Lateralization of Facial Emotion Recognition in the Human Cerebellum:

A Transcranial Direct Current Stimulation (tDCS) Study

by

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Abstract

The cerebellum, one of the oldest structures in the nervous system, is well-known for the important role it plays in the coordination and timing of movement. However, there has been a paradigm shift with recent clinical, neuroimaging, and experimental research suggesting that the cerebellum also plays a role in higher-order cognitive functions such as attention and emotion. The substantial increase in research regarding the cerebellum's ability for emotional processing has indicated that it may be particularly adept at recognizing and processing negative facial expressions (e.g., fear, anger, sadness). Previous research using functional brain imaging and patients with cerebellar brain injuries provide some evidence of cerebellar lateralization, with the left cerebellum being more specialized for processing emotions than the right. To examine this, we delivered transcranial direct current stimulation (tDCS) over the left cerebellum of 67 healthy participants, randomly assigned to a tDCS condition (anodal, cathodal, or sham), and had them complete a facial emotion recognition task pre-tDCS, during-tDCS, and post-tDCS. Anodal and cathodal cerebellar tDCS did not significantly alter participant reaction time and accuracy. Participants did get faster, less variable, and more accurate over time, especially for positive emotions (happy), compared to negative emotions (angry and sad). However, due to relatively limited research examining the role of the cerebellum in emotion processes, and the limitations of the current study, we cannot say for certain why there were no effects of tDCS.

Keywords: cerebellum, cerebellar lateralization, cerebellum and cognition, facial emotion recognition, transcranial direct current stimulation (tDCS)

Lateralization of Facial Emotion Recognition in the Human Cerebellum: A Transcranial Direct Current Stimulation (tDCS) Study

The cerebellum ("little brain") is an ancient and distinct subdivision of the brain, located in the posterior fossa of the skull beneath the tentorium and occipital lobe of the cerebral hemisphere, and is traditionally known for the role it plays in the timing, control, and coordination of movement (Adamaszek et al., 2022; Glickstein et al., 2009). It was evident from the earliest experimental studies on animals that cerebellar lesions cause motor deficits; specifically, lesions impaired coordination, which was related to a fundamental impairment in muscle control (Glickstein & Doron, 2008). For almost 200 years, it was believed that the cerebellum was exclusively involved in motor processes, due to a focus on the pronounced motor deficits and the simultaneous dismissal of any neuropsychiatric, behavioural, or cognitive phenomena that contradicted the established dogma (Schmahmann et al., 2019). One of the reasons that emphasis on motor control was so ubiquitous in research was because the peculiar cerebrocerebellar circuitry made it difficult to examine the cerebellum's organizational properties using traditional techniques (Buckner, 2013). The cerebellum and cerebrum are interconnected contralaterally through two postsynaptic circuits: an input channel that initially synapses on the ipsilateral pons and then crosses into the contralateral cerebellum, and an output channel that projects to deep cerebellar nuclei, the contralateral thalamus, and then to the cerebral cortex (Buckner, 2013). This polycircuitry made it difficult to establish anatomical evidence that the cerebellum projects onto nonmotor structures, leading research to focus almost entirely on motor functions (Buckner, 2013).

Converging evidence accrued over the past several decades indicates that the function of the cerebellum extends beyond motor control, playing a significant role in higher order cognitive

functions (Adamaszek et al., 2017; Glickstein & Doron, 2008; Schmahmann & Sherman, 1998). For example, Leiner et al. (1986) proposed that the cerebellum contributed to mental skills, based on phylogenetic and ontogenetic evidence in early primates that suggests that the cerebellum acts as a powerful, general-purpose computer with a wide variety of applications depending on the evolved input-output connections between the cerebellum and cerebrum. This proposal was later supported by anatomical studies (e.g., Middleton & Strick, 1994) and clinical trials on patients with lesions in the cerebellum (Leiner, 2010). Primate research also shows that the posterior and lateral parts of the cerebellum have expanded disproportionately in the human brain and are interconnected with numerous attention networks in the cerebrum (Adamaszek et al., 2022). Researchers suggest that the increased role of the cerebellum in cognitive and emotional functions may be due to an increase in social interactions as humans evolved to live in groups (Adamaszek et al., 2022). Such findings have majorly revised researchers' understanding of the cerebellum.

Cerebellum and Cognition

As research into the role of the cerebellum in cognition was gaining popularity, an early study by Schmahmann and Sherman (1998) proposed the idea of cerebellar cognitive affective syndrome (CCAS) to describe the constellation of behavioural changes and cognitive dysfunctions they observed in patients. By using neurological examinations, neuropsychological testing, and anatomical neuroimaging of individuals with focal cerebellar lesions, they noted impairments in executive functions, spatial organization and memory, affect, and language deficits. This seminal study can be considered a starting point for a surge of neuroscientific research investigating nonmotor functions of the cerebellum. According to the *dysmetria of thought* theory, the cerebellum provides the same accuracy, appropriateness, and consistency to

cognitive and affective functions that it does for motor related functions (Schmahmann, 1998). Essentially, the cerebellum fine tunes our cognitive and affective processes, similar to its motor role (Baumann & Mattingley, 2022; Schmahmann et al., 2019).

There are three main types of evidence that support the growing idea that the cerebellum is involved in higher order cognitive functions: (1) cerebellar activation in normal subjects as they perform cognitive tasks (e.g., Laird et al, 2005; Stoodley & Schmahmann, 2009), (2) neuropsychological deficits in patients with cerebellar lesions (e.g., Schmahmann & Sherman, 1998), and (3) the anatomical connections between the cerebellum and a myriad of structures in the cerebral cortex that are involved in cognition (e.g., Buckner, 2013; Glickstein & Doron, 2008). Anatomical evidence indicates that output to nonmotor areas of the cerebral cortex, such as the prefrontal and posterior parietal cortex, originate from the ventral portion of the dentate nucleus (Middleton & Strick, 1994; Strick et al., 2009). Neuroimaging and neuropsychological research provide compelling evidence that the cerebellum is functionally important in human cognition and affect. The higher-order cognitive functions of the cerebellum include working memory, attention, executive function, language, learning, and emotion (Buckner, 2013; Gordon, 2007; Stoodley & Schmahmann, 2009).

Resting-state functional connectivity magnetic resonance imaging (fcMRI) studies demonstrate that the cerebellum is contralaterally connected to distinct cerebral areas (Buckner et al., 2011). Functional connectivity maps show that anterior and posterior cerebellar lobes (including lobules IV, V, VI, and VIIIB) mapped to the somatosensory cerebral network (Buckner et al., 2011). Most of the cerebellum (including Crus I and II, and positions of the simplex lobule HVI, HVIIB, and IX) maps to cerebral association networks, including those associated with sensory-motor integration, cognitive control, and default networks (Buckner et

al., 2011). A map of the cerebellum by Buckner et al. (2011) shows that the cerebellum contains multiple complete maps of the cerebral cortex and that, generally, there is a strong, homotopic, relationship between cerebral surface area and its cerebellar representation. Using functional MRI, Stoodley et al. (2012) demonstrated that there is different involvement of cerebro-cerebellar circuits depending on the task performed: sensorimotor cortices were activated along with contralateral cerebellar lobules IV-VI and VIII during overt movement (e.g., finger tapping), while cognitively demanding (e.g., language and spatial processing) tasks engaged parietal, temporal, and pre-frontal cortices as well as cerebellar lobules VI and VII. Additionally, they found that motor tasks typically fall under the domain of the anterior cerebellum, while cognitive tasks are linked to the posterior cerebellum. These neuroimaging studies support the idea that the cerebellum is involved in cognitive tasks in addition to its well-established motor abilities, and that the function of the cerebellar region is defined by its cortical and subcortical connections.

Cerebellar Connections and Lateralization

Hemispheric asymmetry is the concept that the left and right cerebral hemispheres differ in size, shape, and function (American Psychological Association, n.d.). The asymmetries of the cerebral hemispheres in affective and cognitive functions has been extensively studied and most neuropsychological research and neuroscientific literature supports the idea of a right hemisphere lateralization for visuospatial processing, emotion, attention, and arousal (Hartikainen, 2021). As well, the left cerebral hemisphere is known to be lateralized for communicative speech, language functions, and logical reasoning (Hartwigsen et al., 2021).

It has been observed, using neuroimaging procedures, that there are correlated fluctuations between the cerebral cortex and the cerebellum, with preferential coupling to the

contralateral cerebellum (Buckner, 2013). Neuroimaging studies have found that functional asymmetries within the cerebellum will organize as flipped versions of the functional asymmetries in the cerebral cortex (Wang et al., 2013).

In a study of children with cerebellar tumours, researchers found that those with greater damage to their right cerebellar hemisphere had more pronounced language deficits as opposed to children with greater left cerebellar damage, who experienced deficits in non-verbal and spatial skills, which is in-line with the idea that the left cortical hemisphere (specialized for language) projects to the right cerebellum and that the right cortical hemisphere (specialized for visuospatial processing) projects to the left cerebellum (Scott et al., 2001). Resting state fMRI studies provide evidence that cerebellar lobules VI, Crus I, Crus II, and VIIb receive projections from regions known to be involved in language function such as the prefrontal, posterior parietal, and superior temporal cortices (Vias & Dick, 2017). A meta-analysis by Stoodley and Schmahmann (2009) found that language and verbal memory tasks resulted in strong activation peaks lateralized to the cerebellar right lobule VI, CrusI/Crus II, and midline lobule VIIAt. In contrast, they found that spatial processing showed greater left-hemisphere activation, particularly in lobule VI. Wang et al. (2013) found that the most strongly lateralized left cerebellar regions were in lobules VI and VII, both of which linked to right hemisphere cerebral association networks including the right angular gyrus, supramarginal gyrus, and insula. Visuospatial and attention processing involves the right angular gyrus, supramarginal gyrus, insula, and left lobule VI of the cerebellum (Buckner, 2013; Wang et al., 2013). The degree of cerebellar lateralization is correlated with the degree of lateralization in the in the cerebrum – that is, lateralization in the cerebellum is caused by its contralateral connection to the cerebral hemisphere (Wang et al., 2013).

Cerebellum and Emotion Recognition

One area that has received increasing attention in recent years is the potential role of the cerebellum in emotion. As discussed earlier, the landmark study by Schmahmann and Sherman (1998) found that patients with damage to their cerebellum experienced several cognitive and affective symptoms, aptly coined CCAS. The affective symptoms they observed were blunting or disinhibition of affect. The paradigm shift that occurred as a result of this study lead to an increase in research into the role of the cerebellum in cognitive and affective functions. Insights into the cerebellum's ability for emotional processing, perception, recognition, encoding of emotional information, and emotional learning has increased concurrently (Adamaszek et al., 2017). Through clinical, experimental, neuroimaging, and neurophysiological investigations, it has been found that the cerebellum is part of the cortico-limbic network responsible for emotion processing (Adamaszek et al., 2017).

Emotion recognition is a component of social cognition. Social cognition refers to people's ability to infer emotional information from facial expressions; deficits in emotion recognition can lead to difficulties identifying the intentions and opinions of others, thus resulting in impaired social behaviour (Adamaszek et al., 2014). Faces are multi-dimensional stimuli that convey many important signals with complex social meaning; they provide an array of distinctive information (e.g., sex, age, identity), as well as more subtle emotional signals (Ferucci et al., 2012). There are some facial expressions of emotion that are universally recognised, such as happiness, anger, fear, and sadness (Ekman, 1992). Such expressions target specific neural responses, and the ability to recognize the emotional content in facial expression is a hugely important social communication skill in humans (Ferucci et al., 2012; Scheuerecker et al., 2007). Facial perception involves recognizing specific patterns and facial structures, and

dynamic patterns of facial expressions, engaging many brain structures such as the amygdala, insula, fusiform face area, anterior temporal lobes, and portions of the occipital and parietal lobes (Gobbini & Haxby, 2007).

Numerous studies have indicated the right cerebral hemisphere is favoured over the left hemisphere in recognition and processing of emotional information in its overall cognitive networks and at the level of the right amygdala and insula (Gainotti, 2019). Based on the *valence hypothesis*, arousing emotional stimuli, particularly if it is unpleasant or threatening, are prioritized in attentional resource competition, and have prioritized access to right-lateralized attention networks due to evolutionary survival mechanisms (Hartikainen et al., 2000; Gainotti, 2019). The ability to recognize negative emotions, such as anger and sadness, are crucial to an organism's survival because it activates defence systems that are designed to protect organisms against threats, making it likely that such expressions activate phylogenetically older circuits including the cerebellum (Ferucci et al., 2012).

Although the cerebellum has been shown to process both positive and negative emotions, it has been suggested that there is a slight predominance of negative emotional processing (Ferucci et al., 2012; Park et al., 2010). Clinical studies of patients with cerebellar strokes, particularly in the left cerebellum, showed an impairment in the ability to recognize emotions, especially for negative emotions (Adamaszek et al, 2014; Moulton et al., 2011). To optimize human survival, it follows that negative emotions such as fear, sadness, and anger would be directly related to quicker appraisals and behavioural responses because they are time-critical responses (Baumann & Mattingley, 2022). The cerebellum is important in developing internal models of the world and prediction of future events; thereby allowing humans to make swift accurate appraisals of valent emotions (Baumann & Mattingley, 2022).

Data from clinical and neuroimaging studies have identified the cerebellum as a key region in the emotion relevant structures of the brain and that there are distinct regions within the cerebellum that are involved in different primary emotions (Baumann & Mattingley, 2012; Stoodley & Schmahmann 2009; Stoodley & Schmahmann 2010). In particular, the posterior portion of the cerebellum is responsible for emotion recognition and perception (Adamaszek et al., 2022). There are two discrete neural systems that support emotional perception: a conscious (explicit) level and a non-conscious (implicit) level (Scheuerecker et al., 2007). The cerebellum appears to be involved in both implicit and explicit processing of emotions (Scheuerecker et al., 2007). In studies using transcranial magnetic stimulation (TMS), transient lesions of the cerebellum result in reduced accuracy in implicit and explicit emotion recognition tasks (Ferrari et al., 2018). Neurophysiological findings demonstrate that patients with left cerebellar lesions have lowered skin conductivity in response to negative emotional stimuli, further emphasizing the cerebellar involvement in unconscious, automatic neural pathways during emotional processing (Annoni et al., 2003).

In a study of patients with discrete cerebellar lesions, Adamaszek et al. (2014) found that on emotion facial expression tasks, they were impaired in selection and matching of facial affect and on prosody tasks. Prosody tasks involved naming the emotion that a voice was depicting as well as discriminating incongruencies between the emotion a voice was depicting, and the label that was paired with that emotion. These deficits were more pronounced for negative affects and in individuals with damage to their left cerebellum. When processing emotional stimuli, left cerebellar hemisphere clusters involving lobules VI and Crus I were present (Stoodley & Schmahmann, 2009). Neuroimaging studies have demonstrated activation in the left lateral cerebellar hemisphere, particularly Crus I and II of lobule VI, may be key areas of emotional and

cognitive information due to their functional connections to right hemisphere inferior parietal and frontal lobes; this information can then be furthered to prefrontal areas of the cerebral cortex (Guell et al., 2018; Han et al., 2016).

Cerebellar Stimulation

One of the earliest studies linking the cerebellum to emotional functions described a case in which a patient experienced electrical stimulation to their cerebellar dentate nucleus and cerebellar superior peduncle and reported experiencing negative feelings (Nashold & Slaughter, 1969). In the 1970s, it was found that chronic stimulation to the cerebellum improved emotional symptoms such as depression and anxiety in affected patients (Adamaszek et al., 2017). Ferrucci et al. (2012) used cerebellar direct current stimulation in healthy adults and found that, relative to sham conditions, anodal and cathodal stimulation led to a reduction in response time when identifying negative emotional facial expressions. The results of this study are in line with fMRI studies where negative emotional stimuli activated the posterior cingulate gyrus, fusiform gyrus, and the cerebellum (Park et al., 2010).

As interest in the cerebellum has increased, so has the use of transcranial direct current stimulation (tDCS) to study the motor and non-motor functions of the cerebellum (Oldrati & Schutter, 2017). tDCS is an effective, safe, non-invasive neuromodulatory tool that delivers a weak electrical current over the scalp, creating a constant electric field that penetrates the skull to alter neuronal function (Ferrucci et al., 2012; Oldrati & Schutter, 2017). An electrical current of 2.0 mA provided by tDCS for 15-20 minutes can reach the outer layer of the cerebellar cortex (Oldrati & Schutter, 2017). The electrical current flow between the tDCS electrodes has very little functional spread to neighbouring regions and can produce neurophysiological and behavioural changes (Pope & Miall, 2014). Cerebellar tDCS influences cerebro-cerebellar

circuits and can modulate, or even enhance cognitive functions in healthy participants (Pope & Miall, 2014). Typically, when used on the cerebral cortex, cathodal (-) tDCS suppresses neuronal function and anodal (+) tDCS increases neuronal function; however there has been little evidence of polarity-dependent effects for cerebellar tDCS (Oldrati & Schutter, 2017). This is likley due to anatomical differences between the cerebral cortex and the cerebellum **(**e.g., the cerebellum is densely packed and provides inhibitory output to the cerebral cortex) (Oldrati & Schutter, 2017; van Dun et al., 2016).

The Current Study

The current study will investigate the role of the left cerebellum in processing facial emotions by using tDCS. By applying a localized, precise electrical current over the left cerebellum, the neuromodulatory influence of tDCS will work as a tool to investigate the potential of lateralization in the cerebellum. It is well established that the cerebellum is contralaterally connected to the cerebral cortex (e.g., the right hemisphere of the cerebral cortex connects to the left hemisphere of the cerebellum and vice versa) and there are correlated fluctuations in activity between the contralaterally connected structures (Buckner, 2013). Extensive research into cerebral hemispheric asymmetry suggests that the right hemisphere is dominant in emotion perception and recognition, and that it may be particularly adept at dealing with negative emotions (which can be a highly arousing) as it has implications on evolutionary survival mechanisms (Hartikainen et al., 2000, Hartikainen, 2021; Gainotti, 2019). Thus, it would follow that the right hemisphere's contralateral connection to the left cerebellum would result in lateralized emotion recognition. Neuroimaging and neuropsychological studies (e.g., Wang, 2013; Stoodley & Schahmann, 2009; Adamaszek et al., 2014; Baumann & Mattingley 2012) indicate a more direct left cerebellar lateralization for emotion recognition. Furthermore, the

cerebellum may be more proficient at processing negative emotions (e.g., Ferrucci et al., 2012; Adamaszek et al., 2014; Mouton et al., 2011; Annoni et al., 2010).

Therefore, if the cerebellum is lateralized and the left lobe is more specialized for processing emotions, we expect to see changes in the speed and accuracy with which participants recognize emotional expressions, particularly negative emotional expressions, compared to neutral faces for anodal (+) and cathodal (-) tDCS conditions. We do not expect to see these changes in sham tDCS conditions.

Method

Participants

A total of 67 participants (M_{age} = 21.7, 41 females, 26 males, 4 left-handed, 1 ambidextrous, 62 right-handed) were recruited from the MacEwan University research participant pool through the use of SONA and advertisements posted around campus. Each participant was randomly assigned to one of three stimulation conditions, anodal (+), cathodal (-) or sham. Participants received either partial course credit or $15 cash. This study was approved by the MacEwan Research Ethics Board.

Materials

Screening Form

Before participants could sign up for the study, they did an online 27-item screening form to determine eligibility. The only demographic question that would make a participant ineligible was age, anyone under 17 years old and over 65 years old were ineligible to participate. The main exclusion criteria had participants indicate whether they have ever had a brain injury or

have been diagnosed with a neurological condition (e.g., Parkinson's disease, Multiple Sclerosis, Stroke), if they or any of their family have epilepsy or have ever had a seizure, if they experience migraines or are prone to severe headaches, and if they are currently taking any psychiatric medications. If the participant answered "yes" to any of these, they were ineligible to participate in the study (see Figure 1).

tDCS Adverse Effects Questionnaire

At the end of the study participants did an online adverse effects questionnaire to indicate whether they were experiencing any symptoms or side effects on a scale of 1 (absent) to 4 (severe). This included headache, neck pain, scalp pain, scalp tingling, scalp itching, burning sensation on the scalp, skin redness, sleepiness, trouble concentrating, and acute mood change. If there was a symptom or side effect present, they would indicate on a scale of 1 (none) to 5 (definite) whether it was related to the tDCS (see Figure 2).

Facial Emotion Recognition Task

The face stimuli for the emotion discrimination task were selected from the NimStim emotional faces database (Tottenham et al., 2009). From the database 41 (17 female; 24 male) images for, sad, angry, happy, and neutral expressions were selected. The same actors were used for each expression. Every actor from the database with a mean accuracy of less than 50% for each emotion or who were missing an image for any the four emotions used were eliminated from the study. All expressions were the open mouth version because they were the most salient versions of the emotional expressions with the highest average accuracy (i.e., accuracy was highest for open mouth happy compared to extreme happy or closed mouth happy). The same

images were used each time the participants completed the task. All images were black and white photos presented in the centre of the screen at 506 x 650 resolution for 200 milliseconds (ms).

This task was modelled after the study done by Ferrucci et al. (2012). A four-alternative-forced-choice (4AFC) task was created on Testable (testable.org) using the images selected from the NimStim database. Participants completed 12 practice trials where they received feedback on correctness before starting the experimental portion (163 trials) where they no longer received feedback. This task measured the participants accuracy and reaction time (RT). Each participant completed this task three times: once before tDCS (baseline), during tDCS, and immediately after tDCS. Participants indicated, by pressing a key on a computer keyboard whether the emotional facial expression they saw was angry, sad, happy, or neutral ("A" = angry, "S" = sad, "H" = happy, "N" = neutral). The researcher told the participant to respond as quickly and accurately as they could. While doing the 4AFC task, participants had their chin resting on a chin rest about 15.6 inches away from the computer screen (Lenovo ThinkCentre computer, 24-inch widescreen Lenovo ThinkVision monitor, 60 Hz refresh rate) to ensure central fixation and that all participants were looking at the screen from the same angle (straight on). To prepare the participants for the upcoming emotional image and be certain of central fixation, a red fixation cross was presented on the screen for 1 second, followed by a black fixation cross for 1.5 seconds, and then the image of the person displaying an emotional expression was presented for 200 ms. Participants had 3 seconds to respond by pressing the corresponding key on the keyboard, before the task automatically moved on to the next trial. This task took approximately 15 minutes to complete (see Figure 3). The dependent measures were accuracy and reaction time (RT).

Cerebellar tDCS

Participants (N = 67) were randomly assigned one of three tDCS conditions: anodal (+), or cathodal (-), or sham. The tDCS was delivered at 2.0 mA for 20 minutes over their left lateral cerebellum. Participants did not know which stimulation condition they were receiving. Cerebellar tDCS was applied using a stimulator that delivered a constant and direct electrical current (Mind Alive, Edmonton) through wires connected to a pair of saline soaked sponge electrodes. The active electrode (5 x 5 cm) was placed 1 cm below and 4 cm to left of the inion, approximately over left cerebellar lobule VII/Crus I, and the reference electrode (7 x 5 cm) was placed on the left shoulder. This induced a current density of .08mA/cm under the active electrode (i.e., 2mA/25cm^2). The active electrode was held in place by fabric headbands and the reference electrode was held down by a light, weighted bag to ensure a stable connection (see Figure 4). Most participants reported experiencing a mild itching or tingling sensation, particularly where the shoulder electrode was placed, for up to 1 minute and then felt no other sensations. To ensure participants were blind to the tDCS condition they were assigned, during the sham condition, the tDCS machine was changed to a setting wherein active stimulation was delivered for 45 seconds to mimic the initial itching/tingling sensation and then the current ramped down so that they did not receive anodal or cathodal stimulation for the remaining duration of the session. It is important to note that, although the current turned off during the sham session, the lights on the stimulator remained on so it appeared that the stimulator was still running.

Experimental Protocol

Students were recruited through the introductory psychology courses and poster advertisements. The participants then signed up for a 90-minute time slot to take place on

campus at MacEwan University in a psychology research laboratory. These sessions were one-on-one between the participant and the researcher. Participants were assigned an anonymous participant ID. The participants then completed the online tDCS screening questionnaire and the consent form on the lab computer**.** Once consent had been obtained, the researcher gave an overview of what would happen in the study (e.g., when, and how many times they will do the 4AFC task, where the electrodes will be placed). After the instructions for the 4AFC task were explained, the participants completed the 4AFC task for the first time (pre-tDCS, baseline measurement).

After they completed the baseline task, the researcher reiterated the safety of tDCS, and its widespread use in psychological research. The researcher also explained that an itchy, warm, or tingling sensation was completely normal but if it was uncomfortable or they wanted the machine turned off at any point, to immediately let the researcher know. Once the tDCS equipment was set up, the participants did the 4AFC task a second time. Because the tDCS session lasted 20 minutes and the 4AFC task only took 15 minutes, participants were asked to sit still and wait until the tDCS machine turned itself off. If the chin rest was causing discomfort, the researcher guided them into a more comfortable sitting position to ensure a continued, stable connection for the remaining 5 minutes.

Immediately after the tDCS stimulation session ended, the researcher removed the electrodes, headband, and weighted bag from the participant and told them to complete the 4AFC task for the third and final time (post-tDCS). Following completion of all of the 4AFC tasks, the participants completed the tDCS adverse effects questionnaire (see Figure 5). The participants were then given a verbal debrief of the purpose of the study, were made aware that a copy of the

consent form and debriefing form was sent to them via email, and that they were encouraged to contact the researcher if they have any questions or concerns.

The results for the tasks were automatically saved to Testable as CSV files and data from the forms (screening and Adverse Effects) was saved on Google forms.

Results

We analyzed participant responses on the tDCS adverse effects questionnaire using one-way ANOVAs for all three groups (anodal, cathodal, sham) for each symptom (headache, neck pain, scalp pain, scalp tingling, scalp itching, scalp burning, skin redness, sleepiness, trouble concentrating, and acute mood change). There were no cases where the experience of symptoms was significantly different during active tDCS (anodal or cathodal) compared to sham. This suggests that none of the reported experiences were specifically related to active tDCS stimulation (see Table 1).

We had hypothesized that if there is lateralization in the cerebellum and the left lobe is more specialized in processing emotions, there would be changes in the speed and accuracy with which participants recognize emotional expressions compared to neutral expressions for anodal and cathodal tDCS conditions, especially for negative emotional expressions. Such changes were not expected in sham tDCS conditions. Therefore, we expected to see significant ($p < .05$) interaction effects between time, emotion, and tDCS condition.

The individual participant (N = 67) files were processed in excel. For each participant, we first examined their overall accuracy (number of correct responses divided by 164 trials) and accuracy for each emotion (number of correct responses divided by 41 trials). We then examined reaction time (RT) for correct trials to obtain their overall RT. Once the data was narrowed down

to correct responses, any RTs below 150 and above 2990 were removed. RTs below 150 ms were considered anticipatory and RTs above 2990 ms were considered misses as we allowed participants 3 seconds to respond and if no response was detected, an RT between 2990-2999 ms was recorded by the program. Then any outliers two standard deviations above or below the mean for each emotion were removed. Following the preprocessing of the individual data files, a group spreadsheet was created containing overall accuracy, overall RT, the percent accuracy for each emotion, and the mean RT for each emotion at each time point for each tDCS condition. A second group spreadsheet of the standard deviation of RT for each emotion was created to examine changes in RT variability.

All further data analysis was done in JASP (version 0.17.1). First, boxplots were created for participants pre-tDCS overall accuracy to determine which participants accuracy was significantly lower than the group (M = 0.879, SD = 0.058, Minimum = 0.622, Maximum = 0.963). Two participants fell well below the lower interquartile range, with their overall accuracy being 0.73 and 0.62, respectively. Therefore, these participants were eliminated from further analysis due to poor performance on the task. Thus, the final dataset included a total of 65 participants across the three tDCS conditions (anodal N = 23, cathodal N = 21, sham N = 21).

Reaction Time

To examine the effect of tDCS on RT, we used a mixed model ANOVA to analyze the within subject factors of time (pre-tDCS, during tDCS, and post-tDCS) and emotion (angry, happy, neutral, sad), and the between subject factor of tDCS condition (anodal, cathodal, sham). For the within subjects' effects, we found significant main effects of time ($F(2,124) = 49.171$, $p < .001$), and emotion ($F(3,186) = 63.840$, $p < .001$), and a time by emotion interaction ($F(6,372) = 4.522$, $p < .001$). There were no significant interactions involving tDCS (all p's > .242).

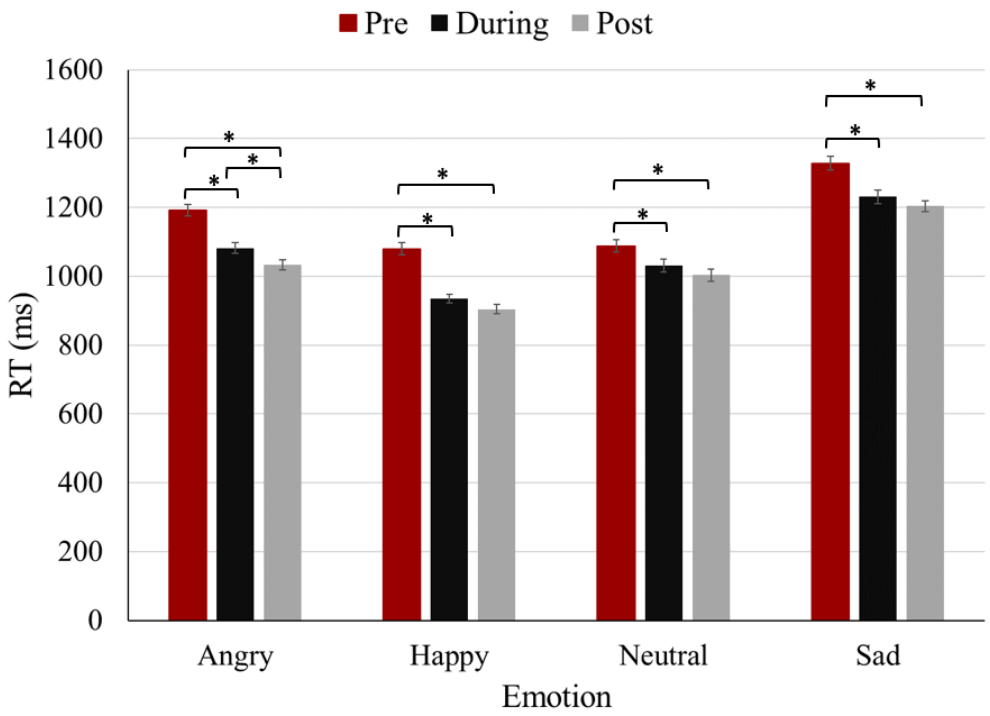
Holm post-hoc tests were conducted to examine the main effects of time and emotion to determine where the differences originated (Holm, 1979). For the main effect of time, there were significant differences in RT between all of the timing points ((pre-tDCS (M = 1172.050) vs during-tDCS (M = 1069.668), $t = 0.398$, $p_{holm} < .001$; pre-tDCS vs post-tDCS (1036.557), $t = 9.511$, $p_{holm} < .001$; during-tDCS vs post-tDCS, $t = 2.324$, $p_{holm} = .022$)).

For the main effect of emotion, there was also significant differences between all of the different emotions ((angry (M = 1102.237) vs happy (M = 973.384), $t = 6.063$, $p_{holm} < .001$; angry vs neutral (M = 1040.760), $t = 2.893$, $p_{holm} = .004$; angry vs sad (M = 1254.654), $t = -7.172$, $p_{holm} < .001$; happy vs neutral, $t = -3.170$ $p_{holm} = .004$; happy vs sad, $t = -13.234$, $p_{holm} < .001$; neutral vs sad, $t = -10.064$ $p_{holm} < .001$)).

To further analyze the time by emotion interaction, we examined the simple main effects of time (pre-tDCS, during-tDCS, and post-tDCS) for each emotion. This analysis revealed that RTs were significantly different between the three time points for each emotion ($F(2) = 36.924$, $p < .001$; happy $F(2) = 50.33$, $p < .001$; neutral $F(2) = 15.472$, $p < .001$; sad $F(2) = 16.253$, $p < .001$; see Figure 6).

Figure 6

*Bar graph of time by emotion interaction for reaction time (RT) in milliseconds (ms). Error bars depict the within subject standard error (Loftus & Masson, 1994). * indicates p < .05.*



To further examine the simple main effect of time for each emotion we carried out separate one-way-within-subject ANOVAs. For the emotion angry, the effect of time was statistically significant ($F(2,128) = 37.573$, $p < .001$). A holm corrected post hoc analysis was performed, and significant differences between the RT at each of the timing points were found ((pre-tDCS (M = 1191.942) vs during-tDCS (M = 1082.168), $t = 5.857$, $p < .001$; pre-tDCS vs post-tDCS (1033.331), $t = 8.463$, $p < .001$; during-tDCS vs post-tDCS, $t = 2.606$, $p = .010$)).

For the emotion happy, the effect of time was statistically significant ($F(2,128) = 51.417$, $p < .001$). Holm corrected post hoc tests found significant differences between the RT at pre-tDCS (M = 1079.455) vs during-tDCS (M = 935.113; $t = 7.834$, $p < .001$) and pre-tDCS vs post-

tDCS (M = 904.550; t = 9.493, p < .001), no significant differences were found at during-tDCS vs post-tDCS (t = 1.659, p = .100).

For the neutral emotion, the effect of time was statistically significant (F(2,128) = 15.669, p < .001). Holm corrected post hoc tests found significant differences between the RT at pre-tDCS (M = 1087.841) vs during-tDCS (M = 1031.183; t = 3.680, p < .001) and pre-tDCS vs post-tDCS (M = 1003.254; t = 5.493, p < .001), no significant differences were found at during-tDCS vs post-tDCS (t = 1.814, p = .072).

Lastly, for the emotion sad, the effect of time was statistically significant (F(2,128) = 16.243, p < .001). Holm corrected post hoc tests found significant differences between the RT at pre-tDCS (M = 1328.853) vs during-tDCS (M = 1231.203; t = 4.244, p < .001) and pre-tDCS vs post-tDCS (M = 1204.209; t = 5.417, p < .001), no significant differences were found at during-tDCS vs post-tDCS (t = 1.173, p = .243).

Variability in RT

To examine whether tDCS stimulation influenced variability in RT, the standard deviation for each participant for each condition was analyzed using a mixed model ANOVA. The within subject factors were time (pre-tDCS, during tDCS, and post-tDCS) and emotion (angry, happy, neutral, sad), and the between subject factor was tDCS condition (anodal, cathodal, sham).

For the within subjects' effects, we found a significant main effect of time (F(2, 124) = 13.627, p < .001), and emotion (F(2, 186) = 52.878, p < .001), and time by emotion interaction (F(6, 372) = 2.188, p = .043). No other effects were significant (all p's >.34).

Holm corrected post-hoc tests were conducted to further examine the main effects of time and emotion. There were significant differences in RT variability between the pre-tDCS (M = 279.418) vs during-tDCS (M = 254.476) time point (t = 3.648, p_{holm} < .001), and the pre-tDCS vs post-tDCS (M = 244.834) time point (t = 5.058, p_{holm} < .001). No significant differences were found between during-tDCS vs post-tDCS (t = 1.410, p_{holm} = .161).

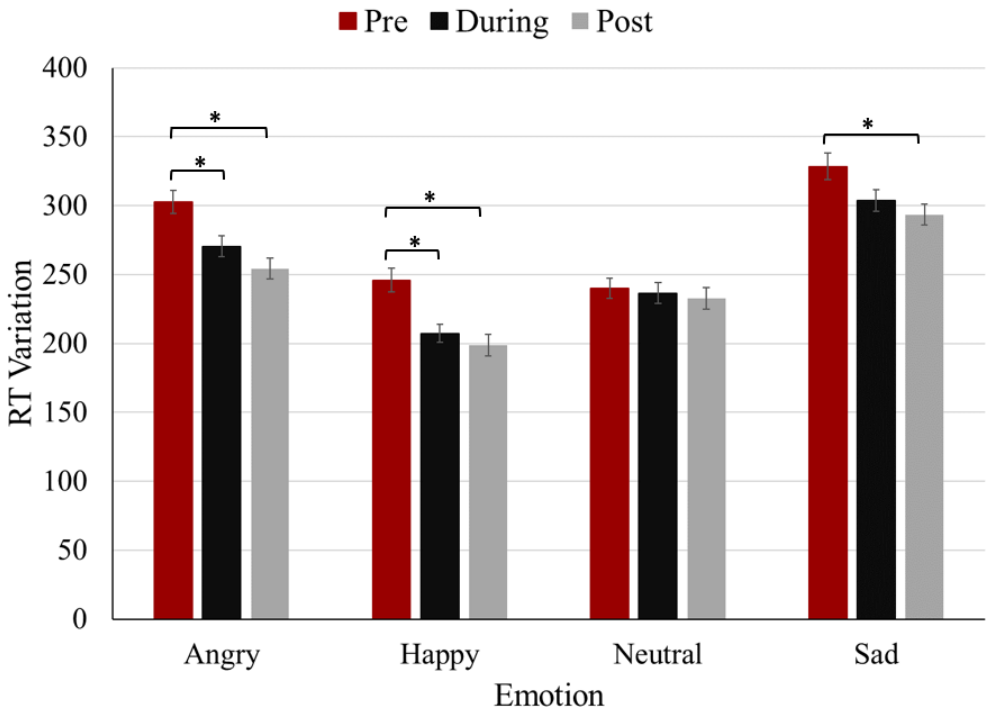
In addition, there were significant differences in RT variability between all of the emotions ((angry (M = 275.891) vs happy (M = 217.375), t = 7.390, p_{holm} < .001; angry vs neutral (M = 236.528), t = 4.971, p_{holm} < .001; angry vs sad (M =308.510), t = - 4.120, p_{holm} < .001; happy vs neutral, t = - 2.419, p_{holm} = .017; happy vs sad, t = - 11.510, p_{holm} < .001; neutral vs sad, t = -9.091, p_{holm} < .001)).

To further analyze the time by emotion interaction, we examined the simple main effects of time at each level of emotion. This analysis revealed a significant effect of time for angry (F(2) = 11.132, p < .001), happy (F(2) = 10.516, p < .001), and sad (F(2) = 4.656, (p = .011), but not for neutral (F(2) = 0.280, p = .756). We then ran separate one-way within-subject ANOVAs analyzing the effect of time for angry, happy, and sad emotions with Holm corrected post-hoc tests.

For the emotion angry, the effect of time was statistically significant (F(2,124) = 10.995, p < .001). Holm corrected post hoc tests found significant differences between the RT variability at pre-tDCS (M = 302.800) vs during-tDCS (M = 270.583; t = 3.680, p < .001) and pre-tDCS vs post-tDCS (M = 254.243; t = 5.493, p < .001), no significant differences were found at during-tDCS vs post-tDCS (t = 1.551, p = .123; see Figure 7).

Figure 7

*Bar graph of time by emotion interaction for variability in reaction time (RT). Error bars depict the within subject standard error (Loftus & Masson, 1994). * indicates p < .05.*



For the emotion happy, the effect of time was statistically significant ($F(2, 124) = 10.924$, $p < .001$). Holm corrected post hoc tests found significant differences between the RT variability at pre-tDCS (M = 302.800) vs during-tDCS (M = 207.271; $t = 3.588$, $p < .001$) and pre-tDCS vs post-tDCS (M = 245.949; $t = 4.389$, $p < .001$), no significant differences were found at during-tDCS vs post-tDCS ($t = 0.801$, $p = .425$).

Lastly, for the for the emotion sad, the effect of time was statistically significant ($F(2,124) = 4.641$, $p = .011$). Holm corrected post hoc tests found significant differences between the RT at pre-tDCS (M = 302.800) vs post-tDCS (M = 293.417; $t = 2.969$, $p = .011$). No

significant differences were found at the pre-tDCS vs during-tDCS (M = 303.939; t = 2.077, p = .080) and during-tDCS vs post-tDCS (t = .892, p = .374).

Accuracy

The overall accuracy across all emotions was 88.5%. To examine for possible effects of tDCS on the accuracy with which participants could discriminate emotions we used a mixed model ANOVA to analyze the within subject factors of time (pre-tDCS, during tDCS, and post-tDCS) and emotion (angry, happy, neutral, sad), and the between subject factor of tDCS condition (anodal, cathodal, sham). For the within subjects' effects, we found significant main effects of time ($F(2,124)= 5.560$, p = .005), emotion ($F(3,186) = 47.835$, $p < .001$), and a time by emotion by tDCS condition interaction ($F(12,372) = 2.008$, p = .023). No other effects were significant (all p's >.178).

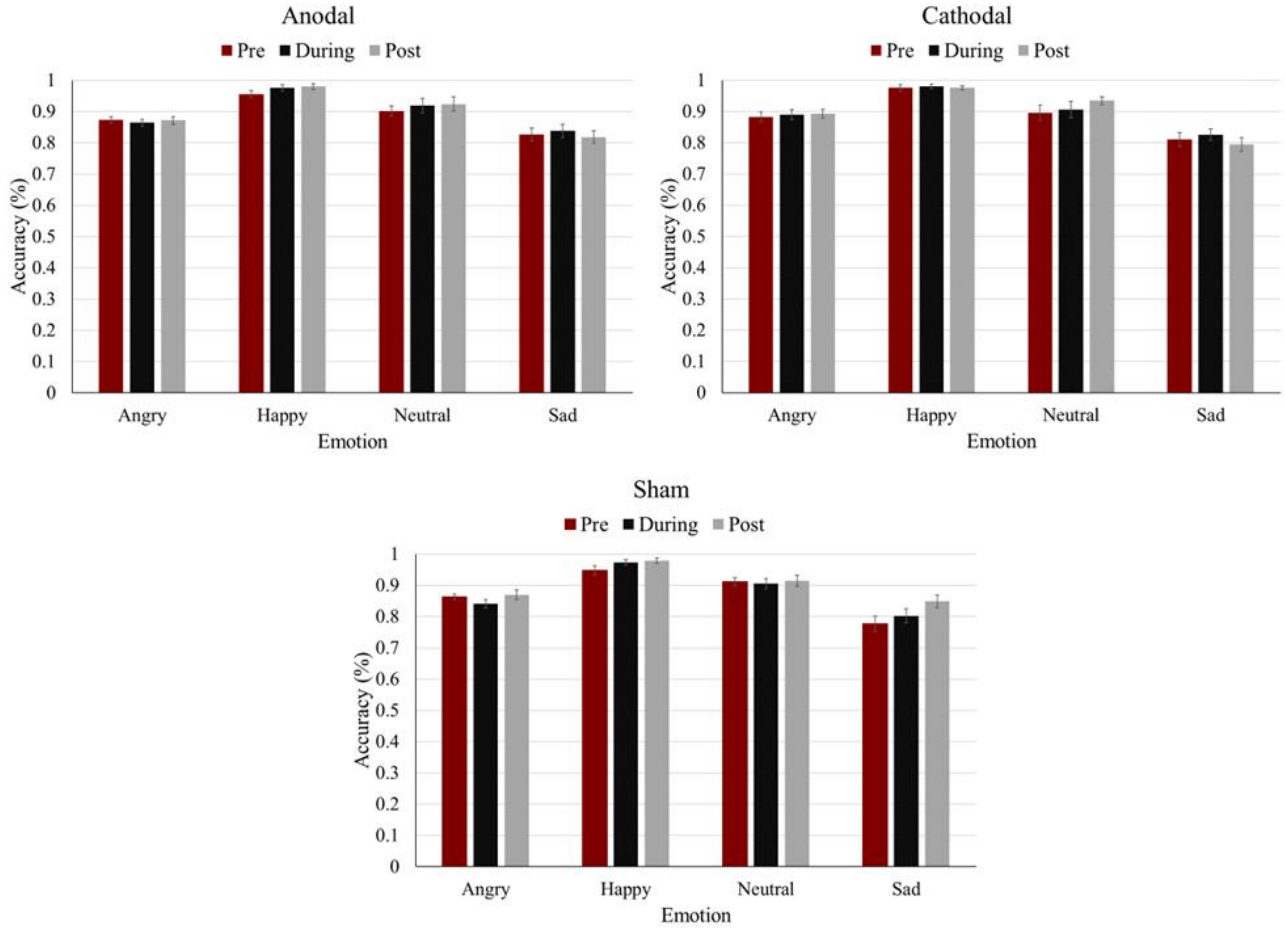
Holm corrected post-hoc tests were conducted to further explore the main effects of time and emotion. There was a significant difference in accuracy between the pre-tDCS (M = .885) and post-tDCS (M = .900; t = - 3.328, p_{holm} = .003). No significant differences in accuracy were found between the other time points ((pre-tDCS vs during-tDCS (M = .894), t = -1.839, p_{holm} = .137; during-tDCS vs post-tDCS, t = -1.489, p_{holm} = .139)).

For the main effect of emotion, significant differences in accuracy were found between all of the emotions ((angry (M = .872) vs happy (M = .971), t = - 7.394, $p_{holm} < .001$; angry vs neutral (M = .913), t = -3.002, p_{holm} = .003; angry vs sad (M = .816), t = 4.202, $p_{holm} < .001$; happy vs neutral, t = 4.392, $p_{holm} < .001$; happy vs sad, t = 11.596, $p_{holm} < .001$; neutral vs sad, t = 7.205, $p_{holm} < .001$)).

To further analyze the time by emotion by tDCS condition interaction effect, we examined the simple main effect of tDCS condition, as moderated by time and emotion. However, no effects were significant (all *p*'s >.12; see Figure 8). Given that the time by emotion interaction revealed no significant differences between tDCS conditions, we did not analyze the data further.

Figure 8

Bar graph of time by emotion interaction for accuracy in %.



Discussion

Previous research has established that the role of the cerebellum extends beyond its motor capabilities; it also plays a significant role in a variety of higher-order cognitive functions through its contralateral connections to the cerebral cortex (Buckner, 2013; Stoodley & Schmahmann, 2009). Research into the cognitive abilities of the cerebellum has increased over the past several decades, and, even more recently, specific focus on its role in emotion processing, recognition, and perception has garnered interest. Existing research suggests that, due to the connection to the right cerebral hemisphere, the left cerebellum may be adept at dealing with emotions, particularly negative emotions due to them being more arousing and evolutionarily significant (Ferrucci et al., 2012; Giannotti, 2019).

The aim of the current study was to add to the burgeoning literature in this field by examining the role of the left cerebellum in processing facial emotions. To do so, we used tDCS to deliver a targeted, mild electrical current over the left cerebellum to modulate neuronal function. The use of tDCS has been found to change both motor and cognitive cerebellar functions, although motor functions may be more affected (Oldrati & Schutter, 2017). Specifically, healthy participants (N = 67) were randomly assigned to receive either anodal, cathodal, or sham stimulation and completed an emotion recognition task across three different timing points (pre-tDCS, during-tDCS, and post-tDCS). We had hypothesized that if the left cerebellum is more specialized in processing emotions, participants would demonstrate changes in the speed and accuracy with which they recognized emotional expressions, particularly negative ones, for anodal and cathodal tDCS conditions. Thus, we would expect to see interactions between emotion, time, and tDCS condition.

The results of our RT analysis found that there were no statistically significant interactions at time by emotion by tDCS condition; therefore, the results of the RT analysis do not support our hypothesis. However, participants were generally faster over time (from pre-tDCS to post-tDCS) and had differing RTs based on the emotion presented. Participants responded quickest to the happy emotion, slowest to negative emotions (with sad having the longest RT), and RTs for the neutral emotion fell in the middle. Stimulation from tDCS did not influence participants RTs.

For RT, we did a secondary analysis to examine for variability in response times. No statistically significant time by emotion by tDCS condition interaction was found; thus, the results of the variability analysis do not support our hypothesis. However, this analysis does demonstrate that participants were less variable in RT when responding to the emotion happy, most highly variable for negative emotions (particularly for sad), with variability for the neutral emotion falling in the middle. As well, this analysis demonstrates that there was typically less variance over time (from pre-tDCS to post-tDCS), except in the case of the neutral emotion where variability remained stable. There were no significant interaction effects for tDCS condition.

Finally, we examined accuracy of participants responses. Although there was a significant time by emotion by tDCS interaction, there were no significant differences between the different emotions that was related to active tDCS stimulation (anodal or cathodal) compared to sham tDCS stimulation. Therefore, the results of our accuracy analysis do not support our hypothesis. Generally, participants were more accurate over time (from pre-tDCS to post-tDCS) and were most accurate for the happy emotion and least accurate for the negative emotions (particularly sad), with accuracy for the neutral emotion falling in the middle.

Lateralization of the cerebral hemispheres is well established, with the left hemisphere being more specialized for language processes and the right being more specialized for visuospatial processing, emotion, and attention (Hartwigsen et al., 2021; Hartikainen, 2021). Interestingly, fMRI studies suggest that the left hemisphere has greater intrahemsipheric interactions, while the right hemisphere has greater interhemispheric interactions (Gotts et al., 2013). Although there is a right hemisphere bias in emotional processes, it may be less strictly lateralized than other functions; for example, research has found that particularly in the case of emotion perception, there is also left hemisphere activation (Lindquist et al., 2012). Research has found that, due to the contralateral connections of the cerebrum and cerebellum, functional asymmetries in the cerebellum may be flipped versions of those in the cerebral cortex (Buckner et al., 2013; Wang et al., 2013). Wang et al. (2013) suggest that the extent of lateralization in the cerebellum is correlated with the degree of lateralization in the cerebral cortex. The role of the right cerebellum in language processes and the left cerebellum in visuospatial skills is better researched and appears to be more definitively lateralized (Stoodley & Schmahmann, 2009). Notably, these are functions are the most lateralized in the cerebral cortex. It is plausible that because emotion is not as significantly lateralized in the cerebrum, it may subsequently not be as lateralized in the cerebellum.

The emotion recognition task used in this study was based off of the study done by Ferrucci et al. (2012), where they found that both anodal and cathodal cerebellar tDCS significantly enhanced healthy participants ability to recognize negative facial expressions, unlike our study. There are several reasons why this may be the case: (1) they used a within-subjects design, (2) they used a larger active electrode (6 x 7 cm), (3) they placed the active

electrode at the midline, 2 cm below the inion, and (4) they waited 35 minutes after stimulation ceased to perform the post-tDCS task.

Limitations and Future Research

The first difference between the study done by Ferrucci et al. (2012) is that they used a within-subjects design, whereas our experiment used a between-subjects design. Within-subjects designs have greater statistical power, they need fewer participants to find statistically significant effects because there is less error variance. We had chosen to conduct a between-subjects design to reduce the potential for practice effects and it was more practical given the limitations of COVID-19 closures over the course of data collection. Specifically, it was easier to recruit participants to complete a single testing session (e.g., anodal, cathodal, or sham) compared to asking them to complete three separate testing sessions (anodal, cathodal, and sham). In addition, had a COVID-19 shutdown occurred while we were collecting data, it would have made it difficult to follow-up with participants for subsequent testing sessions.

The placement of the larger active electrode used in the Ferrucci et al. (2012) study would have led to more midline and widespread cerebellar stimulation. Because the aim of our study was to examine lateralization of emotion recognition, using a smaller active electrode over the left cerebellum (over lobules VII and Crus I) provided a more targeted appraoch. Ferrucci et al. (2012) may have had more widespread neuronal modulation with anodal and cathodal stimulation, leading to significant differences in the ability of participants to recognize emotional expressions, whereas our study is more precise in the areas stimulated. After the during-tDCS task, Ferrucci et al. (2012) waited 35 minutes before administering the post-tDCS task, we opted not to do so as the effects of tDCS stimulation tend to be immediate and it was more practical for the experimental design.

In our study, the most prominent interaction effects found were that of time and emotion – participants tended to get faster and more accurate overtime and were fastest and most accurate identifying the positive emotion (happy) and slowest and least accurate at identifying the negative emotions. The high overall accuracy (88.5%) of participant responses may be the result of a ceiling effect. To make the task more difficult, future studies could use a masking stimulus wherein the stimulus of an emotional face is presented for a brief duration and then a mask, such as a neutral face, is presented for a brief duration to make it more difficult for participants to consciously discriminate the emotion presented. The effects of time may be due to practice effects; therefore, future studies may benefit from having a shorter exposure of the target stimulus (the emotional facial expression) or using different, emotionally equivalent stimuli rather than repeating the same stimuli across the three times the task is completed (e.g., a larger stimulus set). Furthermore, having two negative emotional expressions and one positive may have led to the participants to take longer to make a decision when categorizing the two negative stimuli, which would not have occurred for the positive stimuli, thus using an equal number of stimuli for positive and negative emotional expressions may be prudent.

Future studies may also benefit from using a within-subjects design or gathering more participants if a between-subjects design is used. To assess for lateralization of emotion recognition, future research could examine the influence of targeted anodal and cathodal tDCS over different parts of the cerebellum, such as the right lateral cerebellum or the vermis. Furthermore, this study only considered healthy adult subjects. Research into groups with already impaired recognition of facial expressions as a result of psychiatric disorder (e.g., depression, schizophrenia, anxiety) may lead to further insight into underlying mechanisms and etiology (Ferrucci et al., 2012).

Conclusions

Research examining the role of the cerebellum in cognition has been increasing since Schmahmann and Sherman (1998) proposed the idea of CCAS; however, there is still a relative dearth of literature examining the cerebellum and emotional function. As well, lateralization of the cerebellum is not as clearly defined as it is in the cerebrum. In this study, we examined the role of the left cerebellum in facial emotion recognition by using tDCS. We had predicted that there would be changes in the speed and accuracy with which participants recognized negative emotions compared to neutral or positive emotions when exposed to anodal or cathodal stimulation. RT, variability in RT, and accuracy of participant responses to an emotion recognition task at different tDCS conditions (anodal, cathodal, and sham) at baseline (pre-tDCS), during-tDCS, and post-tDCS were analyzed and compared. If the results supported our hypothesis, we expected to see a significant time by emotion by tDCS condition interaction. None of our analyses supported our hypothesis.

Generally, participants were faster and more accurate over time and when identifying positive compared to negative emotions. However, we failed to observe any clear effects of tDCS on emotion recognition. Due to the relatively limited research in this area and the limitations of this study, it is difficult to determine whether the lack of significant results is due to the left cerebellum not being lateralized for emotion functions, or other factors (e.g., study design, statistical power, etc.). More research into emotion lateralization in the human cerebellum is needed.

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Appendix

Table 1

Descriptive statistics for the tDCS Adverse Effects Questionnaire

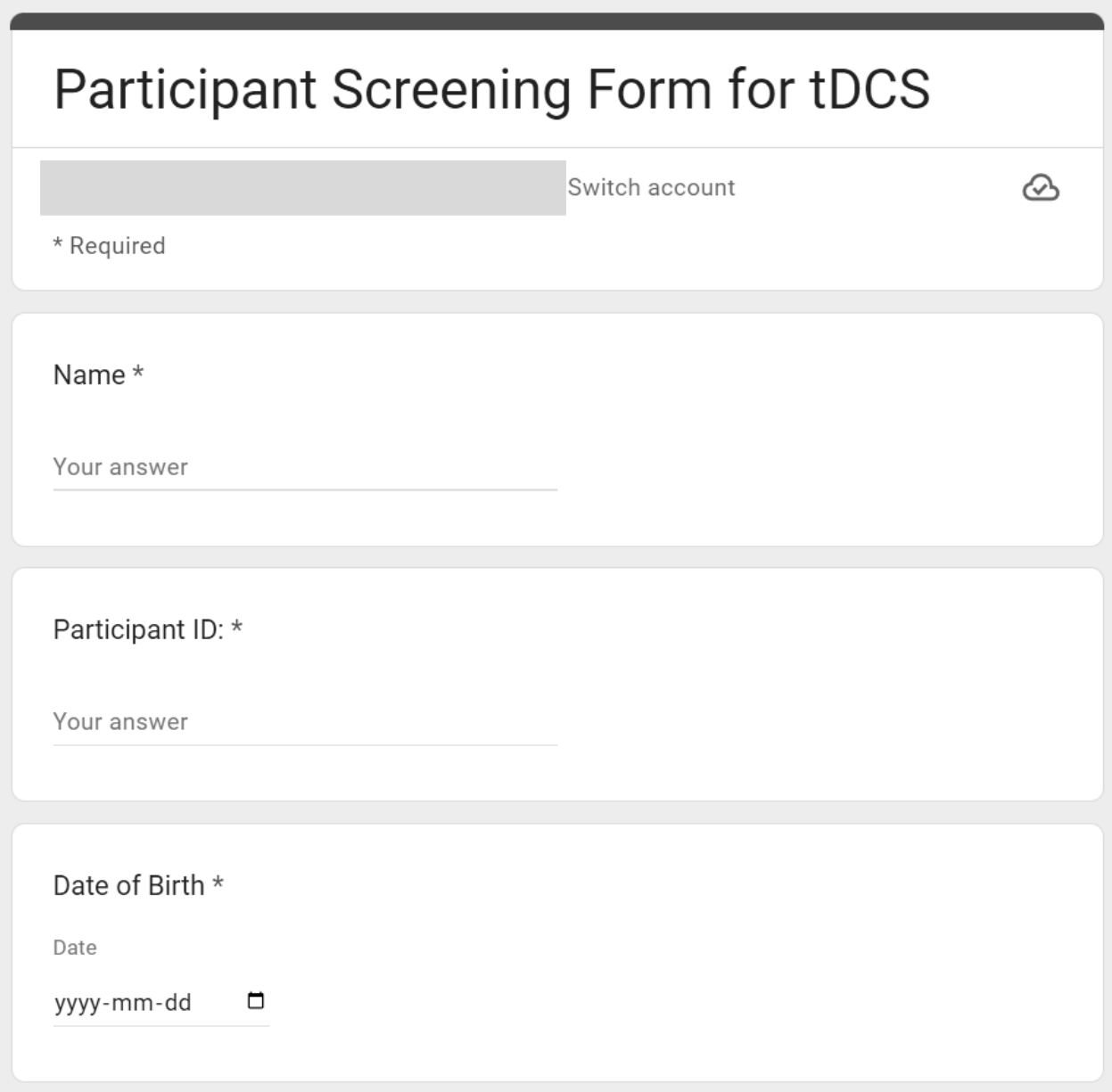
		Valid	Mean	Standard Deviation	Minimum	Maximum
Are you experiencing a headache?	anodal	23	1.348	0.487	1.000	2.000
Are you experiencing a headache?	cathodal	22	1.045	0.213	1.000	2.000
Are you experiencing a headache?	sham	22	1.182	0.395	1.000	2.000
Are you experiencing a neck pain?	anodal	23	1.261	0.449	1.000	2.000
Are you experiencing a neck pain?	cathodal	22	1.227	0.429	1.000	2.000
Are you experiencing a neck pain?	sham	22	1.364	0.658	1.000	3.000
Are you experiencing a scalp pain?	anodal	23	1.000	0.000	1.000	1.000
Are you experiencing a scalp pain?	cathodal	22	1.000	0.000	1.000	1.000
Are you experiencing a scalp pain?	sham	22	1.045	0.213	1.000	2.000
Are you experiencing a scalp tingling?	anodal	23	1.348	0.487	1.000	2.000
Are you experiencing a scalp tingling?	cathodal	22	1.182	0.395	1.000	2.000
Are you experiencing a scalp tingling?	sham	22	1.182	0.395	1.000	2.000
Are you experiencing a scalp itching?	anodal	23	1.261	0.541	1.000	3.000
Are you experiencing a scalp itching?	cathodal	22	1.182	0.395	1.000	2.000
Are you experiencing a scalp itching?	sham	22	1.136	0.351	1.000	2.000
Are you experiencing a burning sensation on the scalp?	anodal	23	1.130	0.344	1.000	2.000
Are you experiencing a burning sensation on the scalp?	cathodal	22	1.136	0.468	1.000	3.000
Are you experiencing a burning sensation on the scalp?	sham	22	1.091	0.294	1.000	2.000
Are you experiencing skin redness?	anodal	23	1.261	0.541	1.000	3.000
Are you experiencing skin redness?	cathodal	22	1.136	0.351	1.000	2.000
Are you experiencing skin redness?	sham	22	1.000	0.000	1.000	1.000
Are you experiencing sleepiness?	anodal	23	2.043	0.825	1.000	4.000
Are you experiencing sleepiness?	cathodal	22	2.227	0.869	1.000	4.000
Are you experiencing sleepiness?	sham	22	2.045	0.785	1.000	4.000

		Valid	Mean	Standard Deviation	Minimum	Maximum
Are you experiencing trouble concentrating?	anodal	23	1.913	0.848	1.000	4.000
Are you experiencing trouble concentrating?	cathodal	22	2.045	0.785	1.000	3.000
Are you experiencing trouble concentrating?	sham	22	1.591	0.796	1.000	3.000
Are you experiencing acute mood change?	anodal	23	1.043	0.209	1.000	2.000
Are you experiencing acute mood change?	cathodal	22	1.091	0.294	1.000	2.000
Are you experiencing acute mood change?	sham	22	1.091	0.294	1.000	2.000

Note. Excluded 10 rows from the analysis that correspond to the missing values of the split-by variable tDCS Condition

Figure 1

Screening form



Handedness *

- ◯ Right
- ◯ Left
- ◯ Mixed

Sex *

- ◯ Male
- ◯ Female
- ◯ Prefer not to answer

Have you previously experienced transcranial Direct Current Stimulation (tDCS) or transcranial magnetic stimulation (TMS)? *

- ◯ Yes
- ◯ No

Have you ever had eye surgery? *

- ◯ Yes
- ◯ No

If you responded yes to the above question, what type of eye surgery?

Your answer

Have you ever experienced an injury to your head by a metallic foreign body which was not removed (e.g., bullet, BB, shrapnel)? *

- ◯ Yes
- ◯ No

Have you ever worked routinely with metal (grinding, fabricating, welding, etc.) or ever had an injury to the eye involving a metallic object (e.g., metallic silvers, shavings)? *

- ◯ Yes
- ◯ No

Do you have a cardiac pacemaker or defibrillator? *

- ◯ Yes
- ◯ No

Do you have severe heart disease (including susceptibility to arrhythmias)? *

- ◯ Yes
- ◯ No

Do you have aneurysm clip? *

- ◯ Yes
- ◯ No

Do you have cochlear (ear) implants? *

- ◯ Yes
- ◯ No

Do you have Meniere's disease? *

- ◯ Yes
- ◯ No

Do you have metal dental work other than fillings? *

- ◯ Yes
- ◯ No

If you answered yes to the above question, what type of metal dental work do you have?

Your answer

Do you have any facial or body piercings that cannot be removed? *

- ◯ Yes
- ◯ No

Do you have any skin conditions (e.g., eczema)? *

- ◯ Yes
- ◯ No

Do you wear a hearing aid? *

- ◯ Yes
- ◯ No

Have you ever experienced a panic attack? *

- ◯ Yes
- ◯ No

Have you ever had an epileptic seizure? *

- ◯ Yes
- ◯ No

Is there a history of epilepsy in your family? *

- ◯ Yes
- ◯ No

Have you ever had a head or brain injury? *

- ◯ Yes
- ◯ No

Have you had any visual disorders? *

- ◯ Yes
- ◯ No

Do you have any neurological disorders (e.g., Parkinson's disease, MS, Stroke)? *

- ◯ Yes
- ◯ No

Are you currently being treated for any psychiatric disorders (e.g., schizophrenia, bipolar disorders, major depression, anxiety)? *

- ◯ Yes
- ◯ No

Are you on any psychiatric medications for depression, psychosis, or anxiety? *

- ◯ Yes
- ◯ No

Do you get migraines and/or are you susceptible to headaches? *

- ◯ Yes
- ◯ No

Have you been intoxicated with alcohol or any recreational drugs in the past 24 hours? *

- ◯ Yes
- ◯ No

FOR FEMALES ONLY: Is there a chance you might be pregnant?

- ◯ Yes
- ◯ No

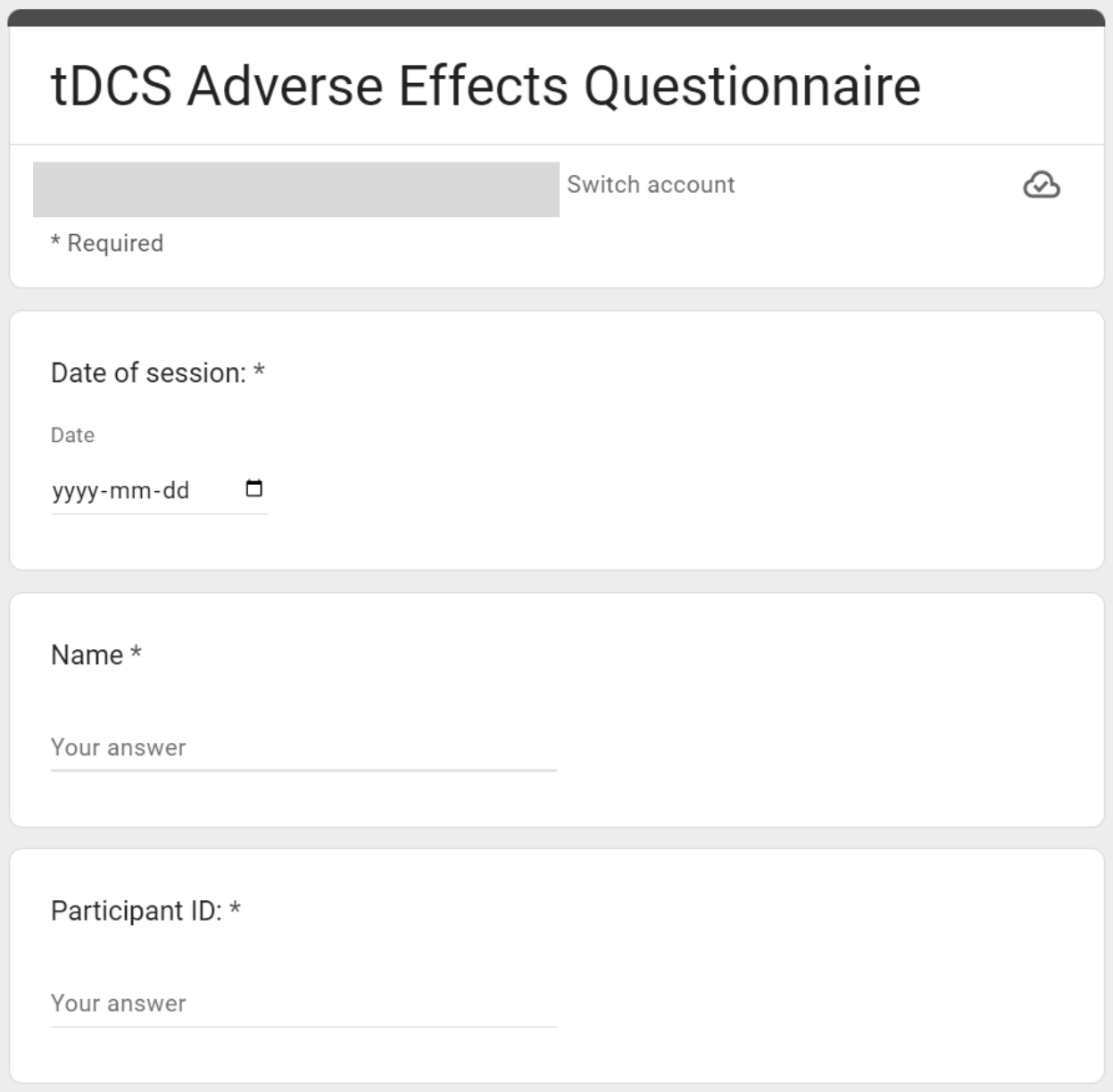
Please confirm that you have removed the following: *

- ☐ Any jewelry above the neck
- ☐ Any facial piercings
- ☐ Any hair pins or barrettes

Submit Clear form

Figure 2

tDCS Adverse Effects Questionnaire



Are you experiencing any of the following symptoms or side effects?
Enter a value (1-4) in the space below (1, absent; 2, mild; 3, moderate; 4, severe).

If present; is this related to tDCS? (1, none; 2, remote; 3, possible; 4, probable; 5, definite).

Are you experiencing a headache? *

- ◯ 1 - absent
- ◯ 2 - mild
- ◯ 3 - moderate
- ◯ 4 - severe

Is the headache related to tDCS?

- ◯ 1 - no
- ◯ 2 - remote
- ◯ 3 - possible
- ◯ 4 - probable
- ◯ 5 - definite

Are you experiencing a neck pain? *

- ◯ 1 - absent
- ◯ 2 - mild
- ◯ 3 - moderate
- ◯ 4 - severe

Is the neck pain related to tDCS?

- ◯ 1 - no
- ◯ 2 - remote
- ◯ 3 - possible
- ◯ 4 - probable
- ◯ 5 - definite

Are you experiencing a scalp pain? *

- ◯ 1 - absent
- ◯ 2 - mild
- ◯ 3 - moderate
- ◯ 4 - severe

Is the scalp pain related to tDCS?

- ◯ 1 - no
- ◯ 2 - remote
- ◯ 3 - possible
- ◯ 4 - probable
- ◯ 5 - definite

Are you experiencing a scalp tingling? *

- ◯ 1 - absent
- ◯ 2 - mild
- ◯ 3 - moderate
- ◯ 4 - severe

Is the scalp tingling related to tDCS?

- ◯ 1 - no
- ◯ 2 - remote
- ◯ 3 - possible
- ◯ 4 - probable
- ◯ 5 - definite

Are you experiencing a scalp itching? *

- ◯ 1 - absent
- ◯ 2 - mild
- ◯ 3 - moderate
- ◯ 4 - severe

Is the scalp itching related to tDCS?

- ◯ 1 - no
- ◯ 2 - remote
- ◯ 3 - possible
- ◯ 4 - probable
- ◯ 5 - definite

Are you experiencing a burning sensation on the scalp? *

- ◯ 1 - absent
- ◯ 2 - mild
- ◯ 3 - moderate
- ◯ 4 - severe

Is the burning sensation on the scalp related to tDCS?

- ◯ 1 - no
- ◯ 2 - remote
- ◯ 3 - possible
- ◯ 4 - probable
- ◯ 5 - definite

Are you experiencing skin redness? *

- ◯ 1 - absent
- ◯ 2 - mild
- ◯ 3 - moderate
- ◯ 4 - severe

Is the skin redness related to tDCS?

- ◯ 1 - no
- ◯ 2 - remote
- ◯ 3 - possible
- ◯ 4 - probable
- ◯ 5 - definite

Are you experiencing sleepiness? *

- ◯ 1 - absent
- ◯ 2 - mild
- ◯ 3 - moderate
- ◯ 4 - severe

Is the sleepiness related to tDCS?

- ◯ 1 - no
- ◯ 2 - remote
- ◯ 3 - possible
- ◯ 4 - probable
- ◯ 5 - definite

Are you experiencing trouble concentrating? *

- ◯ 1 - absent
- ◯ 2 - mild
- ◯ 3 - moderate
- ◯ 4 - severe

Is the trouble concentrating related to tDCS?

- ◯ 1 - no
- ◯ 2 - remote
- ◯ 3 - possible
- ◯ 4 - probable
- ◯ 5 - definite

Are you experiencing acute mood change? *

- ◯ 1 - absent
- ◯ 2 - mild
- ◯ 3 - moderate
- ◯ 4 - severe

Is the acute mood change related to tDCS?

- ◯ 1 - no
- ◯ 2 - remote
- ◯ 3 - possible
- ◯ 4 - probable
- ◯ 5 - definite

Others (specify below if needed)

Your answer

Submit Clear form

Figure 3

Illustration of emotion recognition task

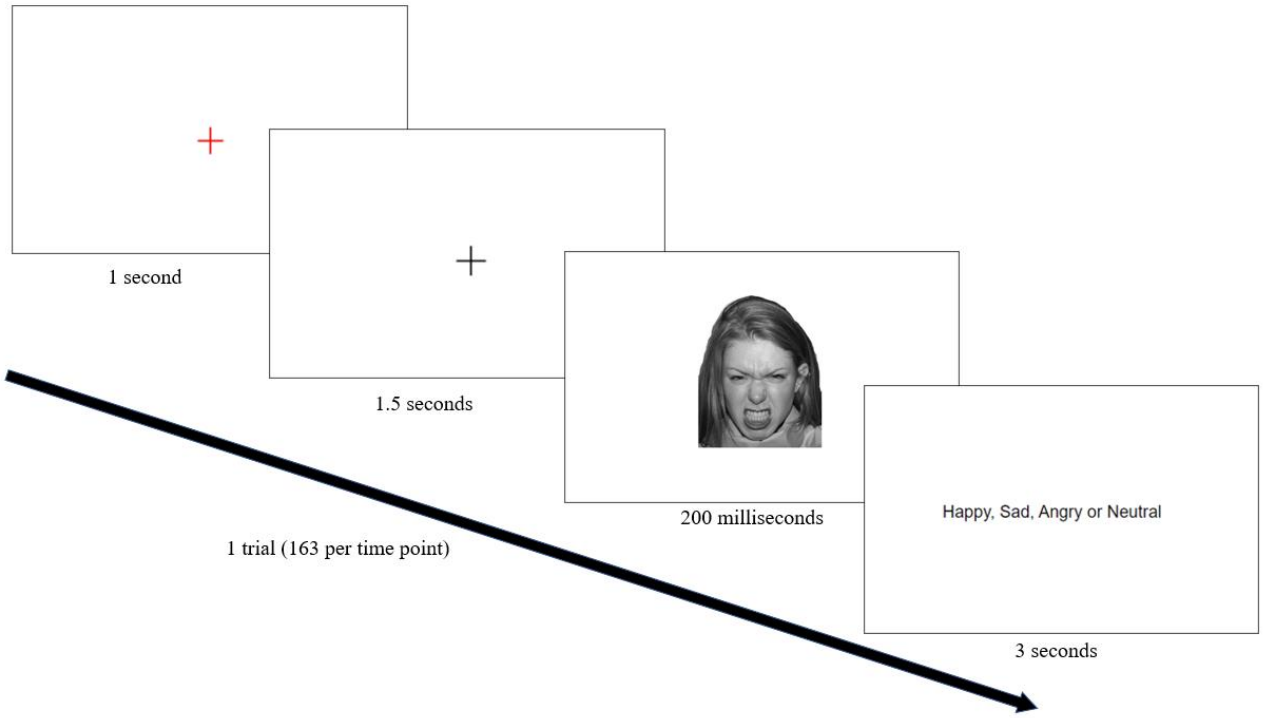


Figure 4

Example of tDCS set-up, placement, and equipment.

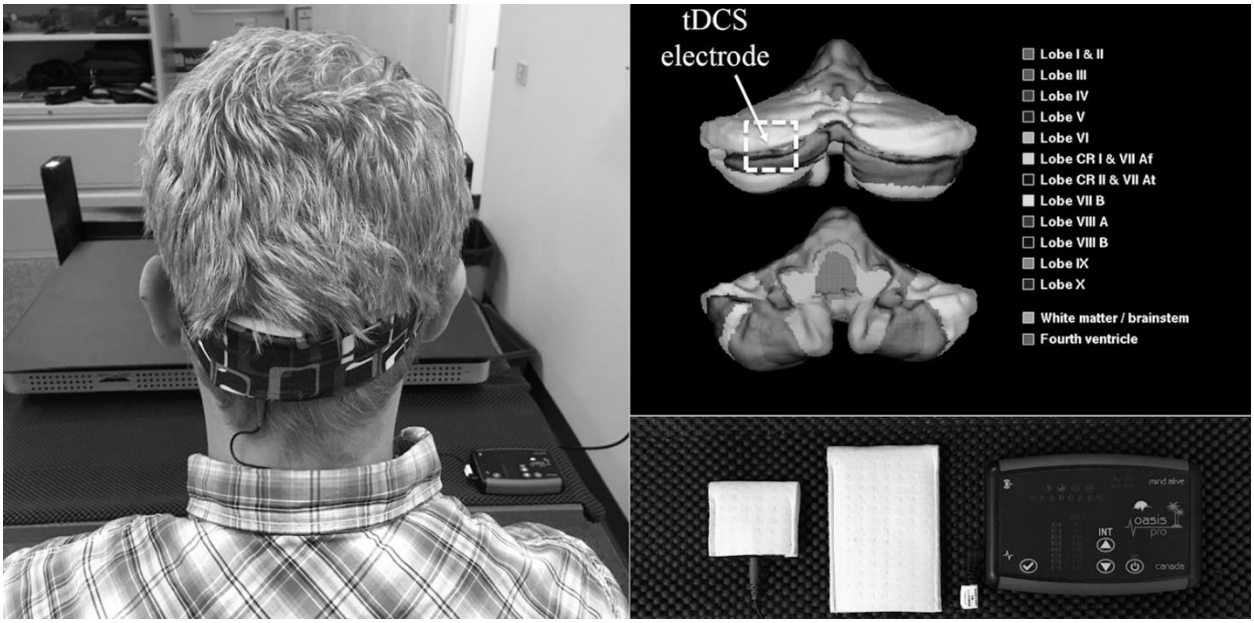


Figure 5

Schematic diagram of experimental design.