitative compatibility effect. The bigger the imitative compatibility effect, the harder is to control the tendency to imitate (Boyer et al., 2012; Cross and Iacoboni, 2014) and to perform self-generated task-relevant actions. Hence, in an individual showing low imitative compatibility effects, there is a higher tendency to suppress the 'other' motor representation and enhance the 'self' representation (self-related motor control). This experimental environment, therefore, allows us to measure self-other control.

To sum up, the presented study searched whether the rTPJ plays a causal role in the control of imitation (self-other control), and if does, whether it functions as a domain-general or domain-specific cognitive mechanism. Low current by tDCS was applied to the rTPJ and a control mid-occipital site (MO) for 20 minutes before completing a behavioural task testing imitative and spatial response tendencies in the presence of task-irrelevant action stimuli.

The study tested **the hypothesis** that anodal stimulation by tDCS of rTPJ when compared to MO stimulation will enhance participants' ability to control imitation resulting in lower imitative compatibility effects.[3] Based on the findings of Sowden and Catmur (2013) and a domain specific account of rTPJ involvement, we would predict reduced imitative compatibility but not spatial compatibility effects, supporting a domain specific role for the rTPJ. If, however, both imitative and spatial compatibility effects are reduced in individuals subjected to rTPJ stimulation compared to MO stimulation, this would support a domain general account, as the effects are not selective to the 'social' aspect of task performance.

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[3] The imitation effect level is lower due to reduced tendency to imitate (enhanced self-other control), therefore the RT in imitative incompatible trial is shorter reducing the difference between incompatible RT and compatible RT.
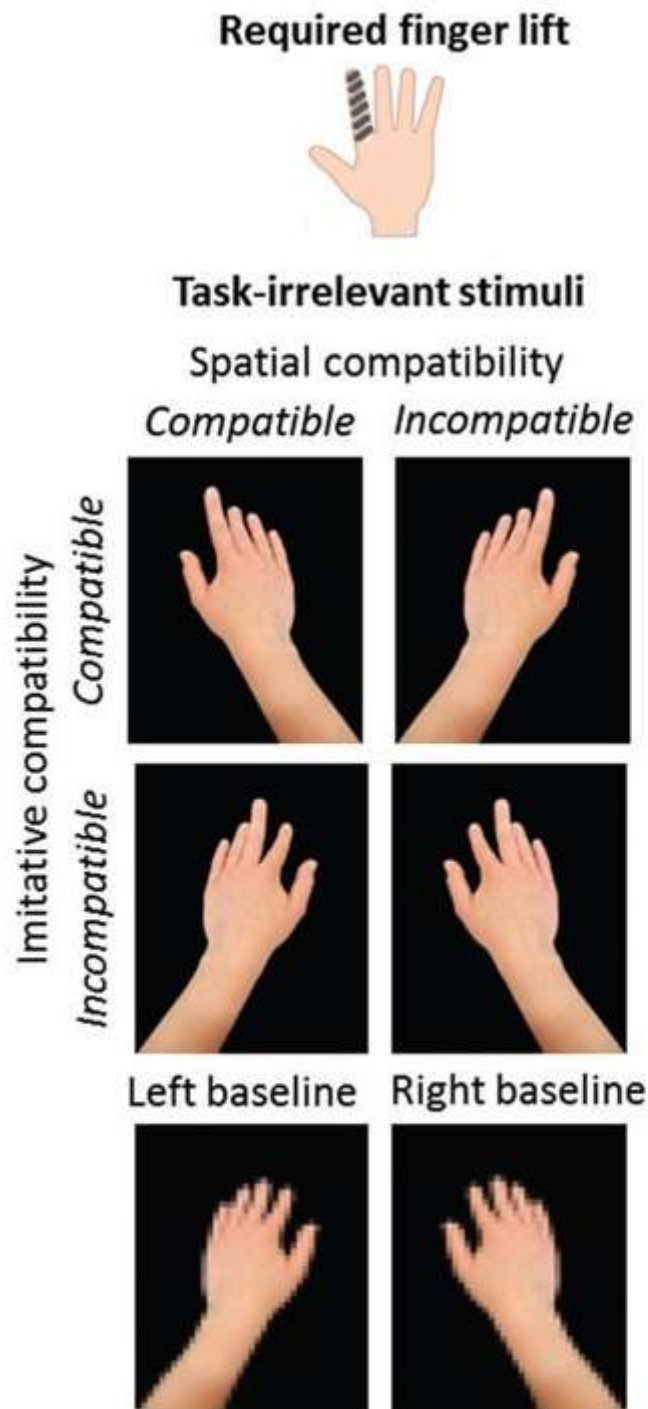
Required finger lift

Task-irrelevant stimuli

Spatial compatibility

	Compatible	Incompatible

Imitative compatibility

Compatible

Incompatible

Left baseline   Right baseline

Figure 1 illustrates the settings of the control of imitation task where task-irrelevant stimuli are presented. The task-irrelevant stimuli have four possible settings – 1) spatially compatible, imitative compatible; 2) spatially compatible, imitative incompatible; 3) spatially incompatible, imitative compatible; 4) spatially incompatible, imitative incompatible. Figure 1 also illustrates the left and right baseline conditions. Each task-irrelevant stimulus was introduced 18 times during the experiment. Taken from Sowden and Catmur (2013).

Spatial compatibility

Compatible   *Incompatible*

Left | Right   Left | Right

Required finger lift

Left | Right

Figure 2 *illustrates spatial compatibility in the control of imitation task. The required finger lift is on the left side of space, therefore task-irrelevant stimuli lifting a finger on the left side is spatially compatible, and lifting a finger on the right side is spatially incompatible (nevertheless index finger is lifted in both cases). Adapted from Sowden and Catmur (2103).*

2 Materials and Methods

2.1 Participants and Design

Twenty-four healthy participants (10 males, 2 left-handed, mean age 23.0 years, standard deviation [SD] = 2.5) were recruited from a pre-existing database held at the Social, Genetic & Developmental Psychiatry Centre, Institute of Psychiatry, and all had no contraindications to tDCS as listed on the screening form. Before issuing their written consent, participants were fully informed about the study procedure and tDCS safety precautions were explained, and finally all participants were given a small monetary reward for their participation. The full procedure was approved by the King's College London - Psychiatry, Nursing and Midwifery ethics subcommittee (PNM/13/14-37). A between subjects design was applied, with half the participants receiving tDCS stimulation to rTPJ and half to a control MO region. This was to avoid the carryover effects of the stimulation or behavioural practise effects in the task. The stimulated site (rTPJ or MO) and assignation of an orange and purple colour to the index and middle fingers were counterbalanced across participants.

2.2 Stimuli

The stimuli were those produced and used by Sowden and Catmur (2013) and were displayed to participants on a 15.6 inch laptop screen using Eprime-2. Figure 1 shows task-irrelevant hand stimuli. Pictures are labelled by spatial and imitative compatibility of the stimuli with respect to the instructed finger lift shown, depicting the 2X2 setup. Also shown are the additional pixelated hand stimuli of right and left hands used in the baseline trials. For example, on a trial in which an index finger lift is instructed, the observation of the task-

irrelevant hand performing an index finger lift is imitatively compatible with the instructed response. However, the observation of a middle finger lift is imitatively incompatible with the instructed response. In the same manner, on a trial in which an index finger lift is instructed, the observation of the right hand stimulus performing an index finger lift is spatially compatible with the instructed response. However, the observation of the left hand stimulus performing an index finger lift is spatially incompatible with the instructed response. During the task, each hand stimulus depicted in Figure 1 was shown 18 times.

Coloured cues (Figure 3) – the appropriate stimuli comprised of purple/orange squares with a visual angle of 0.2°. A white square with the same proportions served as a point on which to fixate. These squares were positioned at equal distances from the tips of the index and middle fingers of the hand stimuli. Task-irrelevant hand stimuli were presented as pictures of a human left/right hand at a horizontal ocular angle of 6.5°, and a vertical ocular angle of either 9.3° for index and middle finger lifts or 8.6° for the static and pixelated control hands. Index and middle finger motions underlay an angle of 0.7°. Left hand stimuli are a straight mirror image of right hand stimuli.

 Press, Bird, Flach, and Heyes, (2005) have previously shown that presenting a static hand followed immediately by a hand performing a movement (such as the index or middle finger lift observed in the current task) generates ostensible movement of the body part, sufficient to produce powerful compatibility effects. As in the example above, the use of left hand and right hand stimuli facilitates the manipulation of spatial compatibility (the spatial position of

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the observed finger motion), at the same time as imitative compatibility (the identity of the
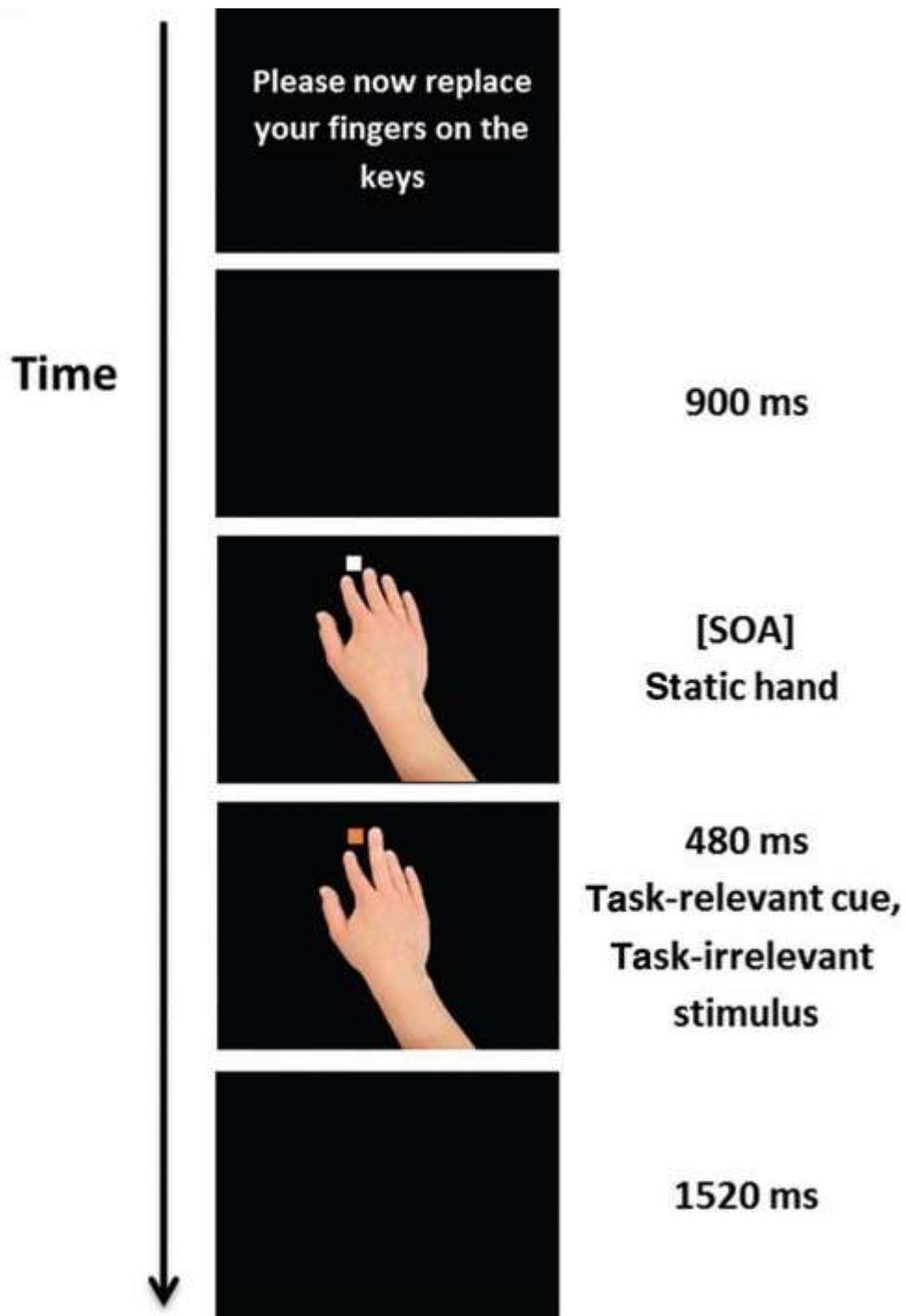
observed finger).

Figure 3 *illustrates the time scale of the control of imitation task and the task-relevant cue with task-irrelevant activity. First, written instructions are presented, then after 900ms the static hand and white coloured cue appear for a particular stimulus onset asynchrony (SOA). The white square changes its colour (to either orange or purple), accompanied by a task-irrelevant stimulus for 480ms. The coloured cue instructs participants on which finger lift response to make. (If orange was assigned to the index finger, then the shown task-irrelevant stimulus is spatially compatible, imitatively incompatible.)Adapted from Sowden and Catmur (2013).*

2.3 Procedure

After being informed of the procedure and issuing written consent, participants were sat on a chair approximately 90 cm from the laptop screen. Their right hand was placed in the identical orientation to the hand stimuli, while supported by a table underneath. All finger-lift responses were performed with the right hand using an external keyboard. The experiment started with 10 practice trials before the main experiment began. Participants received feedback whether they made the correct response during the practice trials and they had to reach at least 80% correct responses before starting the main experiment. During the main experiment participants did not get any feedback. The main experiment was divided into 3 blocks of trials. Each block took about 3-4 minutes, and participants were able to take short breaks between them.

In the experiment the participants were asked to respond to coloured squares which appeared on the computer screen. The participants responded by lifting either the index finger or the middle finger of their right hand. Their fingers were placed on the 'N' and 'M' keys on the external keyboard. They placed their index finger on the 'N' key and their middle finger on the 'M' key. As the response was identified by the action of lifting fingers, the default position was pressing the 'N' and 'M' keys down.

On every trial, after participants pressed the 'N' and 'M' keys a static hand appeared on the screen after a short blank screen interval (900ms). In between its index and middle fingers was a white square. Participants were asked to look at this location during the whole experiment. The static hand and fixation square were shown according to stimulus onset

asynchronies (SOAs; 1660, 2000, or 2400 ms). Following this, the task-irrelevant stimulus was shown for 480 ms, as the white square changed its colour to either orange or purple. Participants were assigned to lift their index or middle finger according to orange and purple stimuli. Participants were split into two halves; one half was instructed to lift their index finger in the presence of the orange square and middle finger in the presence of the purple square. The other half was instructed to lift their index finger in the presence of the purple square and middle finger in the presence of the orange square. Participants were asked to respond as quickly as possible, but to maintain accuracy

Figure 3 shows how every trial started with the command to replace their fingers on the keys. When fingers were pressed on the 'N' and 'M' keys, the trial would begin. First the static hand and a white fixation square were shown for a variable amount of time (SOAs: 1660, 2000, or 2400 ms). This screen was afterwards substituted by the task-irrelevant stimulus together with either the orange or purple cue, introduced for 480 ms. In some of the trials, the static hand was followed by a pixelated left/right hand serving as a baseline condition, which did not evoke any spatial or imitative effects. However, these trials matched the attention-evoking visual alteration of the standard trials. The baseline condition was used to indicate speeding or slowing responses in compatible or incompatible trials, respectively (Bertenthal et al., 2006; Gillmeister et al., 2008; Wiggett et al., 2013).

Task-irrelevant movement stimuli were controlled in a 2 x 2 design. These combinations consisted of:

Spatially compatible, imitatively compatible (SCIC);

Spatially compatible, imitatively incompatible (SCII);

Spatially incompatible, imitatively compatible (SIIC);

Spatially incompatible, imitatively incompatible (SIII).

This resulted in 4 standard trial types. The baseline stimuli for the left hand and right hand made up another 2 trial types. A combination of all of these trial types, 3 SOAs, and 2 colour cues, ensued in a sum of 36 trials, and these were ordered randomly to create one complete block. Thus each participant was subjected to 3 blocks of trials, with every trial type appearing a total of 18 times.

2.4 Stimulation Navigation and Protocol

The stimulation protocol was identical to that used in Santiesteban et al. (2012). Stimulation was induced via two electricity-conductive rubber electrodes placed inside two sponges of 35 cm^2. The sponges were soaked in saline solution roughly 30 minutes prior to stimulation and shortly before the experiment placed over the rubber electrodes. A charged, constant current stimulator (NeuroConn DC-stimulator) was used for stimulation. Firstly, each participant's scalp was wiped with an antiseptic wipe to avoid high impedance. Then, the cathodal electrode was placed over the vertex as a referential point (electroencephalography 10/20 system) (Klem et al., 1999; Herwig et al., 2003), whereas the anodal electrode was placed over CP6 (electroencephalography 10/20 system) in the case of the rTPJ stimulation and OZ (electroencephalography 10/20 system) in the case of the MO region stimulation. This was done according to the stimulation group assignment. A weak constant electrical current at 1mA was induced for 20 minutes with stimulation effects previously suggested to last for 90 minutes (Nitsche and Paulus, 2001). Offline simulation (stimulation prior to task execution) was chosen as previous experiments have shown

greater effects as a result of this stimulation than on-line stimulation (stimulation during task execution) (Nitsche et al., 2005). Stimulation intensity was slowly introduced for 15 seconds prior to stimulation and slowly reduced for 15 seconds at the end of stimulation. Also, impedance[4] was measured and recorded for each participant, with a requirement of lower than 55 kΩ impedance for stimulation to begin. However, the impedance was usually kept lower than 10 kΩ in order to achieve better precision and to avoid the disruption of stimulation by high impedance, which would cause the DC-stimulator to cease stimulation.

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[4] Impedance is a term used for alternating current and not for single direct current used in this study (where the term resistance is appropriate). However, the stimulator can be used for both and its display indicated impedance for single direct current as well. Impedance is also used in tDCS literature, therefore this term is used here to follow the practice.

3 Results

During the experiment the RTs and incorrect responses were registered via the keyboard input. We excluded results for 2 participants whose imitative and spatial compatibility effects significantly differed from the mean of all participants, making them multivariate outliers according to Cook's distance (Appendix A). Another participant was excluded from data analysis because of the possible influence of behavioural practise effects from a previous, similar experiment. There was no need to exclude any participant for making too many errors (none made more than 20% errors, mean = 6.6 errors, standard deviation [SD] = 4.6). Analyses were performed on all 6 trial types for both rTPJ and MO stimulated groups. The compatibility effects were calculated for all RT recordings using the formula: incompatible RTs - compatible RTs. Due to the design of the experiment both imitative and spatial compatibility are present simultaneously, therefore the analyses performed included both levels of compatibility. An independent samples t-test between stimulation groups was carried out on both mean RT (rTPJ mean = 483.4, SD = 74.8; MO mean = 505.0, SD = 81.8) and age (rTPJ mean = 23.8, SD = 2.4; MO mean = 23.0, SD = 2.5). There was no significant difference between the two groups in their mean RT (t [19] < 1, p = 0.54), or their age (t [19] < 1, p = 0.46). Hence, any significant differences in the analyses of interest are not driven by either of these factors.

3.1 Summary Descriptives

The fastest mean RTs for both rTPJ and MO conditions were in trials which were spatially compatible, imitatively compatible (Table 1). On the other hand, the slowest mean RTs for

both conditions were observed in trials which were spatially incompatible, imitatively incompatible. Furthermore, the most response errors for both conditions were made in trials which were spatially incompatible, imitatively incompatible, whilst the fewest response errors were made in trials which were spatially compatible, imitatively compatible. Although it appears that baseline trials in the MO condition produced slower RTs than the rTPJ condition, the left and right baseline trial RTs were roughly similar to one another in both conditions. Overall, spatially and imitatively compatible trials required less time to respond than spatially and imitatively incompatible trials in both stimulation conditions. Also, spatially and imitatively compatible trials elicited fewer errors in both stimulation conditions than spatially and imitatively incompatible trials. Table 1 refers to all mean RTs and errors in each trial type and across stimulation conditions. Baseline RTs are also between compatible and incompatible trials in their magnitude, suggesting compatible trials are, as expected, speeding up responses, whilst incompatible trials are slowing down responses.

Table 1 illustrates mean ± standard error of the mean (SEM) of RT (ms) and errors for all trial types after rTPJ or MO stimulation conditions.

Trial Type	rTPJ		MO	
	RT	Errors	RT	Errors
SCIC	443.5 ± 24.0	0.6 ± 0.3	454.4 ± 22.0	0.2 ± 0.1
SCII	455.4 ± 20.1	0.6 ± 0.3	470.1 ± 22.4	0.8 ± 0.5
SIIC	496.2 ± 24.2	1.5 ± 0.3	520.3 ± 24.1	1.9 ± 0.5
SIII	518.8 ± 27.1	2.9 ± 0.8	548.9 ± 23.5	2.4 ± 0.4
Left Baseline	485.9 ± 21.5	0.9 ± 0.2	509.2 ± 24.6	0.2 ± 0.2
Right Baseline	486.0 ± 21.8	0.4 ± 0.1	511.2 ± 25.4	0.9 ± 0.5

3.2 Inferential Statistics

3.2.1 Response Times

A three-way analysis of variance (ANOVA) (site x spatial compatibility x imitative compatibility) was run on the RT data collected in the standard trials, with a between-subjects factor of the stimulation sites (rTPJ, MO). The within-subjects factors included the two compatibility effects; both spatial (compatible, incompatible) and imitative (compatible, incompatible). Spatial compatibility produced a significant main effect, as slower RTs were produced when task-irrelevant stimuli were spatially incompatible with the instructed finger lift (mean ± the standard error of the mean [SEM]; 521.7 ± 10.8 ms) than when compatible (456.1 ± 10.8), $F(1, 19) = 118.8$, $p < 0.001$. Imitative compatibility also created a significant main effect, as slower RTs were evoked when task-irrelevant stimuli were imitatively compatible with the instructed finger lift (498.9 ± 12.7) than when compatible (479.0 ± 12.4), $F(1, 19) = 24.0$, $p < 0.001$.

However, there was not a significant interaction of the simulation site and the spatial $F(1, 19) = 1.4$, $p = 0.25$, or imitative compatibility $F(1, 19) = 0.02$, $p = 0.55$, effects. There was not found to be any other significant interactions or main effects (at a cut-off of $p < 0.05$). The compatibility effects calculated as incompatible RT – compatible RT, hence indicating the difference between incompatible and compatible RTs for stimulated rTPJ and MO sites, are shown in Figure 4. Even though there was not reached any significance in the effects, both imitative and spatial compatibility effects appear numerically reduced in the rTPJ compared to MO condition.
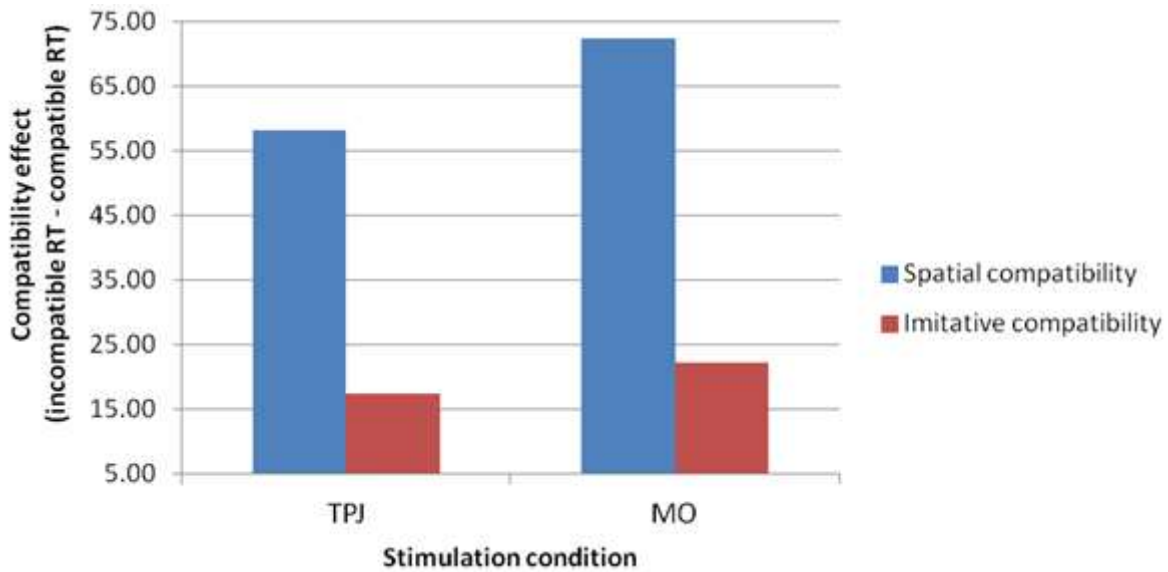
Figure 4 illustrates spatial and imitative compatibility effects in both stimulation conditions (rTPJ and MO).

3.2.2 Response Errors

The same ANOVA in a 3-way manner was run on the error data as on RT data collected in the standard trials. The same between-subjects factor of the stimulation sites (rTPJ, MO) was used. The within-subjects factors were again the same as in the RT data; spatial (compatible, incompatible) and imitative (compatible, incompatible) compatibility. Error data also show a significant main effect of spatial compatibility because fewer errors were made when task-irrelevant stimuli and instructed finger lifts were spatially compatible (0.6 ± 0.2), compared to when spatially incompatible (2.2 ± 0.3), $F (1, 19) = 36.0$, $p < .001$. Participants made fewer errors in imitatively compatible than incompatible trials, creating a significant main effect in imitative compatibility; $F (1, 19) = 6.5$, $p = .02$. When task-irrelevant stimuli were imitatively compatible with instructed finger lifts, fewer mistakes were made (1.0 ± 0.2), compared to when incompatible (1.7 ± 0.3).

There is a lack of a significant interaction between the stimulation site and spatial compatibility, $F_{(1, 19)} < 1$, $p = 0.9$, and the stimulation site and imitative compatibility, $F_{(1, 19)} < 1$, $p = 0.8$, according to errors made during all trial types). In Figure 5 spatially compatible, imitatively incompatible trials show less mean errors (0.7 ± 0.3) than spatially incompatible, imitatively compatible trials (1.7 ± 0.3), and this difference is statistically significant; $t_{(20)} = 6.68$, $p < 0.001$. This therefore suggests that the spatial compatibility of the stimuli have a greater effect on task performance than their imitative compatibility. This is also evident in the much larger spatial than imitative compatibility effects which are typically found (Catmur & Heyes, 2011; Sowden & Catmur, 2013), and which are evident in the current RT data (see again Figure 5)
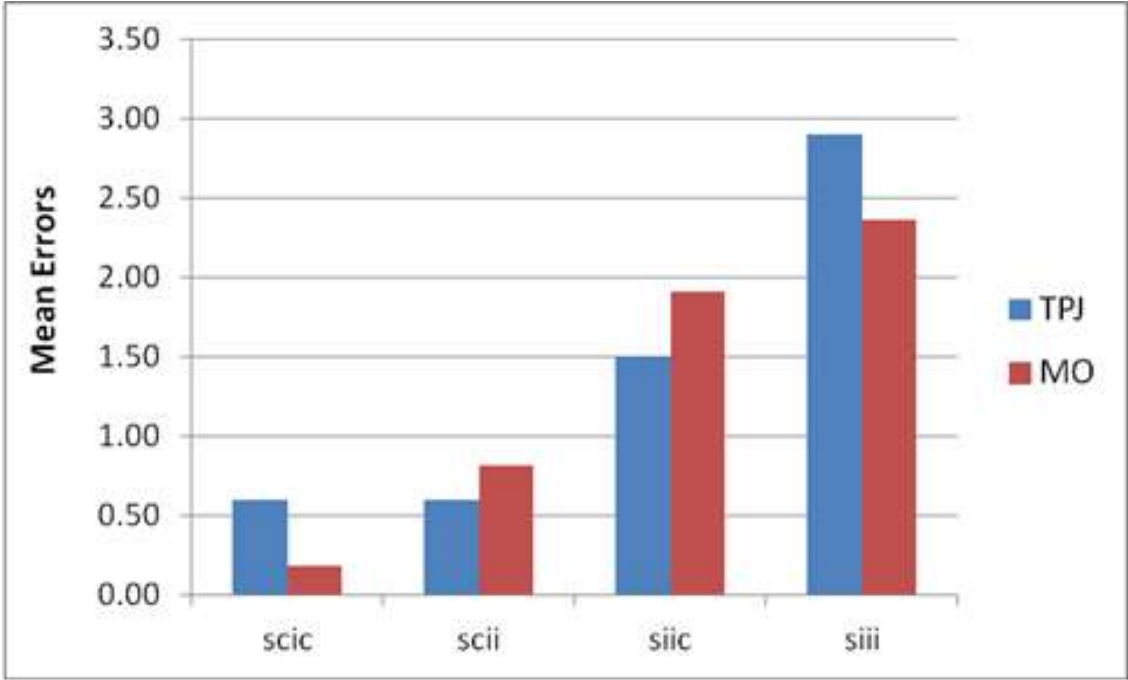

Figure 5 *illustrates mean errors in four different trial types (SCIC, SCII, SIIC, SIII) across stimulated sites (rTPJ, MO).*

3.2.3 Further Response Error and Response Time Analyses

In order to allow the manipulation of spatial compatibility alongside the manipulation of imitative compatibility, two hands either left or right were shown during the trials. Another three-way ANOVA (stimulation site X right/left baseline hand x instructed index/middle finger lift) was performed on the baseline trials to estimate if the main effects found in the standard trials could be due to the hands presented (left/right), instructed finger lift (index/middle), and whether these interacted with the stimulation site (rTPJ, MO). This was done on both the error and RT data. In the response error data, there were no significant main effects of the right/left hand observed; $F_{(1, 19)} < 1$, $p = 0.71$, or the instructed finger lift (index/middle); $F_{(1, 19)} = 1.5$, $p = 0.24$, and there were also no significant interactions between any of the factors included at a cut-off of $p < 0.05$.

Once again in the RT data that same analyses revealed no significant main effect of the hand observed; $F_{(1, 19)} < 1$, $p = 0.87$, or the response required; $F_{(1, 19)} = 2.3$, $p = 0.15$, and there were no significant interactions between any of the factors considered (all $ps > 0.05$). Thus, whether any particular trial presented a right or left hand to the participant and whether an index or middle finger lift was required did not affect the performance on the task in terms of RTs or error rates, and neither of these factors interacted with the stimulation administered.

4   Discussion

We stimulated the rTPJ in order to investigate its causal role in social cognition, especially the control of imitation. For this purpose designed experiment showed significant spatial and imitative compatibility main effects declaring that the task and stimuli have, as predicted, been set properly in order to elicit spatial and imitative compatibility effects. The site of stimulation (rTPJ/MO) did not have a significant effect on spatial or imitative compatibility, and therefore does not support the current hypothesis that anodal stimulation to rTPJ, relative to MO stimulation, would lead to a reduced imitative but not spatial compatibility effect.

A slight numerical reduction in both imitative and spatial compatibility effects can however be seen in RT data as a result of rTPJ relative to MO stimulation. This indicates that with more participants the experiment may possess greater power and thus lead to significant differences here. The present study is suggestive that on a larger scale tDCS to rTPJ may have resulted in both an enhanced ability to control imitation (a reduced imitative compatibility effect) as well as an enhanced ability to control spatial compatible response tendencies (a reduced spatial compatibility effect). This is opposing to our hypothesis and tentatively supports a domain general account of the rTPJ's involvement in such a cognitive task. However, as the differences in compatibility effects are not significant, no firm conclusion regarding the domain-generality of the TPJ can be made from these data.

As previously outlined, enhanced performance at both an imitative (social) and spatial (non-social) level of behaviour as a result of excitatory stimulation to the rTPJ would support a

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domain general account (Mitchell, 2008). Selective enhancement of behaviour at the imitative, but not spatial level, however, would support a domain-specific account, and the rTPJ's role may indeed be unique to the social aspects of behaviour (Stone and Gerrans, 2006; Rothmayr et al., 2011). However, the study of the domain-specificity of the TPJ continues to produce much debate and contradictory findings (Mitchell, 2008; Scholz et al., 2009, and therefore it is perhaps not surprising that our results provide an unclear picture of the role of the TPJ and do not support our main hypothesis.

Past TPJ investigation has shown that TPJ is also involved in bodily self-reference or self-location (Lenggenhager et al., 2006; Ionta et al., 2011a, 2011b, 2014). This means that TPJ provides us with multisensory information about our bodily position giving us the sense of bodily self-consciousness. The notion of bodily position helps us to distinguish between the self and the other as these two concepts differ it their positions. Automatic imitation is associated with the ability to socially interact though the empathetic notion, in other words, when we imitate we can better relate to others, which helps us in social situations to achieve any goals we might seek them for (Ainley et al., 2014; Bonini et al., 2014; Rizzolatti and Fogassi, 2014). Therefore we imitate in some social situations, and we also inhibit imitation in other social situations because it is not advantageous to imitate every action we observe. Therefore, one can understand the requirement for a brain mechanism which *controls* imitation, or more generally controls representations of the self and of others. Relating to other objects in this way in non-social situations would not bring us any benefit as they lack any emotions and intentions present in social situations. Thus it seems there may be something truly unique about strictly *social* interaction. Self-other control as required in the

control of imitation has indeed been considered to be domain-specific or unique to social cognition. Our approach in other non-social situations with the environment seems very different; it does not elicit imitation, and hence it seems intuitive that it may not require such a cognitively and energetically demanding mechanism and dedicated site in the brain as has been suggested for self-other control in social cognition.

Consequently, much research in the literature appears to support a domain-specific role for a brain region such as the TPJ. Let us now consider some reasons why this hypothesis is not reflected in the current data. The first reason can be the method used in our study. The stimulation method tDCS is less accurate than TMS in the focus on a particular brain region. Also, tDCS differs from TMS in temporal resolution, which is in the case of tDCS lower because it must be applied in the timeframe of minutes compared to immediate action potential induction by TMS (Torres et al., 2013). These two methods require different technical parameter settings, and therefore they produce variance in the causal effects (Miniussi and Ruzzoli, 2013). Lower spatial resolution and more diffuse effects in tDCS compared to TMS can affect our results. If tDCS stimulates a larger region than TMS, then other regions are modulated which may impact on behavioural performance. This might explain why tDCS stimulation seemed to numerically reduce both imitative and spatial compatibility effects contrary to the selective modulation of imitative compatibility found by Sowden and Catmur (2013).

There is also a possibility of variance of results in two studies using the same tDCS technique as its stimulation impact varies across individuals. The current can reach distinct brain

regions in diverse amounts and distributions according to individual physiology and anatomy. The difference can be caused by influences such as skull thickness, subcutaneous fat, and distribution of cerebrospinal fluid (Truong et al., 2013). Another limitation of tDCS can modify the results. Electrodes placed directly on specific brain regions do not necessarily deliver inward positive current to the cortex of that brain region, the specificity of brain regions can alter the current flow. This is caused by the surface shape of the cortical areas as the nearby gyri and sulci (ridges and grooves) dramatically change the polarity (Rahman et al., 2013). Therefore, the individual brain anatomy can alter the effects of tDCS providing different results. The impact of tDCS on the excitability is also limited by the current orientation, which is either aiming into the cortex (radial) or parallel to the cortex (tangential) (Dmochowski et al., 2011). Radially ordered current will cause somatic depolarization, on the other hand, tangentially ordered current cause effects that are connected with polarization of afferent axons (Rahman et al., 2013). Contrary to the dominant view, tDCS currents are mainly tangential, aiming in a parallel manner to the cortex, hence cells aligned parallel to the cortex are more excited than radially ordered cells under the stimulated site (de Berker et al., 2013). This notion points towards the spatial resolution limitation of tDCS, when tDCS contrary to TMS stimulated more broad area, disallowing specific site stimulation.

Secondly, the design of the control of inhibition task could affect the spatial and imitative compatibility effects. The task was primarily planned to function as a social cognition measure, hence it can be the case that the spatial measure is not a 'pure' measure of attentional bias to spatially compatible and incompatible cues. The task is quite far removed

from classic attentional cueing tasks such as the Posner task (Posner, 1980). However, the task represents the most appropriate design so far to test the hypothesis of domain-specificity versus domain-generality.

And thirdly, cognitive functions which are here represented by the control of imitation do not operate only in one specific region, which is typically targeted by tDCS, but are known to operate on multiple functionally connected brain regions (Luft et al., 2014). The other main region activated during the task is mPFC (Wurm et al., 2011), which should be considered in the complex dynamic interplay of brain regions involved in this specific cognitive task. The current set-up and method might be too focused on how one specific area of the brain responds in isolation to answer the question about domain-specificity and domain-generality. However, alternating current stimulation between rTPJ and mPFC could be employed in order to investigate the connectivity between these two sites.

There are, however, a number of other promising findings from the present study. Firstly, the lack of a main effect of the hand observed in baseline trials indicates that it is not significantly easier to respond when the left or right hand is shown. The same can be said about the instructed finger lifts. It is not easier or harder to lift either index or middle finger, as indicated by the lack of a main effect of the instructed response in either RT or error data. These data all indicate that the experimental protocol has been designed appropriately to place no biases on responses, except those produced by the desired imitative and spatial compatibility manipulations. We also see that baseline trials are well designed and serve as a good index of baseline performance to execute finger lift responses. This is clear as RTs on

these trials lay between those of the compatible and incompatible trials of the standard trials.

The self-other control functions as an automatic non-conscious mechanism involving motor representations (Obhi and Hogeveen, 2013) as opposed to non-automatic, consciously processed executive function (Diamond, 2013). This description can be applied to imitation because in the task participants rely on the environment – they take the information from the environment because it is cognitively more sufficient, hence they tend to perform better when presented with compatible task-irrelevant stimuli. When a finger lift is instructed, it is easier and quicker to imitate the task-irrelevant stimuli, and this produces shorter RTs and more accuracy during imitatively compatible tasks. The situation is the same in the case of spatial compatibility. We do not look at the two possible conditions index finger or middle finger, but we look at the two possible conditions left or right side of space. We take information of the spatial location from the environment and we do so in a non-conscious, automatic manner.

However, there has been some difference between imitative and spatial compatibility in our results. Spatial compatibility has shown significantly greater effect on response times than imitative compatibility. Welsh and colleagues (2014) proposed that in general during an incompatible trial one has to select the correct of two stimuli (one task-relevant, one task-irrelevant) to attend and respond to, with the two stimuli being incongruent to one another. However, in imitatively incompatible trials participants responded on average 80ms quicker than in spatially incompatible trials (Brass, Bekkering, Wohlschläger, & Prinz, 2000). Their

different effect magnitudes suggest that they may not function identically, and therefore may be mediated by distinct brain regions. Even though they are both automatic coupled kinds of cognition, spatial and imitative compatibility may support different higher-level decoupled (detached from environment) executive functions if rTPJ was domain-specific for social situations. That could be the reason why in many previous studies (Costa et al., 2008; Santiesteban et al., 2012; Sowden and Catmur, 2013) imitative compatibility effect was modulated by rTPJ stimulation while spatial compatibility effect was not because they do not cause identical compatibility effects. It can be proposed that this distinction would be greater if there was a higher-level decoupled cognitive function involved.

However, this distinction between social and non-social aspects of cognition and behaviour is more on the level of suggestion, and therefore further investigation is advised that would provide us with more information about the characters of spatial and imitative cognitive processing. The distinction between spatial and imitative cognitive capacity is not only relevant for social cognition and neuroscience, but they also contribute to the overall picture of human cognition and brain functioning.

The study of the mode of rTPJ's functioning could also help to solve the dispute between 2 theories explaining mindreading, the ability to understand and predict the actions of others - Theory-theory, defining mindreading as a theoretical discipline (Gopnik and Wellman, 1992) and Simulation Theory, defining mindreading as interpreting others through one's own individual internal design (Gallese and Goldman, 1998). Simulation Theory uses the concept of mimicking as we mimic what we would personally do in certain situation, however this

mimicking is the opposite of imitative mimicking that enables us to relate oneself to the other. Simulation Theory does not offer the account of the other, and hence self-other control. If we read social situations by applying our own behaviour to others, then we never really take the perspective of the other as we focus only on our own perspective. On the other hand Theory-theory describes mindreading as a theoretical conscious discipline, which automatic imitation and imitation inhibition is not, but Theory-theory could be better informed and related to automatic processes if it accepted these processes as underlying lower-level processes, such as self-other control is considered to be.

For example, in the director task (Santiesteban et al., 2012), the participant has to move objects in a shelf by instructions from a 'director' who stands behind the shelf, and they must do so from his perspective. In this situation, the participant has to inhibit the self and relate to or enhance the perspective of the other. In this case the 'other' is the director. To begin, there is an automatic process, often leading to errors in the movement of an object, however, when the participant successfully 'controls' which perspective she will take, this may also involve some aspects of executive function. This may provide a good means by which to study both automatic and more conscious responses; with early, instinctive RTs and errors providing an insight into automatic processes, and later/slower RTs and errors across a trial highlighting more controlled, executive processes.

In conclusion, the study showed that there is a main effect in imitative compatibility and also in spatial compatibility, therefore the task is functional and ready to be employed in other studies. Even though the causal evidence of rTPJ's role in social cognition, especially in the

control of imitation, has not been demonstrated, with further research and more robust data this could be achieved. Although contradictory to our hypothesis, our results tentatively support, based on numerical but not significant differences, a domain general role for the rTPJ here. However, caution should be taken in concluding this, as Sowden & Catmur (2013) found the direct opposite results on the same task. This may be explained, however, due to the use of different stimulation techniques with very different focality of stimulation. TMS may indeed provide a better, more focal modulation of target brain regions than the currently used tDCS. Other research is needed, therefore in order to determine whether the role of the rTPJ is domain-specific for social cognition, and also its functional role in more general social cognition theories and broad cognition theories.

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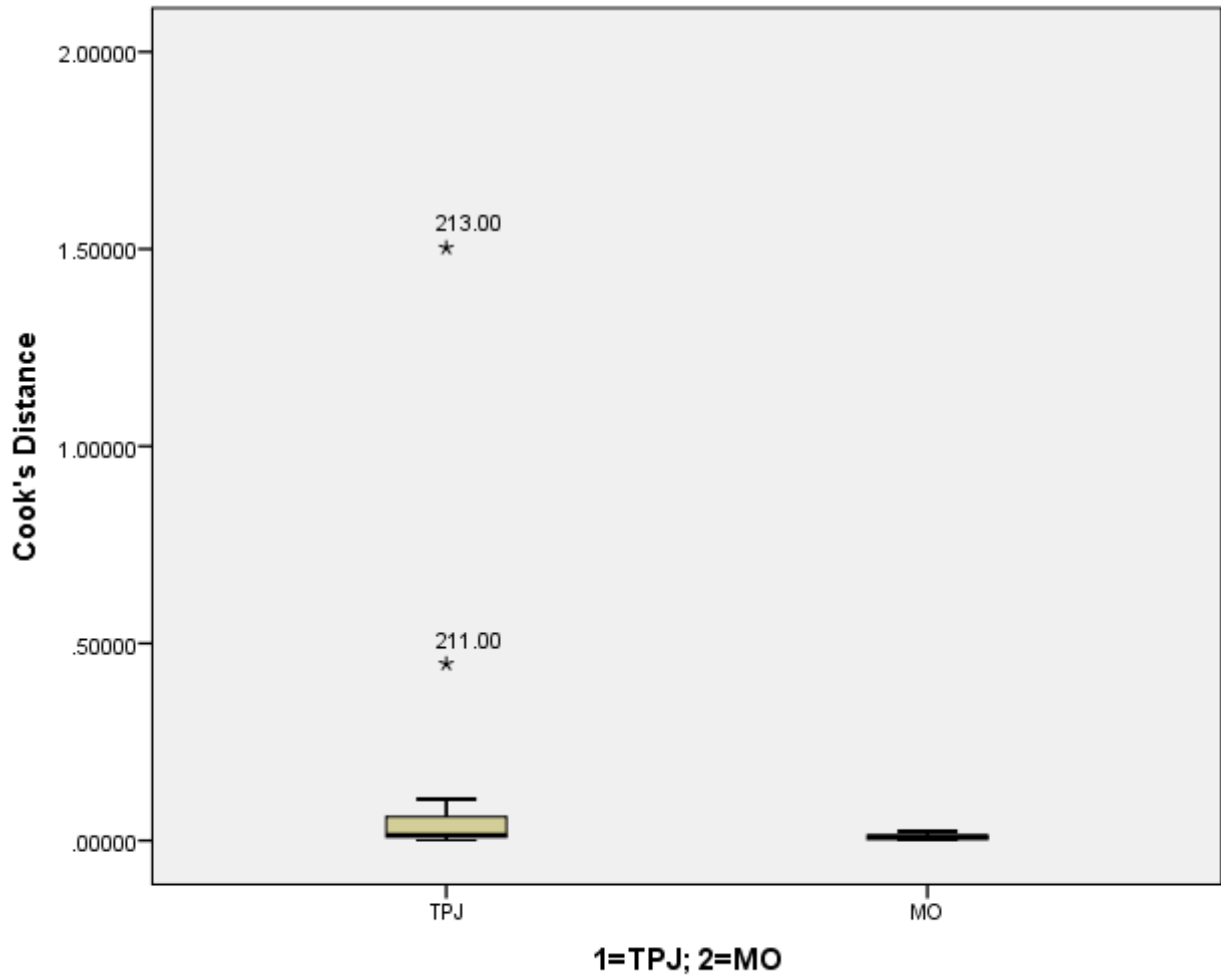
Appendix A

Cook's Distance

Figure 6 *illustrates Cook's distance performed (in SPSS v22) on the data from all participants (n = 23, TPJ = 12, MO = 11). It indicates the effect of deleting a given observation. 2 data points with large residuals identified as outliers were excluded because they may distort the outcome and accuracy of a regression.*