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Social Exclusion : How Inhibition and Excitation of the Dorsal Lateral Prefrontal Cortex (DLPFC) Influences Feelings of Social Exclusion

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Abstract

Social exclusion refers to the experience of rejection by one or more people during a social event. Cyberball, a computer program, is one of the most common tools for analyzing social exclusion. Cyberball simulates a game of catch in which any number of individuals or computer-generated players can pass a virtual ball to one another. Regions of the brain that underlies pain perception include networks lined to the Dorsal Lateral Prefrontal Cortex (DLPFC). Direct manipulation of this area may provide a better understanding of how the DLPFC can influence the perception of social exclusion. Transcranial magnetic stimulation (TMS) was applied to both the left and right DLPFC to gauge different reactions to the Cyberball experience. Social exclusion responses were influenced to further explore the role of the DLPFC. It was found that there were elevated levels of agitation from 10Hz rTMS processes that excited the DLPFC.

Keywords: Social exclusion, DLPFC, TMS, rTMS, pain, social pain, Cyberball

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Social Exclusion: How Inhibition and Excitation of the Dorsal Lateral Prefrontal Cortex (DLPFC) Influences Feelings of Social Exclusion

by

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Contents

List of Tables

List of Figures

…

1. **Introduction**

1.1 Social Exclusion and the Brain

Social creatures, including humans, have evolved to form complex social bonds to secure necessities such as shelter and resources (Baumeister & Leary, 1995; Snyder-Mackler et al., 2020). Social interactions that involve exclusion of an individual from a group can trigger a threat response, as well as have a direct impact on the mental health of the individual (Macdonald & Leary, 2005; Riva & Eck, 2016; Twenge et al., 2001; Wang et al., 2017). Individuals may label social scenarios as positive or negative experiences, which can lead to feelings of loneliness if the individual was excluded (DeWall et al., 2011). Exclusion experiences can be during a physical social exclusion event, or a virtual representation of one via computer programs (Williams et al., 2000). Social exclusion events can be deliberate or inadvertent, especially in a larger group setting. Cyberball, a computer program that replicates firsthand exclusion events, can be used to evaluate human interactions with ostracism (Hartgerink et al., 2015; Jamieson et al., 2010; Schoel et al., 2014; Zadro et al., 2004).

Exclusion refers to the rejection by others, which then affects the cognition and well-being of the excluded individual (Mwilambwe-Tshilobo & Spreng, 2021). Isolation may occur in various forms and is subjectively experienced depending on the individual because of exclusion (Eisenberger et al., 2003; Williams & Nida, 2022). Humans need social interactions, therefore moments of exclusion can aid in the determination of bonds while also provoking a sense of crisis (Kawamoto, Ura, et al., 2015).

When social connections are threatened, mortality rates increase (Cacioppo & Berntson, 1992; Cacioppo et al., 2015; Caspi et al., 2006; Patterson & Veenstra, 2010). A 2006 study reported that socially isolated children were at increased risk for health problems such as cardiovascular disease (Caspi et al., 2006). Other risk factors, such as socioeconomic status and general health, did not contribute to the results. These findings underscored the value of social connections by showing how isolation during critical human developmental stages can have a negative influence on health over a lifespan (Caspi et al., 2006; Danese et al., 2009).

Social exclusion scenarios tend to elicit pain responses from the DLPFC (Ducasse et al., 2014; Eisenberger et al., 2003). The DLPFC is responsible for many different roles, one of which may involve the regulation of pain in both a physical and emotional regard. This idea is supported by research showing that there is greater activation in the DLPFC when remembering events such as abandonment (Ducasse et al., 2014). Studies suggest that the DLPFC displays similar responses to actual pain and potential pain by activating what has been termed the pain matrix (Eisenberger, 2012; Eisenberger et al., 2006). The pain matrix consists of the insula, cingulate cortex, and somatosensory cortices (Eisenberger, 2012; Kross et al., 2011). In both physical and social rejection, there is an increase in activity in the dorsal Anterior Cingulate Cortex (dACC) and the anterior insula, which are regulated by the DLPFC in the pain control network (Eisenberger et al., 2003; Hatzitaskos et al., 1999; Sansone & Sansone, 2012; Schmahl et al., 2012). This highlights the importance of the DLPFC and how regulation of these processes is conducted by the DLPFC, thus signifying the area as a key region for the feeling of pain when social exclusion occurs.

In addition to the pain matrix, the DLPFC is connected to the top-down control of other behaviors, such as the regulation of emotions (Goldin et al., 2008; MacDonald et al., 2000; Ochsner & Gross, 2005; Schmitz et al., 2004). Furthermore, the regulation of emotions in the DLPFC can influence the amount of distress experienced in social settings (Ochsner & Gross, 2005). Interestingly enough, not only does the DLPFC regulate the amount of distress experienced, but it is believed that sensitivity to rejection can be found within the brain region (Ehrlich et al., 2015). This idea can be further supported in studies that measure rejection and rejection detection in terms of social scenarios (Kawamoto, Nittono, et al., 2015). It has been suggested that social rejection activates detection processing in the brain (Kawamoto, Ura, et al., 2015; Yanagisawa et al., 2011). While previous research has focused on the PFC in regard to isolation, we intended to target the DLPFC to further evaluate social context and utilize Cyberball as a firsthand exclusion invoker.

The DLPFC has been shown to play a crucial role in the control of emotions (Dörfel et al., 2014; Kohn et al., 2014; Morawetz et al., 2017). Utilizing either stimulating or inhibiting TMS procedures on the left and right DLPFC may result in differing effects in terms of social decision-making and exclusion scenarios. This was based on a meta-analysis of TMS studies and the DLPFC (Christian & Soutschek, 2022). Fairness and selfishness in social interactions have been found to be influenced by disruptive low frequency TMS, such as 1Hz of the DLPFC and more specifically the right DLPFC (Baumgartner et al., 2011; Knoch et al., 2006; Strang et al., 2014). It was found that inhibition of the right DLPFC correlated with increased selfishness (Strang et al., 2014). Further research revealed that right DLPFC disruption did not significantly affect assessments of fairness and that fairness perception may be independently represented (Knoch et al., 2006; Strang et al., 2014).

1.2 TMS and rTMS

Transcranial magnetic stimulation (TMS) is a non-invasive technique for stimulating different brain regions. Low frequency TMS (1Hz) inhibits the brain, while a higher frequency such as 10Hz excites the brain. TMS has been clinically used for various conditions, such as anxiety and depression (Cappon et al., 2022). Typically, TMS and rTMS are performed on the left side of the brain for depression treatments; more specifically, the left prefrontal areas are targeted daily (Perera et al., 2016). Patients who undergo TMS treatment for depression usually attend sessions for around 4-6 weeks, although in some cases patients may require additional weeks depending on the condition (Janicak et al., 2010; McDonald et al., 2011). Ultimately, patients experienced a dramatic decrease in depression levels around the four-week mark (O'Reardon et al., 2007; Perera et al., 2016).

TMS is utilized to treat anxiety, but it can also considerably increase anxiety levels among individuals with underlying factors such as panic disorder (Mishra et al., 2011). TMS can generate changes within brain networks to help with anxiety, just like it can have a beneficial effect on depression when used routinely (Huerta & Volpe, 2009). Studies support the idea that the use of low frequency rTMS in the right DLPFC can lessen the effects of anxiety (Cirillo et al., 2019; Diefenbach et al., 2016; Dilkov et al., 2017). The consensus is that inhibitory rTMS can show favorable outcomes in disorders such as generalized anxiety disorder and panic disorder, along with other conditions (Bystritsky et al., 2008; Bystritsky et al., 2009; Racine et al., 1995).

A 2020 study used TMS to explore social pain using pictures while targeting the ventrolateral prefrontal cortex (VLPFC) (He, Zhao, et al., 2020). The main finding of this study was that it supported the notion that emotional social regulation is a function within the VLPFC (He et al., 2018; He, Liu, et al., 2020). 10Hz rTMS to the right DLPFC, as well as the right VLPFC, showed that there was a relief in social pain (Zhao et al., 2021). Furthermore, relief was measured through distraction, which relates to the concept that the DLPFC is involved in attention during early stages of emotional regulation (Kohn et al., 2014). Additional research demonstrated that the same region of the brain in non-human primates also correlated with social situations (Sliwa & Freiwald, 2017). The various studies supported the idea that social interactions are determined and perceived through the prefrontal cortex, which justified the use of TMS to further investigate these relationships.

As previously indicated, social exclusion can trigger the same brain pathways as physical pain (Eisenberger, 2012). Current literature supports that there may be overlapping brain circuitry between physical and emotional pain (Eisenberger, 2012). For example, some patients who experience somatoform pain disorders with no medical explanation had also reported higher levels of traumatic social events (Brown et al., 2005). Similarly, exclusion events have been correlated with higher sensitivity to physical pain. This concept was supported by recording increased pain levels when participants immersed their hands in ice water which followed an exclusion event (Levine et al., 1993; van den Hout et al., 2000). Furthermore, the growing body of research has shown that social support helped reduce feelings of physical pain, suggesting that influences on either social or physical aspects of life have impacts on one another (Eisenberger, 2012).

During childhood, social rejection can also trigger more aggressive behavior, especially in the more developmental phases (Achterberg et al., 2020). Social scenarios that are particularly negative can increase aggression, meaning that aggression has a linear relationship with the severity of isolation or bad experiences (Chester et al., 2014; Twenge et al., 2001). Moreover, results support that there are key activations within the DLPFC and VLPFC when assessing social rejection, further supporting the claim that social processing and pain are located within these regions (Cacioppo et al., 2013; Eisenberger et al., 2003).

In addition to ostracism, the fear of being ignored before an event is equally as powerful a feeling (Holte et al., 2022). A 2003 study suggests that the idea of being excluded from a social event is physically painful (Nolan et al., 2003). Furthermore, those who have experienced social rejection tend to report higher-than-average levels of depression (Rudert et al., 2021). Depression has also been reported in older adults as a direct cause of social isolation (Taylor et al., 2018). This ties in well with the fact that TMS is now commonly employed to clinically treat depression by specifically targeting the DLPFC (Cash et al., 2021; Cheng et al., 2021; O'Reardon et al., 2007; Sonmez et al., 2019).

The DLPFC is one region in a network involved in the experience of painful social exclusion. For example, the neighboring dorsal anterior cingulate cortex (dACC) is an additional brain region implicated in the neurological response to social exclusion (Eisenberger, 2012). The dACC, which is activated in response to both physical pain and social exclusion, is thought to aid in the treatment of emotional and social pain (see also Eisenberger et al., 2003).

1.3 Cyberball: Creating Exclusion

Manipulation of social exclusion can be completed in various ways. For exclusion scenarios, some of the most reliable studies use a program called Cyberball. Cyberball is a tool that allows users to be excluded from a virtual game through a pre-programmed social situation (Williams et al., 2000). Participants are excluded from being thrown a ball after a set number of throws, which then results in the ostracizing scenario, thus achieving the goal of any study involving this phenomenon. The number of tosses, length of game, and number of participants are commonly manipulated variables.

1.4 Gap in Literature and Hypothesis

Although numerous Cyberball experiments have been performed, there is a lack of research when it comes to directly manipulating brain function to see a direct causal link to social exclusion. A 2021 study provided evidence that targeting the DLPFC as well as the VLPFC improved the ability to regulate emotions (Zhao et al., 2021). Additionally, cognitive control is developed in these regions of the brain and is suggested to have a role in the attention towards social situations (Crone & Steinbeis, 2017; Zwanzger et al., 2014). Therefore, while there have been studies that implement 10Hz rTMS on the DLPFC and PFC, such as the 2021 study conducted by Zhao et al., it was not done with a firsthand exclusion game such as Cyberball (Zhao et al., 2021). Thus, the goal of our study was to influence the responses to firsthand social exclusion and further explore the role of the DLPFC through manipulation. We hypothesized that 10Hz rTMS to the right DLPFC would cause increased negative feelings of social exclusion.

2. Materials and Methods

2.1 Participants

Thirteen participants were recruited for the study through social media, word-of-mouth, and a brochure handed out on the Montclair State University campus. The participants' ages ranged from 18 to 65, with 4 males, 8 females, and 1 identifying as ‘other’. Participant self-reported ethnicities included 6 Hispanic, 1 Asian, 4 Caucasian, and 2 who declined to answer. Two participants self-reported being left-handed and 11 right-handed. In exchange for their participation in the experiment, the participants were paid $25. This study was approved by the Institutional Review Board at Montclair State University, and all participants were treated ethically and per APA guidelines.

2.2 Materials

All TMS stimulation employed a 7cm figure-of-eight coil and a Magstim 200 rapid stimulator to deliver pulses at both 10Hz and 1Hz. All presentations, excluding the virtual game of catch, were done on a Lenovo Thinkpad T490 using Testable. Cyberball 5 empirisoft software was downloaded and installed to implement the exclusion game (www.empirisoft.com/cyberball.aspx). Using both Trigno wireless MEP amplifiers and DelSys software, the motor threshold (MT) of each participant was determined (Delsys; www.delsys.com). For the duration of the experiment, the participants wore a Lycra swim cap as well as earplugs.

2.3 Stimuli

Following the conclusion of the Cyberball game, participants were asked a series of questions specific to their experience while playing the game (Supplemental Table 1). A questionnaire was constructed using portions of a question bank made specifically for Cyberball.

Williams provided questions based on senses of belonging, self-worth, control, and meaningful existence (Williams, 2009), while certainty questions were made by Hales and Williams (See supplemental table 1)(Hales & Williams, 2018). Additional questions were made by the research team and placed into Testable. The categories of the question consisted of control, mood, certainty, belonging, self-esteem, anxiety, and the perception of others. These sets were divided into reflexive and reflective scales that referred to how participants felt during (reflexive) or after (reflective) the game. Questions were pulled from a pool, and answers were given using a slider response bar that ranged from 1 to 100. All other numbers were not visible, and the slider started at the neutral position of 50.

2.4 Procedure

Prior to the experiment, each participant signed an informed consent form. Wassermann's guidelines were followed to determine threshold (Wassermann, 1998). Before TMS was administered, a Lyrca swim cap was measured to find the DLPFC, which was marked on the cap. Earplugs were worn while receiving TMS (Shelansky et al., 2022).

To ensure the proper levels of TMS were applied, the participant's MT was established before the experiment. The investigator applied supra-threshold TMS pulses to the contralateral abductor pollicis brevis muscle. This revealed the location of the strongest motor evoked potential (MEP). The coil of the TMS machine was held at a 45-degree angle from the hemispheric line. The coil was then moved around the head of the participant until locating the area that had the maximal peak-to-peak amplitude MEP. The MT of the participant was determined when a MEP of >50 μV was elicited after 50% of the TMS pulses had been delivered. This was done by using the methods recommended by the International Federation of Clinical Neurophysiology (Rossini et al., 2015). TMS was administered throughout the experiment at 90% of the MT, and all MT measurements were performed through Trigno/DelSys.

Utilizing a Lenovo ThinkPad T490, the Cyberball program was administered to the participants once before any TMS. The number of players in the game was 3, with 2 of them being the computer and one of them being the participant. The number of throws was set to 20. The human participant received the ball 3 times at the beginning of the game, immediately followed by the exclusion scenario in which the player did not receive the ball for the rest of the game.

Following the establishment of the participant's MT, TMS was administered to the DLPFC on both the left and right sides. There were a total of 5 trials that were randomized: being Sham for control, 10 Hz Left, 10Hz Right, 1Hz Left, and 1Hz Right. For sham, the TMS coil was held over the vertex (standard 10/20 system coordinates) at a 90-degree angle. TMS was discharged, but no pulses were delivered during the sham trial. 10Hz TMS was administered for 6 seconds in 5 trains, which totals 300 pulses, followed by a 20 second break between each of the trains. The 1Hz TMS was administered for 5 minutes in a single train, for a total of 300 pulses. Following the completion of each TMS session, the Testable stimuli were given to the participant (see above).

3. Results

Data on the 13 participants (N=13) were analyzed using SPSS. We examined differences between reaction times (RT) and brain areas, along with reflexive and reflective answers to the questionnaire. Reflexive questions pertained to how the participants were feeling *during* the Cyberball game itself, whereas reflective questions were tailored to how the participants felt *after* the game.

The mean reflective response was 47.79 (SD=17.36) and the mean reflexive response was 57.10 (SD=17.00). The mean reflective RT was 3956.80 (SD=907.13) and the mean reflexive RT was 5043.56 (SD=1291.36). To determine if there was a relationship between slider response and RT, a bivariate correlation was performed. In terms of reflective responses, it was found that as the slider response increased, RT decreased (r(12)=-.579, p=.038). For reflexive responses, a similarly significant relationship was found (r(12)=-.633, p=.020). These data indicated that there was a possibility that the less time a person contemplated a response, the more negative the response was likely to be (Figures 1 & 2).

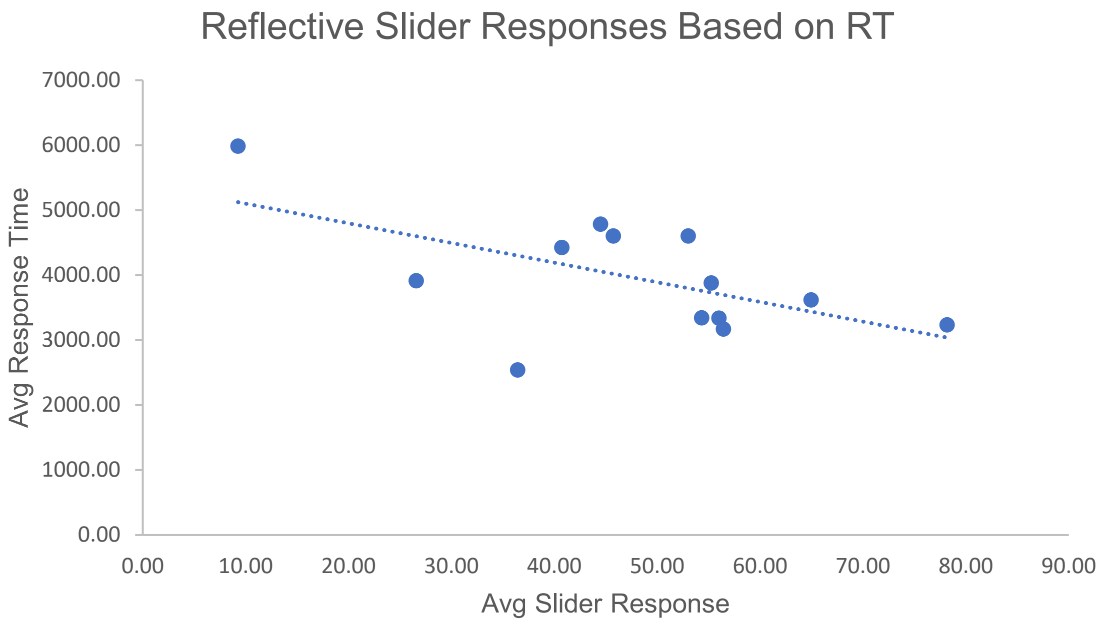

Figure 1. Reflective slider responses based on reaction time. This figure shows the relationship between the various reaction times and slider responses. There is a trend that shows quicker reaction times may attribute to higher scores of exclusion.

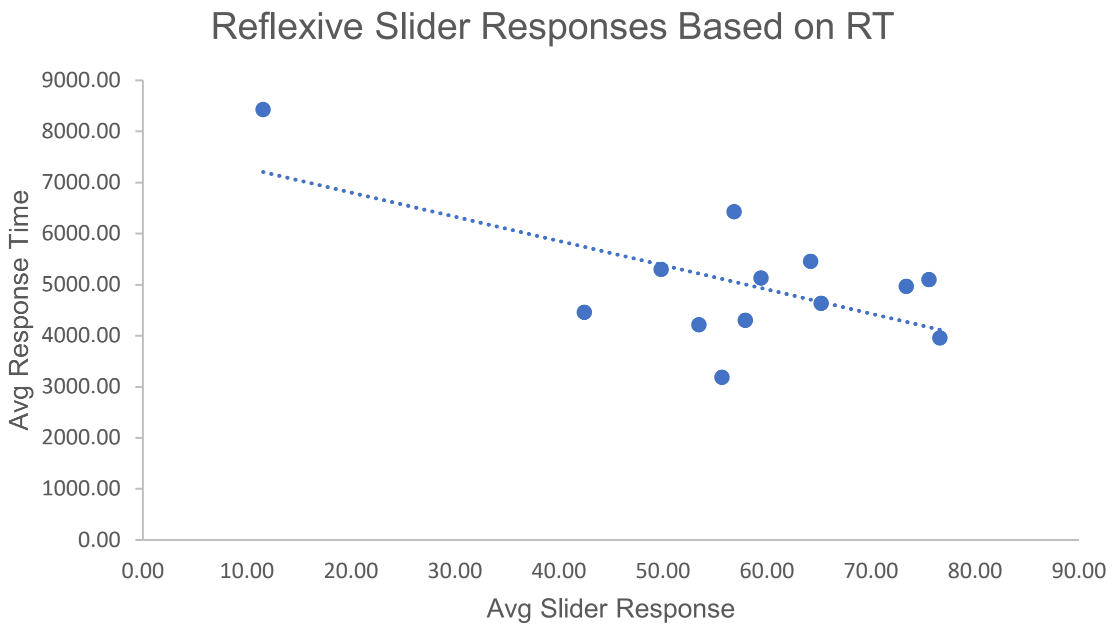

Figure 2. Reflexive slider responses based on reaction time. This figure shows the relationship between the various reaction times and slider responses. There is a trend that shows quicker reaction times may attribute to higher scores of exclusion, which is similar to *Figure 1*.

In addition to the RTs, five brain conditions were analyzed employing repeated measures ANOVAs for the various subscales. The reflective responses had no significant findings. For the reflective belonging responses, there were no significant differences (F(4,44)=.364, p=.833). Reflective certainty scales had no significance (F(4,44)=.465, p=.761). The control questions for the reflective scale had no significance (F(4,44)=.431, p=.786). Reflective mood scales also had no significance (F(4,44)=.635, p=.640). When it came to the perception of others, the reflective scale had no significance (F(4,44)=.349, p=.843). Anxiety, and more specifically social anxiety, has no significance when examining the reflective scale (F(4,44)=.238, p=.935). Lastly, for the reflective scale, self-esteem had no significance either (F(4,44)=1.373, p=.259).

The insignificant results included mood (F(4,44)=1.158, p=.342), manipulation check (F(4,44)=.134, p=.969), perception of others (F(4,44)=1.310, p=.281), and anxiety (F(4,44)=1.001, p=.417).

For the reflexive certainty scale, there was a trend for significance between two different areas. Overall, (F(4,44)=2.430, p=.083) and the post-hoc tests revealed a significant difference between 10Hz right (M=60.792 SD= 22.5343) compared to 1Hz left (M=44.875 SD= 26.7719, p=.046). There was also a significant difference between 1Hz Right (M=62.333 SD=21.4055) and 1Hz left (p=.017). Figure 3 shows the relationship between the different brain regions.

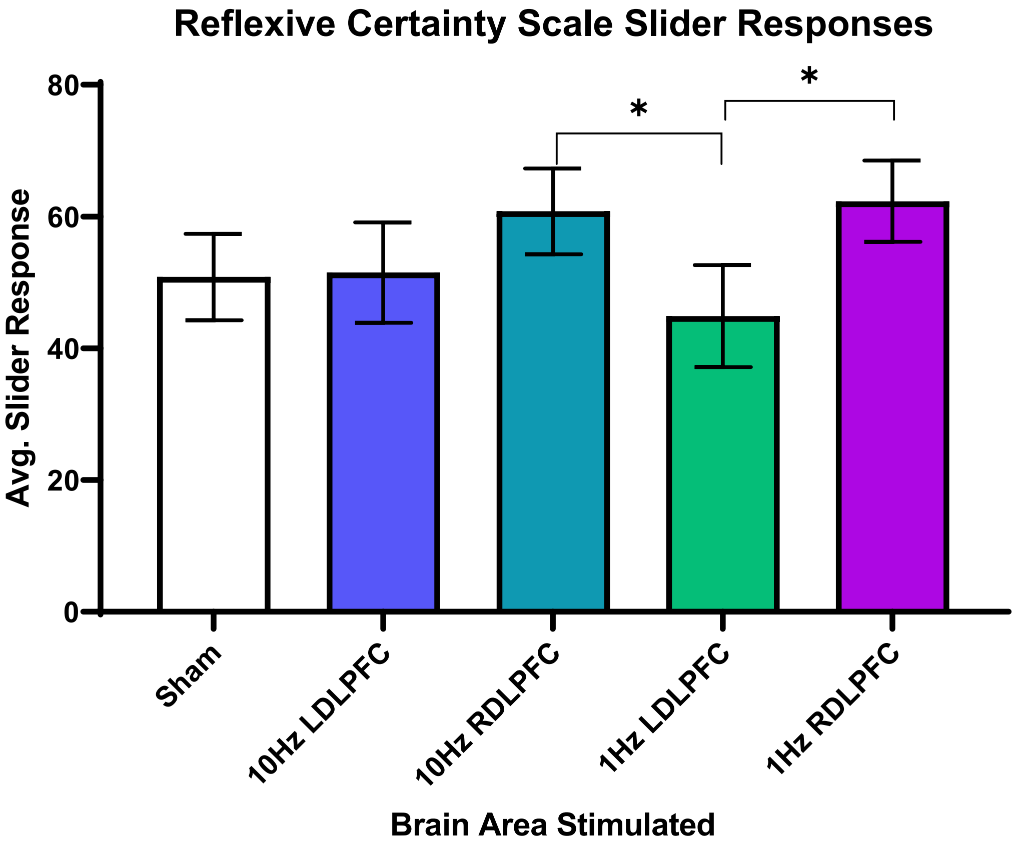

Figure 3. Reflexive certainty scale slider responses. This figure shows the average slider responses based on the region where TMS was performed. Significance was tested using a post hoc analysis. The significance between 10Hz Right and 1Hz Left is p=0.046. Whereas the significance between 1Hz Left and 1Hz Right is p=0.017. Error bars display standard error, and all other connections are non-significant.

For reflexive self-esteem, there was also a significant difference (F(4,44)=3.084, p=.025). The post-hoc tests revealed a significant trend between 10Hz Left (M=55.31,SD=23.84) and 10Hz Right (M=61.04, SD=23.68, p=.075). In Figure 4, it can be seen how there are differences between the brain regions stimulated by TMS.

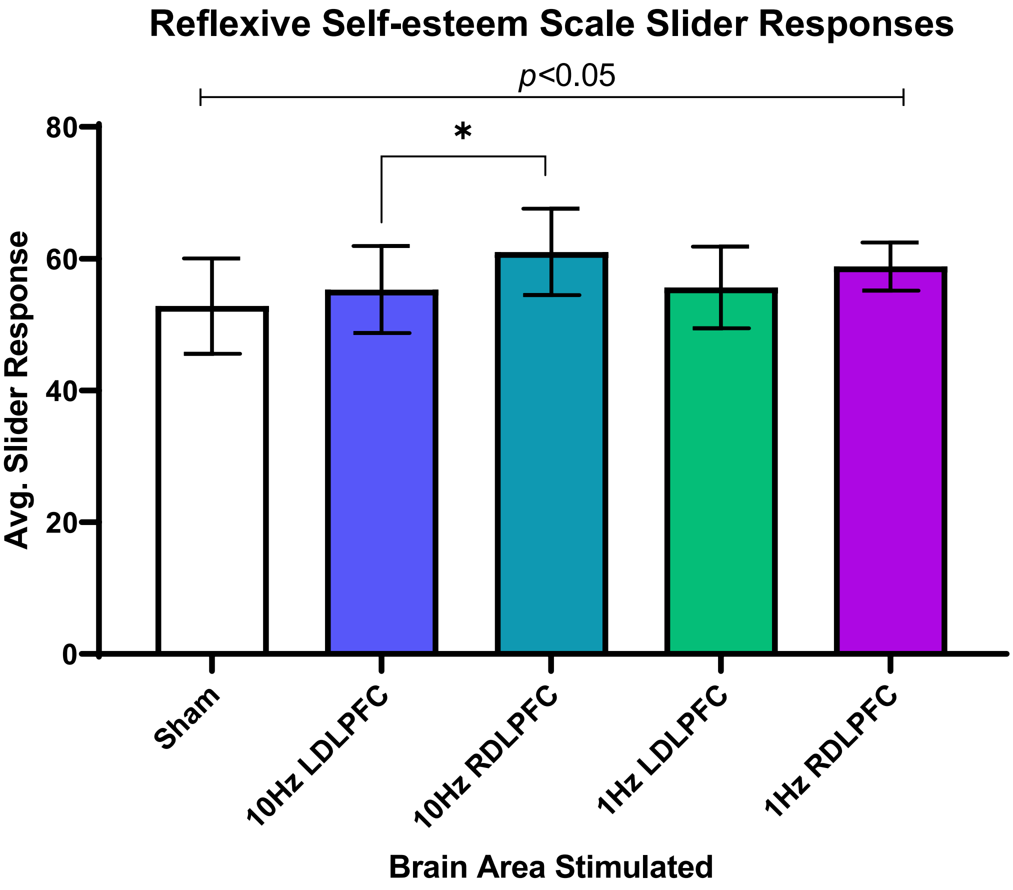

Figure 4. Reflexive self-esteem scale slider responses. The relationship between each area is shown based on a post hoc test. The significant differences are for the 10Hz right and left p=0.075 with an overall significance of p=0.025. Standard error is plotted, and no other relationship is significant.

For reflexive control, there was another significant difference (F(4,44)=3.789, p=.011). Post-hoc tests revealed a significant difference between 10Hz Right (M=75.83, SD=24.38) compared to 1Hz Right (M=66.67, SD=23.84, p=.04). Figure 5 shows the effects of stimulating the right DLPFC with 10Hz, and inhibition of the right DLPFC 1Hz.

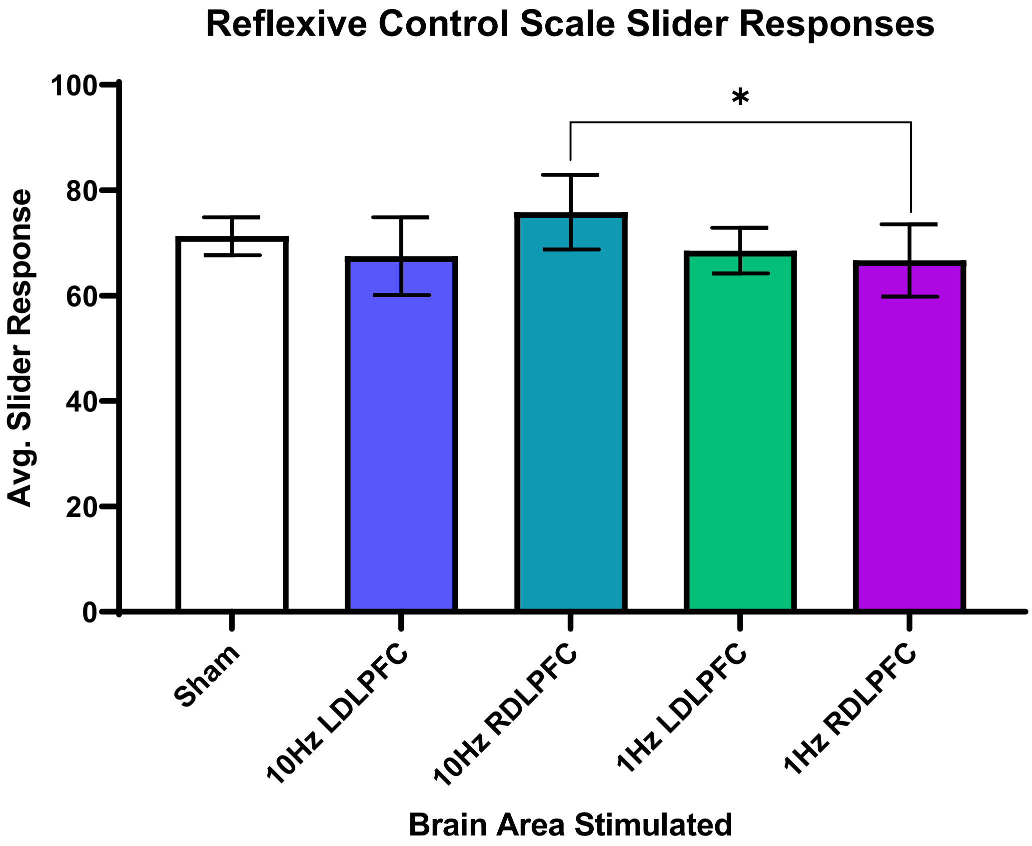

Figure 5. Reflexive control scale slider responses. This figure shows the relationship between the slider responses when asked about control over the game. There are significant differences in the 10Hz Right and 1Hz Right regions p=0.04. Standard error is plotted, and no other significant findings were reported.

4. Discussion

This study employed TMS to examine how manipulating brain activity affects how social exclusion is perceived. The results demonstrated that the DLPFC, more specifically the right DLPFC, may be a key area when processing social exclusion. In comparison to the left hemisphere, the right hemisphere of the DLPFC appeared to have a greater effect on feelings of exclusion. When assessing the data, participants consistently felt more excluded when the right DLPFC was excited.

Of interest is that quicker response times correlated with greater feelings of exclusion. There is a negative correlation between response times and slider responses. This infers that a more painful feeling of exclusion could elicit a quicker response. Conversely, given more time to think, participants had more positive responses. This relationship may be caused by demand characteristics or the halo effect. Demand characteristics occur when participants may be aware of what the researchers are investigating (McCambridge et al., 2012). Participants may have known about the manufactured exclusion scenario and replied based on what they believed we were looking for. Alternatively, the halo effect could be used to provide a similar explanation. Participants in this situation may have responded more positively because they had more time to do so, enhancing their self-image and countering the idea of being excluded.

Our findings are in line with other exclusion experiments that suggest the prefrontal cortex is a key area when processing exclusion and other social experiences (Bicks et al., 2020; Eisenberger et al., 2003; Park et al., 2021; Ruocco et al., 2010). Makinodan and colleagues suggest that isolation events can instill both behavioral and cognitive changes in adults and may correlate with white matter alterations in the prefrontal cortex (Makinodan et al., 2012).

The reflexive certainty scale evaluated the participants on how they felt about themselves during the Cyberball session. There were significant differences in slider responses when comparing both 10Hz right and 1Hz right TMS to 1Hz left TMS. When both exciting and inhibiting the right DLPFC, participants were more uncertain of themselves in the social event. This suggests that when exciting the right DLPFC, feelings of uncertainty about the social scenario increased. Conversely, it was seen that inhibition of the left DLPFC reduced feelings of exclusion compared to sham, suggesting that inhibition of the left DLPFC reduced the effects of exclusion. Previous findings have indicated left PFC TMS reduces social exclusion (Elliott et al., 2012; Heller et al., 2013). Additionally, a previous study demonstrated that excitation of the right DLPFC can lead to a decrease in the ability to make decisions (Chrysikou et al., 2017). To elaborate, the previous study found a significant decrease in approach behavior when exciting the right DLPFC. Contrary to our current results, it was previously found that excitatory TMS of the left DLPFC improved certainty of social decision making (Chrysikou et al., 2017). Based on our data, it is suggested that inhibition of the left DLPFC may improve certainty in social decision making.

For the reflexive responses, self-esteem scores went beyond the concepts of certainty and instead emphasized the participants’ insecurities and sentiments. While overall feelings of exclusion were higher than average for each brain region, there was a significant difference between the 10Hz left and 10Hz right scores. Similar to the other subscales, the 10Hz right region had the strongest feelings of exclusion, suggesting that when increasing self-awareness through excitation, participants became more self-conscious of themselves. Specifically, the excitation of the right DLPFC was significantly higher than the excitation of the left DLPFC. Studies suggest that the DLPFC is recruited when judging oneself, and increased activity in the

DLPFC leads to stronger criticism (Longe et al., 2010; Lord et al., 2012; Paulus & Stein, 2010). A further study found that highly self-critical people tend to have lower self-esteem (Heine et al., 1999). These findings imply that the right DLPFC may be more responsible for negative self-view. Additionally, the DLPFC shows greater connectivity to other regions that are involved in negative feelings, such as the insula (Jiang et al., 2018). Moreover, the same connection is stronger in the right lateral prefrontal cortex, thus inferring the right side is an area of significance (Ochsner & Gross, 2004; Petrides, 2005). It is possible, based on our current results, that the exclusion event may amplify feelings of self-criticism.

The last significant finding was the reflexive control scale. The results showed this subscale had the strongest feelings of exclusion. Questions pertained to feeling in control and having influence over the game. Additionally, based on the questions asked, it could potentially relate to fairness. For example, there was a specific question that asked if participants felt the other players decided everything during the game. Based on our current findings, participants may have found the game less fair when the right DLPFC was excited. The current results could challenge previous findings that fairness is independent of the right DLPFC (Knoch et al., 2006; Strang et al., 2014). Additionally, the DLPFC is a key area of cognition control, so altering it will most likely have effects on responses (Fuster, 2001; Goldman-Rakic, 1996). Our current results suggest that inhibition of the left DLPFC reduces feelings of exclusion, as is seen in previous studies that relate to reduction in conditions such as depression (Asgharian Asl & Vaghef, 2022).

While there were consistent findings and trends for the right DLPFC, this study had some limitations. Future studies should replicate these results using a larger sample. Further studies may manipulate the length and parameters of the game with more sessions. Another limitation was the number of questions which could be expanded if longer trains of TMS were delivered

(Supplemental Table 1). Moreover, questions could be rephrased to account for demand characteristics and the halo effect. Additionally, the study only targeted the DLPFC, and exploring other brain regions may be beneficial.

In conclusion, based on the responses, the excitation of the DLPFC correlated with increased feelings of exclusion. Furthermore, this study supports the idea that the right DLPFC may have a more involved role in social scenarios and pain processing than originally thought. Conversely, the study also suggests that the left DLPFC can be involved in exclusion scenarios as well. This would suggest that there is more lateralization involved than a total frontal lobe effect. What this means is that the left and the right sides of the DLPFC may have independent influences over social exclusion. These findings may lead to a better understanding of how our brain works in relation to a vital aspect of human life, social scenarios.

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6. Supplemental Information

Supplemental Table 1. Stimuli Question Pool

Questions	Category
I felt "disconnected" during the game.	Belonging
I felt "rejected" during the game.	Belonging
I felt like an outsider during the game.	Belonging
I felt good about myself during the game.	Self-esteem
My self-esteem was high during the game.	Self-esteem
I felt insecure during the game.	Self-esteem
I felt like I had control during the game.	Control
I felt the other players decided everything during the game.	Control
I felt powerful during the game.	Control
I felt uncertain about myself during the game.	Certainty
I did not know what I should be doing during the game.	Certainty
I felt unsure of what makes me who I am during the game.	Certainty
I felt friendly during the game.	Mood
I felt angry during the game.	Mood
I felt happy during the game.	Mood
I was ignored during the game.	Manipulation check
I was excluded during the game.	Manipulation check
I felt like I wanted to escape the game.	Anxiety
I felt like I wanted to leave the game.	Anxiety
I felt uneasy during the game.	Anxiety
I liked the other players.	Perception of others
I enjoyed playing with the others.	Perception of others
I was angry at the other players.	Perception of others
I feel 'disconnected'.	Belonging
I feel 'rejected'.	Belonging
I feel like an outsider.	Belonging
I feel good about myself.	Self-esteem
My self-esteem is high.	Self-esteem
I feel insecure.	Self-esteem

I feel like I have control.	Control
I feel the other players decided everything.	Control
I feel powerful.	Control
I feel uncertain about myself.	Certainty
I do not know what I should be doing.	Certainty
I feel unsure of what makes me who I am.	Certainty
I feel friendly.	Mood
I feel angry.	Mood
I feel happy.	Mood
I would join another game.	Anxiety
I would sign up for another game.	Anxiety
I look forward to my next social event.	Anxiety
I like the other players.	Perception of others
I enjoy playing with the other players.	Perception of others
I am angry at the other players.	Perception of others