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ORIGINAL ARTICLE

Effects of tDCS on emotion recognition and brain oscillations

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ABSTRACT

Introduction: Emotion recognition, the ability to interpret the emotional state of individuals by looking at their facial expressions, is essential for healthy social interactions and communication. There is limited research on the effects of tDCS on emotion recognition in the literature. This study aimed to investigate the effects of anodal stimulation of the ventromedial prefrontal cortex (vmPFC), a key region for emotion recognition from facial expressions, on emotion recognition and brain oscillations.

Method: A single-blind randomized-controlled study was conducted with 54 healthy participants. Before and after brain stimulation emotion recognition tasks were administered and resting-state EEG were recorded. The changes in task performances and brain oscillations were analyzed using repeated-measures two-way ANOVA analysis.

Results: There was no significant difference in the emotion recognition tasks between groups in pre-post measurements. The changes in delta, theta, alpha, beta and gamma frequency bands in the frontal, temporal, and posterio-occipital regions, which were determined as regions of interest in resting state EEG data before and after tDCS, were compared between groups. The results showed that there was a significant difference between groups only in delta frequency before and after tDCS in the frontal and temporal regions. While an increase in delta activity was observed in the experimental group in the frontal and temporal regions, a decrease was observed in the control group.,

Conclusions: The tDCS may not have improved emotion recognition because it may not have had the desired effect on the vmPFC, which is in the lower part of the prefrontal lobe. The changes in EEG frequencies observed section tDCS may be similar to those seen in some pathological processes, which could explain the lack of improvement in emotion recognition. Future studies to be carried out for better understand this effect are important.

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KEYWORDS
Brain oscillations; EEG; emotion recognition; tDCS; ventromedial prefrontal cortex (vmPFC)

Introduction

Emotion recognition is the process of interpreting an individual's emotional state by looking at facial expressions (Behere, 2015). Emotion recognition skills are important building blocks for healthy social relations and interpersonal communication (Kadak et al., 2013). There are six basic emotions that can be recognized universally. These are anger, disgust, happiness, surprise, sadness, and fear (Ekman, 1992). However, Wingenbach et al. (2016) stated that in addition to these six basic emotions, there are three complex emotions: contempt, shame, and pride.

While the prefrontal cortex and temporal cortex are generally considered important in the perception of emotions from facial expressions, Philippi argues that emotion recognition function from facial expressions is realized through wide and diffuse networks. The occipito-temporal cortex, basal ganglia, frontal and parietal opercula, insula, amygdala, orbito-frontal cortex are important areas and structures in these networks. Especially, the amygdala has central role in recognizing facial emotional expressions. In addition, it was observed that the frontal face area and superior temporal gyrus were also activated during emotion recognition in neuroimaging (Kadak et al., 2013; Kessels et al., 2014).

Multiple studies have shown that the ventromedial prefrontal cortex (vmPFC) plays a critical role in recognizing facial emotions, and that damage to the vmPFC can lead to impairments in emotion recognition (Heberlein et al., 2008). In addition, the orbital and medial regions of the frontal lobe are associated with processing emotions, subjective emotion experiences, recognition of nonverbal emotion expressions, and normal behavior in social relations. It is stated that there are deteriorations in the areas specified in bilateral ventromedial prefrontal lobe damage and in the recognition of emotion-related facial expressions (Saracli et al., 2012).

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Emotion recognition difficulties can be seen in various situations. Autism is a developmental disorder and autistics have difficulties in recognizing emotions from facial expressions and in interpersonal relationships (Kadak et al., 2013). The people who have schizophrenia (Behere, 2015), mood disorders (Yamada et al., 2021) and antisocial personality disorder (Pera-Guardiola et al., 2016) have difficulties in recognizing emotion.

Brain stimulation is a method that changes or modulates nerve activity by delivering electrical or pharmaceutical agents directly to the target area by an external effect. These methods act on the nervous system and reorganize the existing nervous state in order to treat various diseases. Neuromodulation methods that provide this reorganization are divided into two. These are invasive and noninvasive methods (Buhagiar et al., 2020).

Invasive methods include sub-cortical applications such as Deep Brain Stimulation (DBS) and cortical applications such as motor cortex stimulation (Cavlak et al., 2019). Non-invasive neuromodulation methods include methods such as repetitive transcranial magnetic stimulation (rTMS), transcranial direct current stimulation (tDCS), transcranial alternating current stimulation (tACS), transcranial static magnetic field stimulation (tSMS), and cranial electrotherapy stimulation (CES) (Romero-Martínez et al., 2020).

tDCS, which was used in our study, is a noninvasive, painless, and reliable brain stimulation method that provides stimulatory or suppressive effects on different regions of the brain. It is also a neurorehabilitation technique that increases neuroplasticity and provides therapeutic benefits by affecting the existing nervous system functionality in the targeted region of the nervous system (Cavlak et al., 2019; Hızlı Sayar et al., 2012). However, it has also been frequently used recently in improving cognitive functions in healthy individuals and in studies examining the brain–behavior relationship (Brennan et al., 2017; Clausi et al., 2022; Hızlı Sayar et al., 2012; Willis et al., 2015).

Excitability is increased or decreased by passing a weak direct current through the cortex using anode and cathode electrodes placed on the scalp. While anodal tDCS increases excitability, cathodal tDCS decreases excitability. The effect of tDCS on excitability is provided by subthreshold modulation in the neuronal membrane resting potential. While anodal tDCS depolarizes neurons, cathodal tDCS hyperpolarizes them. The specified current is generally 1–2 milliamperes (mA) and the application is made for approximately 5–30 min. Current enters the cortex through the anode and exits through the cathode. It is called anodal stimulation or cathodal stimulation, depending on the placement of anode or cathode electrodes in the area of the brain where a change is desired (Cavlak et al., 2019; Hızlı Sayar et al., 2012). Electrode dimensions are generally 25 cm^2 (5×5 cm) or 35 cm^2 (5×7 cm). However, the electrode sizes used vary depending on the application area and the targeted stimulation intensity (Berryhill & Martin, 2018; Thair et al., 2017).

Single session tDCS is a widely used experimental approach. A single active tDCS session is conducted and performances are compared to placebo (sham) stimulation. The single-session approach can be used to address questions regarding structure–function relationships and allows for the use of within-subject experimental designs. It was shown that a single anodal tDCS session has a temporary effect on cognitive performance. Findings from longitudinal studies show that, in repeated applications, the mechanism probably involves permanent neuroplasticity changes, unlike acute effects (Berryhill & Martin, 2018).

When the literature is examined, it is seen that there are studies on the effectiveness of tDCS in emotion recognition. These studies have shown the suitability of using tDCS in modulating emotion recognition, as it provides significant improvements in emotion recognition (Nejati et al., 2022).

The effects of tDCS applied to the cerebellum and right prefrontal cortex were examined, and the results showed that tDCS applied to the cerebellum facilitated the recognition of facial expressions, especially negative emotions, but tDCS applied to the right prefrontal cortex did not have any effect (Ferrucci et al., 2012). In another study, it was stated that anodal tDCS application in the left dorsolateral prefrontal cortex improved emotional face recognition, especially positive facial expressions, and that tDCS application in the prefrontal cortex had an effect related to the emotional state during the formation process in healthy subjects (Nitsche et al., 2012).

Studies have shown that applying cathodal tDCS to the left inferior frontal gyrus to reduce excitability facilitates emotion recognition (Klimm et al., 2015), and anodal tDCS applied to the right orbitofrontal cortex increases facial expression recognition (Willis et al., 2015). Similarly, it has been shown that anodal stimulation of the bilateral dorsolateral prefrontal cortex has a significant effect on emotion recognition, and anodal tDCS applied to the left dorsolateral prefrontal cortex causes a significant improvement in the control group and a significant effect on general emotion recognition (Brennan et al., 2017; Rassovsky et al., 2015).

It has been reported that anodal stimulation applied to the left dorsolateral prefrontal cortex three times a week for 6 weeks in drug-resistant depression patients showed significant improvement in recognizing the emotions of anger, disgust, fear, and happiness (D. M. Martin et al., 2018). Again, in a study conducted with depression patients, a general improvement was observed in emotion recognition performance, especially in sad expressions, after anodal tDCS applied to the dorsolateral prefrontal cortex (Berryhill & Martin, 2018).

Studies have shown that anodal cerebellar tDCS applied to Parkinson's patients significantly increases the recognition of sad facial expressions (Imbert et al., 2022), and that anodal tDCS applied to the right orbitofrontal cortex in individuals with autism between the ages of 14–21 increases functional connectivity in the right medial prefrontal cortex and supports social functionality (Ruggiero et al., 2021). Anodal tDCS applied to the right temporoparietal region (CP6 region according to the EEG 10–20 system) in adults with autism has been shown to increase empathy and reduce misrecognition of threatening facial expressions (Han et al., 2022). In another study conducted with schizophrenia patients, it was shown that multi-session anodal tDCS applied in the superior temporal sulcus improved some social cognition areas, especially theory of mind (Wilson et al., 2021).

In recent studies conducted with healthy adults, cathodal tDCS applied to the right inferior frontal operculum increased the discrimination of angry faces, while cathodal tDCS applied to the left inferior frontal operculum impaired the discrimination of sad faces (Yamada et al., 2022); Anodal tDCS applied to the right temporoparietal region (CP6) improved the recognition of spontaneous micro expressions, especially fear-related expressions (Iarrobino et al., 2021); Anodal cerebellar tDCS has been shown to improve processes related to the ability to recognize the mental state of another person (Clausi et al., 2022).

However, there are also studies in which no significant effect was observed. For example, in a study conducted with schizophrenia patients, no significant effect was observed on emotion recognition in anodal, cathodal, or sham stimulation in the left dorsolateral prefrontal cortex (Ge et al., 2022), and in another study in which anodal stimulation was performed in the left dorsolateral prefrontal cortex, no significant effect was observed in emotion recognition (Rassovsky et al., 2018). Similarly, no significant effect of tDCS was applied to the left dorsolateral prefrontal cortex in healthy adults (Overman et al., 2020) and tDCS applied to the dorsolateral prefrontal cortex in panic disorder patients (Palmisano et al., 2021) was observed.

There are studies on emotion-related tDCS applications in the ventromedial prefrontal cortex (Fpz region according to the EEG 10–20 system), which is one of the important brain regions associated with emotion recognition. However, in these studies, the processing of emotions (Aksu et al., 2022) and emotional facial expressions (Nejati et al., 2021) was studied. Additionally, Salehinejad et al (Winker et al., 2018). examined the effect of tDCS applied to the Fpz region on the theory of mind test, which includes emotion recognition skills, in children with autism. Their results showed that anodal stimulation of the Fpz region improved theory of mind. Similar findings have been seen in the other studies (Adenzato et al., 2017, 2019; A. K. Martin et al., 2017). However, no existing study has been found on how tDCS applied to the Fpz region specifically affects emotion recognition.

Electroencephalography (EEG) is a neuroimaging method that allows directly measuring the electrical activity of nerve cells in the brain (Kaya, 2017). While EEG recording is being made, electrodes are placed on the scalp according to the international 10–20 systems (Biasiucci et al., 2019). EEG brain oscillations are fluctuations formed by the overlap of brain waves in five different frequency ranges (Lesser & Picton, 1991). The values of these frequency bands are in many studies; Delta band is specified as 0.5–3.5 Hz, Theta band is 3.5–7 Hz, Alpha band is 8–13 Hz, Beta band is 18–25 Hz, Gamma band is 30–70 Hz (Alotaiby et al., 2015; Amatachaya et al., 2015; Başar, 2013; Güntekin & Başar, 2014; Güntekin et al., 2013). Delta oscillations are associated with cognitive processes such as perception, attention, learning, and decision making (Güntekin & Başar, 2016). In various studies, it has been shown that the increase in resting state EEG delta oscillations is generally associated with pathological conditions such as aging, mild cognitive impairment, Alzheimer's, and dementia (Vecchio et al., 2018). It was stated that Theta oscillations are related to memory and affect (Kayalar & Sazak, 2018; Xing et al., 2019), Alpha oscillations are associated with memory, attention, and sensory stimulation (Başar & Güntekin, 2012; Kayalar & Sazak, 2018; Xing et al., 2019). Also, it was stated that Beta oscillations are associated with sensory and motor processes (Başar & Güntekin, 2013; Kayalar & Sazak, 2018; Xing et al., 2019), Gamma oscillations are associated with functions such as memory, state of consciousness, attention (Başar, 2013; Kayalar & Sazak, 2018; Lesser & Picton, 1991). Three types of EEG brain oscillations have been identified: resting-state EEG oscillations, evoked oscillations, and event-related oscillations. Resting state EEG oscillations are spontaneous oscillations that occur when no physical external stimulus is present (Alotaiby et al., 2015).

There are neuroimaging studies examining how brain stimulation affects the brain physiologically.

tDCS, one of the brain stimulation methods used to provide neuromodulation in neuroscience, provides stimulation by affecting the existing neural activity in the targeted area through direct current (Xing et al., 2019). It is important to examine the physiological processes underlying the tDCS method with EEG, which provides good temporal measurement (Herrmann et al., 2016). Because EEG shows the fluctuations in regional potentials arising from the postsynaptic potentials of neurons in the cortex and the differences in neuronal resting membrane potential as a result of tDCS (Hanley et al., 2016).

When the studies examined which are about resting state EEG recordings before and after tDCS application, delta (0.5–3.5 Hz) (Donaldson et al., 2019; Mangia et al., 2014; Moliadze et al., 2015), theta (4–7 Hz) (Donaldson et al., 2019; Moliadze et al., 2015; Wirth et al., 2011), alpha (8–13 Hz) (Cavinato et al., 2019; Dong et al., 2020; Jacobson et al., 2012; Kim et al., 2020) shows that there are changes in beta (15–25 Hz) (Hanley et al., 2016; Jacobson et al., 2012; Spitoni et al., 2013) frequencies.

Keeser et al. (2011) have shown that anodal stimulation of the left dorsolateral prefrontal cortex could modulate regional electrical activity and increase neuronal activity in the prefrontal cortex and anterior cingulate cortex. In another study, it has stated that anodal stimulation of the parietal cortex in healthy individuals caused an increase in temporoparietal and central delta power, and cathodal stimulation caused an increase delta and theta power in the frontal region (Mangia et al., 2014).

Boonstra et al. (2016) examined the resting state EEG before, during and after stimulation of anodal tDCS applied to the left dorsolateral prefrontal cortex and showed that there was a general slowdown in oscillations. However (Gordon et al., 2018), stated that there was no significant change in the resting state EEG of tDCS applied with five different parameters in healthy individuals. In a HD-tDCS study, anodal stimulation was applied on Fpz region. Four cathode electrodes were positioned over the left and right prefrontal cortices (PFCs). Stimulation had no significant effect on resting-state EEG frequencies (Ghafoor et al., 2022).

Stimulation of the bilateral DLPFC region, created a significant delta band power decrease at F4 and increase at F3; additionally theta, alpha, and beta band powers increased at F3 and F4 after the tDCS (Wysokiński et al., 2023). Anodal/cathodal stimulation of the C3 region on healthy individuals showed to globally modulate the cortical connectivity of the brain and alter the underlying functional organization of stimulated networks (Vecchio et al., 2018). Another study, anodal/cathodal stimulation of the P4 region and anodal stimulation of the C6, TP8, PO8, P2 regions in the parietal cortex on healthy individuals caused an increase on the temporoparietal and central delta power, and cathodal stimulation increased delta and theta power in the frontal region. Additionally, Amatachaya et al. (2015) showed that anodal stimulation on F3 region increase alpha frequency. Gordon et al. (2018) were also examined that the effects of tDCS and tACS in the Fpz region on resting state brain activity with fNIRS and EEG; and the results showed that tDCS created a general increase in EEG frequency bands, although not significantly.

When we look at the special frequencies on the studies; for delta frequency band, Wirth et al. (2011) showed a decreasing delta power after the applied tDCS in the F3 region. Also Donaldson et al. (2019) showed an increase in temporoparietal and central delta power after anodal stimulation. Additionally, an increase was shown delta and theta power in the frontal region after the cathodal stimulation. For theta frequency band, Jacobson et al. (2012) was showed decreased theta power in the right inferior frontal gyrus anodal stimulation region, Moliadze et al. (2015) was showed C3 region anodal stimulation increased delta and theta power. Also it has been shown that anodal tDCS on the right inferior frontal gyrus creates a significant and selective decrease on theta power in this region (Wirth et al., 2011), anodal tDCS stimulation in the C3 region also causes a decrease in theta power (Donaldson et al., 2019).

For alpha frequency band, anodal stimulation on the right posterioparietal region showed alpha band changes (Spitoni et al., 2013). P4 region single session anodal stimulation an increase alpha power was observed in the P8 region during tDCS and in the O_2 region after the tDCS (Y.-S. Lee et al., 2023). Additionally, it was showed increased alpha activity in parieto-occipital region after the Oz anodal stimulation (Dong et al., 2020). For beta frequency band, Song et al. (2014) showed that an increase the beta power during stimulation of left dlPFC. Cavinato et al. (2019) showed that an increase was seen in frontal-parietal alpha and beta frequencies after active tDCS in power and coherence. Also, Vimolratana et al. (2024) were shown that an increase beta power after the anodal tDCS of central region. For gamma frequency band, M. Boudewyn et al (2019, 2020). have showed that an increased gamma power after the frontal anodal tDCS. It have shown that an increase was suppressed in interhemispheric coherence and the absolute gamma power in the left parietal region was reduced in the tDCS group compared to the sham group at one-month follow-up evaluation in a long-term HD-tDCS study (J.-Y. Lee et al., 2021). On the other hand, in a HD-tDCS study were studied anodal HD-tDCS in Fpz region. It was showed that the stimulation had no significant effect on resting-state EEG frequencies (Ghafoor et al., 2022).

When the literature is examined, there are studies examining the effects of tDCS on emotion recognition and EEG oscillations separately. However, when the article databases were queried with the keywords "emotion recognition, tDCS and EEG," no study was encountered that examined the effect of tDCS on emotion recognition and resting state EEG oscillations together. In addition, studies on the effect of tDCS on emotion recognition generally show stimulation to the left dorsolateral prefrontal cortex (F3) region (Brennan et al., 2017; Ge et al., 2022; Ghafoor et al., 2022; D. M. Martin et al., 2018; Nitsche et al., 2012; Overman et al., 2020; Palmisano et al., 2021; Rassovsky et al., 2015, 2018). However, no study has been found examining the effect of tDCS applied to the ventromedial prefrontal cortex, one of the important brain regions associated with emotion recognition, especially on emotion recognition. It is thought that our study contributes to the literature by studying the effect of anodal stimulation of the one of the important brain regions associated with emotion recognition skills ventromedial prefrontal cortex region on emotion recognition and EEG oscillations.

Materials and methods

Ethics statement

All participants signed the informed consent form prepared in accordance with the Declaration of Helsinki. The study was approved by the Istanbul Medipol University Non-Invasive Research Ethics Committee (no. 609/03.06.2021). The study was registered in ClinicalTrials.gov (ClinicalTrials.gov ID: NCT05623072).

Participants

This study is a single-blind randomized-controlled study. 54 individuals between the ages of 18–40, who agreed to participate in the study by signing the informed consent form and met the inclusion criteria, were included in the study. Participants were reached through classroom announcements, social media and student clubs at Istanbul Medipol University, and volunteers were found by promoting the research.

The sample size was determined by power analysis, taking into account the Cohen values for repetitive measurement analysis of variance (within and between subjects) (Kalaycıoğlu & Akhanlı, 2020). In studies similar to our study, the effect size was generally 0.4 or 0.5. Also it is stated that the effect size was generally 0.5 for analysis for repeated measures ANOVA within and between interactions, like our method, according to the Cohen values (1988) (Aksu et al., 2022; Faul et al., 2007, 2009; Frings et al., 2018; Ge et al., 2022; Lefaucheur et al., 2017; Nejati et al., 2021, 2021). In our study, pre- and post-effect size calculations were made with G power program (Faul et al., 2009). When the power was determined as 0.80, the alpha error value as 0.05 and the effect size as 0.5, it was determined that the current study should be carried out with a total of at least 34 participants (Faul et al., 2007). Also, a post-hoc calculation was performed after the research was conducted with 54 participants, revealing that the achieved statistical power was 0.95. There were 29 participants in the experimental group and 25 participants in the control/sham group.

There were some inclusion criteria; being between the ages of 18–40 and having a score of 17 or below on the Beck Depression Inventory. Also, there were some exclusion criteria; having a history of serious neurological and psychiatric disease, currently using medication that changes the level of cortical excitability, having vision defects that cannot be corrected with glasses, being left hand dominant, use of intracranial metal objects, implanted stimulating devices or pacemakers.

Measurement tools

Emotion recognition task

Facial expression recognition was evaluated using the emotion recognition task prepared with the Amsterdam Dynamic Facial Expression Set – Bath Intensity Variations (ADFES-BIV) video stimulus set. ADFES-BIV is a standard video stimulus set of emotional expressions of different intensities (low, medium, high) of six basic emotions (anger, happiness, disgust, fear, surprise, sadness) and three complex emotions (contempt, shame, pride) (Wingenbach et al., 2016). It was stated that the overall raw accuracy of emotion recognition from facial expressions of videos was 69%, and this rate was compatible with commonly used video stimulus sets such as Reading the Mind in the Eyes Test (RMET). The findings showed that the newly created video set (ADFES-BIV) of emotional expressions of different intensities of basic and complex emotions is a valid set of stimuli that can be used in emotion research.

Amsterdam Dynamic Facial Expression Set – Bath Density Changes (ADFESBIV) material was obtained from the researchers who developed the test and necessary permissions were obtained for its use. The emotion recognition task applied with the ADFES-BIV

Figure 1. An example visual from the emotion videos (anger high) (Wingenbach et al., 2016).

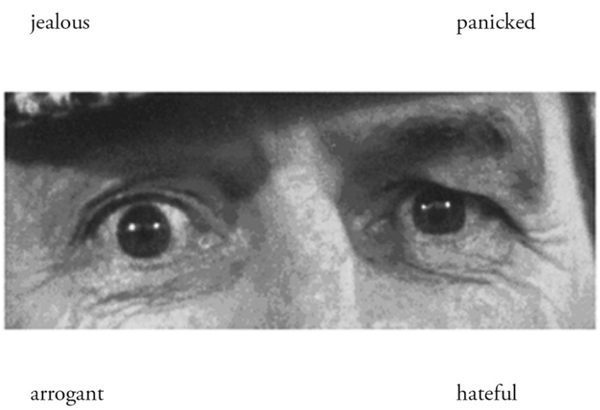

Figure 2. An example visual from the RMET (Yıldırım et al., 2011).

video stimulus set was performed via a laptop using the PsychoPy stimulus presentation software, and the answers were automatically transferred to Excel with the program (Peirce et al., 2019).

The task used 81 videos containing 9 different expressions of emotion at three different intensities (low, medium, high). An example visual from the emotion videos (anger high) is presented Figure 1. After each video they watched, the participants were presented with a screen with buttons containing 9 numbered emotional expressions and they were told to mark whichever number corresponded to the correct answer using the number keys on the keyboard (1-Anger, 2-Happiness, 3-Disgust, 4-Fear, 5-Surprise, 6-Sadness, 7-Contempt, 8-Shame, 9-Pride). After the experimental tasks, the total of the participants' correct answers to the emotional expressions in the videos was evaluated. A total of 81 videos were presented and each correct answer was worth 1 point. Then, total scores' pre-post differences were compared with the statistical analysis for within and between subjects.

In order to ensure equality between the two tasks, the stimulants were the same both tasks. They were repeated in the two sessions. In the posttest, as same as the pretest a total of 81 videos were presented the same order and each correct answer was worth 1 point.

Reading the mind in the eyes test (RMET)

Reading the Mind in the Eyes Test (RMET) is a frequently used to measure theory of mind and emotion recognition. Participants are shown pictures of people with only their eyes visible. They are then asked to choose the option that best describes what the person in the picture is thinking or feeling (Yıldırım et al., 2011).

Yıldırım et al. (2011) was adapted the latest version of the 36-question RMET, developed by Baron and Cohen in 2001, into Turkish. The test consists of a total of 37 pictures, one of which is an exercise, and includes four options: one correct answer and three distractors for each picture. During the application, the participant is asked to mark the option that best describes what the person in the picture is thinking or feeling. An example visual from the RMET is presented Figure 2. A high score indicates that theory of mind skills, one of the social cognitive abilities, are good. During the adaptation of the test to Turkish, two questions (25 and 35) were removed from the study due to linguistic incompatibility. In addition, when the consistency level in questions 19 and 21 was found to be low, these two questions were removed from the test, and the reliability results examined with Kuder-Richardson 20 increased from KR20 = 0.69 to 0.72. It has been stated that RMET, which is widely used for theory of mind and emotion recognition, can be used reliably in research with its 32-question version in Turkish. The necessary permission to use the RMET has been obtained. The 32-question test was presented to the participants with visual cards, and the participants marked the answer keys on the paper they were asked to do.

In the RMET task, the 32-question test was presented to the participants with visual cards and the participants were asked to mark the correct answer on the paper. There are four options for each visual card and this changes with each question. The participant was asked to mark the option that best suited him. In the test consisting of a total of 32 questions, each correct answer was worth 1 point and the final score was calculated based on the total number of correct answers.

tDCS

The Neurosoft-Neurostim tDCS device from Russia was used to deliver transcranial direct current stimulation.

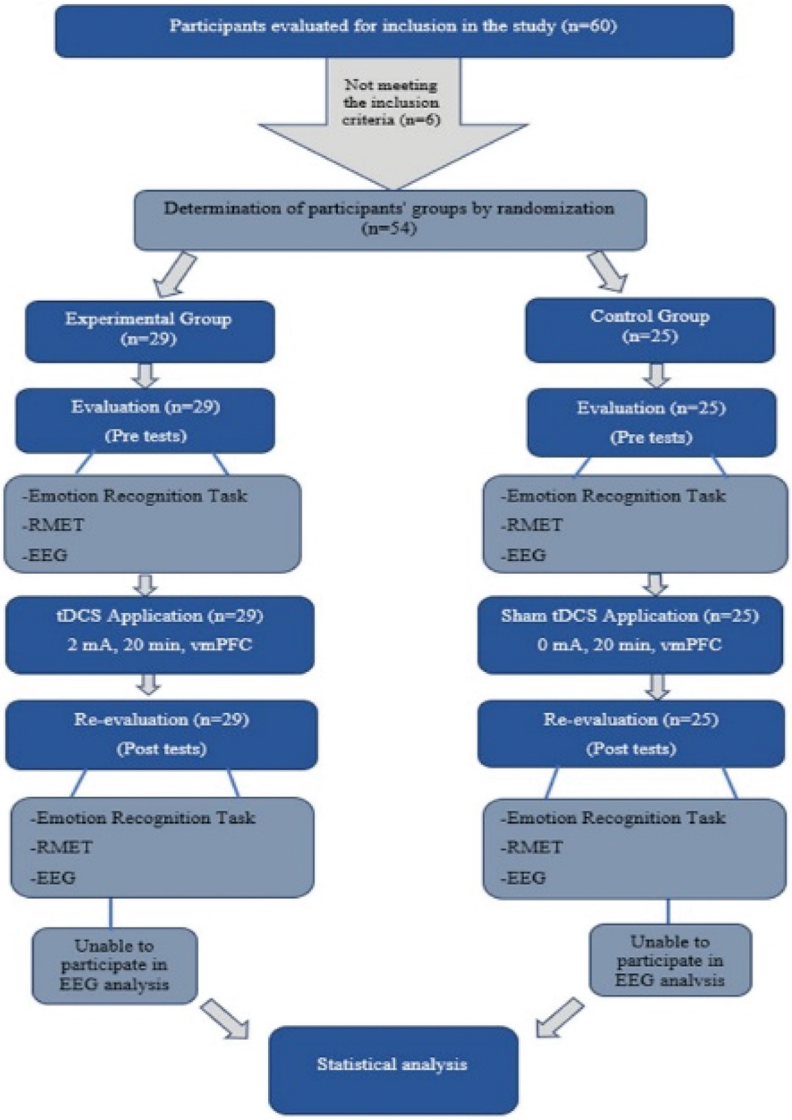

Figure 3. The working flow diagram.

The device includes a battery, a pair of electrodes and a pair of sponges. The dimensions of the electrodes used are 5 × 5 cm.

Two different stimulation protocols were used, one for tDCS and the other for sham stimulation. A single session of anodal tDCS stimulation was applied to the Fpz region targeting the ventromedial prefrontal cortex (vmPFC) to modulate the emotion recognition of the participants in the experimental group. In the sham protocol, participants in the control group ($n = 25$) a single 20-min sham application was done, they were not given electrical current. In the sham protocol, one ramp-up/down at beginning didn't used. tDCS device was opened but stimulation wasn't started. Participants were thinking that the stimulation was started despite stimulation wasn't started.

Electrode placement was determined according to the International 10–20 EEG system. Before application, the electrodes were wetted with isotonic sodium chloride. The anode superficial electrode was placed on the Fpz region over the ventromedial prefrontal cortex (vmPFC) which corresponds to Brodmann area 10, and the cathode electrode was placed on the clavicle on the left shoulder. In the implementation of the protocols, controls were provided in the safety guide by paying attention to the information in the literature. The application has been audited in terms of ethics and security, and no negative situations have occurred.

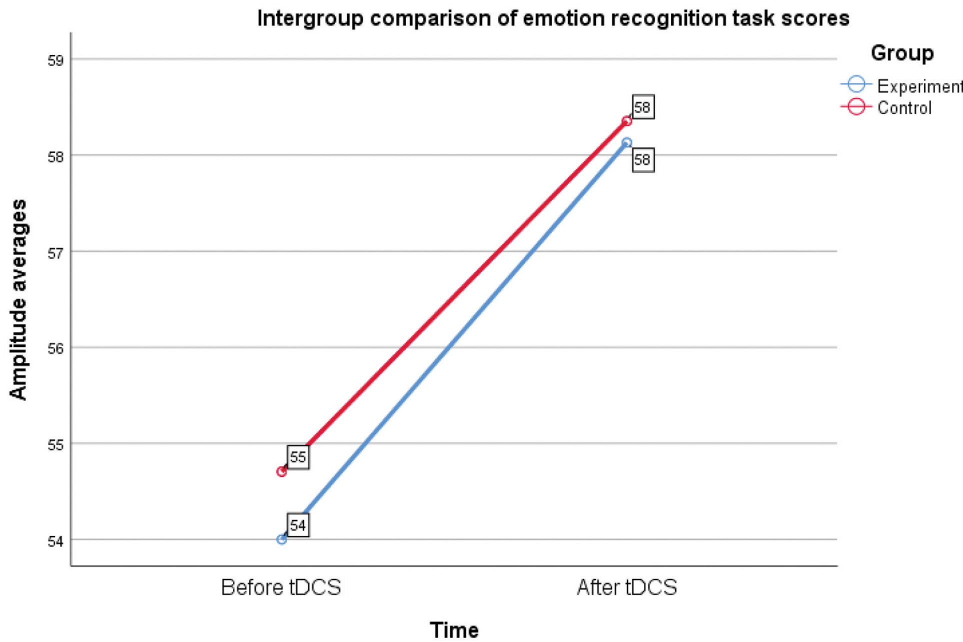

Figure 4. Intergroup comparison of emotion recognition task scores.

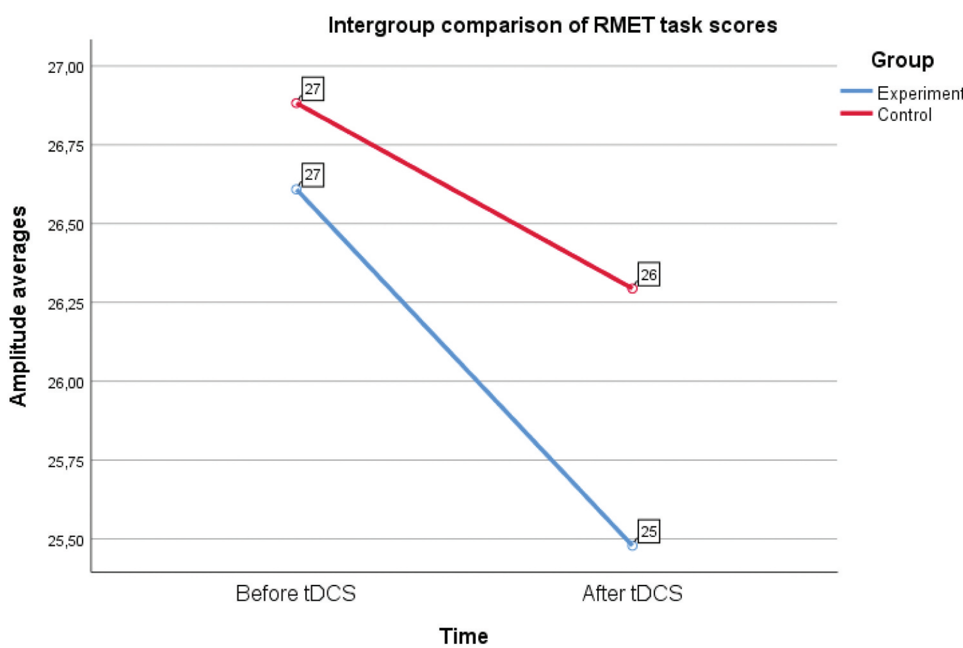

Figure 5. Intergroup comparison of RMET task scores.

The participants were asked whether they felt any disturbing effects during and after the stimulation. It was observed that there were generally mild effects such as mild itching and pins and needles in the stimulated area. No serious negative situation was encountered in any participant. Also, each participant was asked after the experiment whether they thought they were in the sham group or the group receiving tDCS stimulation. The answers were heterogeneous.

EEG

The EEG signals were obtained with 32 channels mobile LiveAmp32 wireless amplifier and the signals were recorded using the Brain Vision Recorder (Brain Products, Gilching, Germany). The signals were sampled with 500 Hz and band-pass filtered (0.01–250 Hz). Electrodes were placed according to the international EEG 10–20 system: Fp1, Fp2, Afz, F7, F3, Fz, F4,

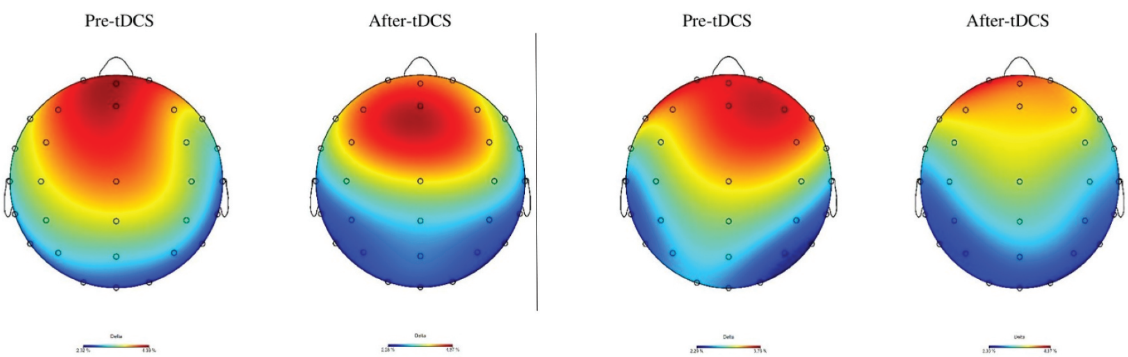

Figure 6. Delta oscillations with eyes open (the left two figures are experimental group and the right two figures are control group).

F8, FT7, FC3, FC4, FT8, T7, C3, Cz, C4, T8, Tp7, Cp3, Cpz, Cp4, Tp8, P7, P3, Pz, P4, P8, O1, Oz, O2 (Biasiucci et al., 2019).

The reference electrode was placed in the FCz and the ground electrode was placed at the right earlobe. Electrooculogram (EOG) recording was used to detect eye movements, and while the 31st electrode was placed on the participants' left eye as electrooculogram horizontal (EOGH), the 32nd electrode was placed on the participants' right eye as electrooculogram vertical (EOGV). The impedance values of all electrodes were set to be below 20 kΩ.

During EEG recording, the resting state electrical activity of the brain was recorded for a total of 8 min, 4 min with eyes open and 4 min with eyes closed. After, a single session of tDCS was applied and immediately afterward, resting state EEG recording was repeated in the same way.

EEG analysis

The EEG signals were analyzed offline using Brain Vision Analyzer (Brain Products, Gilching, Germany). Firstly, a wide filter between 0.01 and 60 Hz was applied to the EEG data, followed by division into 1000 ms epochs. Then, manual artifact rejection was performed to remove noise from the data. Next, Fast Fourier Transform (FFT) power analysis was applied to all epochs, and the average of all epochs was taken. The results were then transferred to SPSS for statistical analysis.

Resting state EEG data were compared between groups in terms of changes in delta (0.5–3.5 Hz), theta (4–7 Hz), alpha (8–13 Hz), beta (15–25) and gamma frequency bands (28–48) before and after tDCS. In the statistical analysis of the channels, three ROIs were selected as regions of interest. These are frontal, temporal, and posterio-occipital regions. Frontal ROI consists of Fp1, Fp2, Afz, F7, F3, Fz, F4, F8 channels; Temporal ROI consists of T7, T8, FT7, FT8, TP7, TP8 channels, and Parieto-Occipital ROI consists of P7, P3, Pz, P4, P8, O1, Oz, O2 channels.

Procedure

At the beginning of the study, all participants completed the emotion recognition task and the RMET (about 20-min total). Then, EEG recordings were taken (8 min). Next, the experimental group received a single session of anodal electrical stimulation (2 mA, 20 min). The sham group received the same procedure, but without any current stimulation. Immediately after stimulation, EEG recordings were taken again (8 min). Finally, the tasks were repeated as prior (20-min total). There was no more than 1 min between each step. Terms are balanced in order. Each participant performed all tasks and procedures in the same order, both in the before-after conditions and in the tDCS or sham conditions. The visual from the working flow diagram is presented Figure 3.

Statistical analysis

Mean, standard deviation, minimum-maximum values and percentage values are presented in the descriptive statistics of the variables. The normal distribution of the variables was evaluated using the Kolmogorov–Smirnov Test. In instances of normal distribution, the relationship between the variables was evaluated through Pearson Correlation analysis; in cases where normal distribution was not present, Spearman Correlation analysis was employed. To examine whether there were variations in emotion recognition performance based on sex, Independent Sample T Test applied, and between-group pretest and posttest differences were analyzed using One-Way ANOVA analysis. Pre and post emotion recognition tasks and EEG recordings, capturing time-dependent differences within groups, as well as intergroup time*group interactions, were subjected to Two-Way Repeated Measures ANOVA analysis. Type 1 error was controlled using Bonferroni correction in multiple comparison analyses like researches which are similar to our study (Aksu et al., 2022; Ge et al., 2022; Han et al., 2022; Iarrobino et al., 2021). All statistical analyses were conducted using the "SPSS 25 (Statistical Package for the Social Sciences) for Windows" software, and significance was determined at a threshold of $p < 0.05$ for all tests.

Results

Comparison of demographic data

The average age of individuals in the experimental group ($n = 29$) is 21.93(M) ± 0.39(SD), and the average age of individuals in the control group ($n = 25$) is 22.32 (M) ± 0.44(SD). Individuals in the experimental group are at least 18 and at most 26 years old, and individuals in the control group are at least 18 and at most 29 years old. When we look at the sex distribution, the participants consist of 30 females and 24 males. Considering the educational status, one of the participants is a high school graduate, 48 are undergraduate students and 5 are graduate students.

There was no statistically significant difference between the groups in terms of age, sex and educational status ($p > 0.05$). The results of the Spearman Correlation analysis performed to examine the relationship between age and emotion recognition scores showed a significant positive correlation between age and the emotion recognition task pretest, post-test and RMET posttest ($p < 0.05$); RMET showed that there was no significant relationship between the pretest ($p > 0.05$). There was no significant difference between sex and emotion recognition task scores ($p > 0.05$). There was a significant difference between sex and RMET pretest ($p = 0.002$) and RMET posttest ($p = 0.003$) scores. In both cases, females scored higher than males.

tDCS effects on emotion recognition

The emotion recognition performances were compared before and after tDCS to within and between subjects. Time effect was meaningful favor of posttest ($p < 0.05$) in the experimental group when comparing before and after emotion recognition performances. However, *time*group* interaction was not significant ($p > 0.05$) when the comparing before and after emotion recognition performances in between groups. Comparison of emotion recognitions scores between pre- and post-tests of tDCS in experimental and control group is presented Table 1 and also intergroup comparison of emotion recognition task scores is presented Figure 4.

tDCS effects on RMET

The Reading the Mind in the Eyes test (RMET) scores of both groups didn't change before and after the tDCS application ($p > 0.05$) in within groups. *Time*group* interaction was also not significant when the comparing before and after RMET performances between groups ($p > 0.05$). Comparison of reading the mind in the eyes test scores between pre and post-tests of experimental and control group is presented Table 2. And also, intergroup comparison of RMET task scores is presented Figure 5.

Table 1. Comparison of emotion recognitions scores between pre- and post-tests of tDCS in experimental and control group ($n = 54$).

Task	Group	Pre-test M (SD)	Post-test M (SD)	Time (p)	Group x Time (p)	F	Partial η2
ADFES-BIV emotion recognition task	tDCS (Experimental group)	53.90 (7.26)	57.76 (7.94)	**<0.001***	0.79	0.068	0.002
	Sham (Control group)	54.08 (7.21)	58.60 (9.80)	0.050			

(M: Mean, SD: Standard Deviation, η2: Eta-squared, *$p < 0.05$).

Table 2. Comparison of reading the mind in the eyes test scores between pre and post-tests of experimental and control group ($n = 54$).

Task	Group	Pre-test M (SD)	Post-test M (SD)	Time (p)	Group x Time (p)	F	Partial η2
RMET task	tDCS (Experimental group)	26.54 (2.62)	25.24 (3.59)	0.098	0.56	0.340	0.009
	Sham (Control group)	26.71 (1.65)	26.21 (2.20)	0.356			

(M: Mean, SD: Standard Deviation, η2: Eta-squared, *$p < 0.05$).

Table 3. Within and between groups comparison of delta activity.

	tDCS (Experimental group)				Sham (Control group)				Difference		
	Pre	Post	F	Time *(p)*	Pre	Post	F	Time *(p)*	F	Partial *η2*	Group x Time *(p)*
	M (SD)	M (SD)			M (SD)	M (SD)					
Frontal	164.55±16.73	185.67±21.44	1.979	0.176	169.41±21.60	134.26±27.68	3.720	0.080	5.502	0.155	**0.026***
Temporal	77.42±18.97	94.53±18.93	3.660	0.070	120.77±21.73	104.00±21.68	1.368	0.260	4.399	0.112	**0.043***
Parieto-Occipital	72.14±18.05	80.00±16.73	1.692	0.207	71.69±21.16	61.85±19.62	2.459	0.138	3.969	0.099	0.054

(M: Mean, SD: Standard Deviation, *η2*: Eta-squared, *$p<0.05$).

tDCS effects on resting-state EEG oscillations

Resting state EEG data were compared between groups in terms of changes in *delta*, *theta*, *alpha*, *beta* and *gamma* frequency bands before and after tDCS. In the statistical analysis of the channels, frontal, temporal and posterio-occipital regions, which were determined as regions of interest (ROI: region of interest), were evaluated. Frontal ROI from Fp1, Fp2, Afz, F7, F3, Fz, F4, F8 channels; Temporal ROI consists of T7, T8, FT7, FT8, TP7, TP8 channels, and Parieto-Occipital ROI consists of P7, P3, Pz, P4, P8, O1, Oz, O_2 channels.

The analysis showed that the eyes open and eyes closed conditions did not significantly affect the results. For this reason, data taken with both eyes open and eyes closed were added to the frequency averages calculated in the determined ROI analyses. It was examined whether the difference between the experimental and control groups before and after tDCS within the group differed significantly depending on whether they were in the experimental or control group in the three determined ROIs. Therefore, separate analyzes were conducted for both within-group results and between-group results.

The results showed that there was a significant difference between groups only in delta frequency before and after tDCS in the frontal and temporal regions ($p < 0.05$). While an increase in delta activity was observed in the experimental group in the frontal and temporal regions, a decrease was observed in the control group. Within and between groups comparison of delta activity is presented Table 3. And also, delta oscillations with eyes open (the left two figures are experimental group and the right two figures are control group) is presented Figure 6.

Discussion

Studied that the effects of anodal stimulation one of the important brain regions associated with emotion recognition skills ventromedial prefrontal cortex region on emotion recognition in the present study. In this way, it is thought that our study contributed to the literature, in addition it will add the innovation to studies in this field, as the paired group design method was used unlike existing studies and the emotion recognition task consists of a current standard video set, which includes different intensities emotional expressions. Also, it is thought that the results of the study may be also beneficial in practice in terms of therapeutic applications which will developed in the future for individuals who have difficulties in emotion recognition skills like autism, schizophrenia and various psychiatric disorders.

When we look at the results, there was no significant difference between sex and emotion recognition task. However, there was a significant difference between RMET test scores and female received higher scores than male. These findings are consistent with the findings of previous studies using RMET and tDCS (Adenzato et al., 2017, 2019; A. K. Martin et al., 2017). Although most studies in the literature show that emotion recognition varies significantly according to age and sex, there are also studies in which no significant difference is observed (Abbruzzese et al., 2019; Adenzato et al., 2017, 2019; Andric et al., 2016; Demenescu et al., 2014; Hayes et al., 2020; Ruffman et al., 2008). Therefore, it can say that the results were partially compatible with previous studies on age and sex in emotion recognition. Also, it was observed that there was a positive significant relationship between age and emotion recognition task scores in our study, since there are different results on this subject in the literature, it may be normal to see conflicting results in our study. It can also suggest that this may be due to the limited age range. It is stated that the studies to be carried out in this field are important and it is recommended to work with larger age and sample groups in future studies.

When we look at the tDCS effects on the emotion recognition tasks and EEG oscillations; although a single session of anodal tDCS applied in the vmPFC region did not cause a significant effect on emotion recognition tasks, it was observed that neuromodulation had a significant effect on some regions in resting state brain oscillations by modulating the electrical activity in the brain.

Contrary to our expectations our study shows that tDCS application to the vmPFC did not cause a significant difference in emotion recognition task scores. Although we did not see any behavioral change, there was a significant difference between groups in delta frequency before and after tDCS in the frontal and temporal regions.

Since brain stimulation can also be used to enhance cognitive functions in healthy individuals, studies on the enhancing of emotion recognition have increased recently (Brennan et al., 2017; Clausi et al., 2022; Hızlı Sayar et al., 2012; Willis et al., 2015). Although similar methods to other studies were used in our study, our results mostly seem to be inconsistent to other studies. Even though this study used similar brain stimulation methods to those in the literature, but stimulation targeted that the ventromedial prefrontal cortex, a less studied region. It is thought that it may because of the vmPFC region is located in the lower part of the prefrontal lobe, etc., it is thought that this may be due to the fact that full stimulation of tDCS may not have created a strong stimulation in the targeted region.

However, in various studies, it was also observed that tDCS applied in the prefrontal region did not cause any significant effect same as our study (Ferrucci et al., 2012; Overman et al., 2020; Rassovsky et al., 2018). It is seen that our study results are compatible with these studies in that there is no significant effect on emotion recognition.

When we look at the studies in which tDCS was applied on the ventromedial prefrontal cortex (vmPFC), the region where tDCS stimulation was applied, it was mostly studied on the processing of emotions (Nejati et al., 2021) and emotional facial expressions (Winker et al., 2018). It is seen that there is no study that directly examines emotion recognition skills. However, in a study conducted with children with autism, it was shown that anodal tDCS applied to the ventromedial prefrontal cortex improves theory of mind, including emotion recognition skills (Salehinejad et al., 2021). The results of our study do not seem to be compatible with this study. It is thought that this may be due to the fact that the sample groups are in different age groups and health status, emotion recognition tasks are applied differently and have different content.

As can be seen, studies on the effect of tDCS on emotion recognition mostly showed that tDCS had a positive effect; on the other hand, it is understood that there are also studies that did not reveal any significant effect. Considering the results of our study, it can be said that there are some contradictory results in this area. It is thought that the differences in important factors such as the characteristics of the sample applied, the type and region of stimulation, and the emotion recognition tasks used may have an effect on obtaining different results in the studies.

The stimulation protocol factor, which is thought to be one of the reasons for obtaining inconsistent results, is very important. Although the single session method used in our study is frequently used in research, it is known that repeated sessions are important in order to see the effects of tDCS. Although studies with repeated sessions are few, they present important findings (Aksu et al., 2022; Han et al., 2022; D. M. Martin et al., 2018; Ruggiero et al., 2021; Yamada et al., 2022). Since the results of these studies are seen to be inconsistent, it is recommended that tDCS stimulation be performed as repeated sessions in future studies, considering that more studies should be conducted on the effect of repetitive stimulation on emotion recognition. Also, it is thought that future studies with HD-tDCS method, which is one of the more modern methods and can provide more regional stimulation, are also important (Parlikar et al., 2021). In addition, although most studies use anodal stimulation, there are also studies using cathodal stimulation. For example, it has been shown that reducing excitability with cathodal tDCS applied to the left inferior frontal gyrus facilitates emotion recognition (Klimm et al., 2015). It is thought that future studies will be important to clarify the effect of both anodal and cathodal stimulation methods on emotion recognition.

On the other hand, there are studies showing that tDCS studies performed in regions such as the cerebellum, centroparietal, and inferior frontal operculum also have a significant effect on emotion recognition (Ferrucci et al., 2012; Iarrobino et al., 2021; Ruggiero et al., 2021; Wilson et al., 2021). It is thought that brain stimulation studies to be carried out in different regions in this way will help to illuminate the emotion recognition process and will guide the effective use of neuromodulation in emotion recognition.

When we look at the studies tDCS and EEG; it is seen that EEG, which enables the measurement of electrical activity in the brain, is mostly examined in terms of changes in the frequency bands in the resting state EEG activity in neuromodulation studies. In these studies, similar to our study, it was examined whether the resting state EEG recordings taken before and after tDCS application showed a significant difference after stimulation compared to before. Studies show that stimulation can modulate electrical activity locally (Boonstra et al., 2016; Keeser et al., 2011; Vecchio et al., 2018). Based on these studies, a similar method was applied in our study and the effect of the applied tDCS on the resting state EEG frequency bands was examined. Significant differences were observed between groups in delta frequency before and after tDCS in the frontal and temporal regions in our study results. These results showed that neuromodulation modulates electrical activity in the brain. In this sense, our results seem to be compatible with other studies.

In addition to all these, it should be noted that there is only one EEG-tDCS study with stimulation in the Fpz region (Ghafoor et al., 2022), and tDCS did not have a significant effect on EEG oscillations in this study.

When we look at the results specifically for the frequency bands; for delta frequency band, a statistically significant difference was seen in the changes in activity in the frontal and temporal regions before and after tDCS inter groups. In these regions, after tDCS delta activity increased in the experimental group and decreased in the control group. It contrasts other studies which showed delta frequency band activity was reduced after the tDCS (Moliadze et al., 2015; Wang et al., 2024; Wirth et al., 2011; Wysokiński et al., 2023). However, it was consistent with a study showing an increase in delta after tDCS (Donaldson et al., 2019). For theta frequency band, a statistically significant difference wasn't seen. This result contrasts other studies which showed theta frequency band activity was changed after the tDCS (Donaldson et al., 2019; Jacobson et al., 2012; Moliadze et al., 2015). However, it was consistent with studies showing didn't change in theta after the tDCS (Ghafoor et al., 2022; Gordon et al., 2018). For alpha frequency band, a statistically significant difference wasn't seen. This result contrasts other studies which showed alpha frequency band activity was changed after the tDCS (Amatachaya et al., 2015; Cavinato et al., 2019; Dong et al., 2020; Mangia et al., 2014; Spitoni et al., 2013). However, it was consistent with studies showing didn't change in alpha after the tDCS (Ghafoor et al., 2022; Y.-S. Lee et al., 2023). For beta frequency band, a statistically significant difference wasn't seen. This result contrasts other studies which showed beta frequency band activity was changed after the tDCS (Cavinato et al., 2019, p. 202420; Mangia et al., 2014; Song et al., 2014; Vimolratana et al., 2024). However, it was consistent with studies showing didn't change in beta after the tDCS (Ghafoor et al., 2022; Gordon et al., 2018). For gamma frequency band, a statistically significant difference wasn't seen. This result contrasts other studies which showed gamma frequency band activity was changed after the tDCS (M. Boudewyn et al., 2019; M. A. Boudewyn et al., 2020; J.-Y. Lee et al., 2021). However, it was consistent with studies showing didn't change in beta after the tDCS (Ghafoor et al., 2022; Gordon et al., 2018).

As can be seen, when we looked at the comparisons between groups, the fact that there was no significant difference on the power of theta, alpha, beta and gamma frequencies after anodal tDCS in our study seems to be mostly contradictory with the results of others. On the other hand, there is some consistent studies. It is thought that to eliminate this uncertain situation, future studies in this field will be useful in clarifying these contradictions.

As a conclusion, in our study contrary to expectations, considering the studies in the literature, there was no positive effect on emotion recognition. It may because of the vmPFC region is located in the lower part of the prefrontal lobe, etc., it is thought that this may be due to the fact that full stimulation of tDCS may not have created a strong stimulation on the targeted region; and also may be due to changes in EEG frequencies were modulation similar to some pathological processes reported in the literature. In addition, it is thought that this finding supports the idea that brain oscillations can be affected by stimulation, leading to deterioration in cognitive functions.

Limitations and future directions

One of the limitations of the present study is being of the number of participant data that can be analyzed in the delta frequency band in EEG data is less than in other frequency bands. In addition, the other one is inability to perform area modeling with a program such as SimNIBS for brain stimulation. It is thought that using current stimulation modeling in the future studies which are about tDCS on the Fpz region will be important. Also, in the emotion recognition tasks we didn't control the learning/practice effects in the present study. So, it can be also a limitation and being attention the learning/practice effects in the future studies will be beneficial.

RMET, recently begun to be questioned significantly although it is frequently used as an emotion recognition/mentalization task (Higgins et al., 2023; Navarro, 2022; Oakley et al., 2016). This also can be a limitation in the present study. So, it was recommended that thinking about the using the RMET in the future studies. In addition, the not using tDCS protocols that have been shown to be effective, such as online and repetitive stimulation and the not using one ramp-up/down at beginning in sham stimulation can also be limitations of the study. So, in the future studies, it can be recommended that the using various protocols which have been shown to be effective of tDCS and ramp-up

/down at the beginning of sham stimulation in the future studies.

There are various studies on emotion recognition which were used online tDCS in the prefrontal region. The results show that tDCS applied to the online prefrontal region improves emotion recognition (Brennan et al., 2017; Han et al., 2022; Iarrobino et al., 2021; Klimm et al., 2015; D. M. Martin et al., 2018; Nitsche et al., 2012; Zemestani et al., 2022). However, offline tDCS was used in our study. The participant was not subjected to any task during tDCS stimulation. Therefore, may be thought that it is also a limitation. It is thought that it is important to examine the effects of online tDCS applied to the vmPFC region on emotion recognition in the future studies.

Also in the future studies, it is recommended to examine the effect of both anodal and cathodal stimulation methods and repeated tDCS sessions on emotion recognition in vmPFC. In addition, it is important to examine the effects of online tDCS applied to the vmPFC region on emotion recognition. It is thought that the future works will provide a better understanding of the emotion recognition process in the brain, thus forming an important basis for the steps to be taken in the improvement of emotion recognition skills both in healthy individuals and pathological conditions.

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Data availability statement

The data underlying this article will be shared on reasonable request to the corresponding author.

References

Abbruzzese, L., Magnani, N., Robertson, I. H., & Mancuso, M. (2019). Age and gender differences in emotion recognition. *Frontiers in Psychology*, *10*, 2371. https://doi.org/10.3389/fpsyg.2019.02371

Adenzato, M., Brambilla, M., Manenti, R., De Lucia, L., Trojano, L., Garofalo, S., Enrici, I., & Cotelli, M. (2017). Gender differences in cognitive theory of mind revealed by transcranial direct current stimulation on medial prefrontal cortex. *Scientific Reports*, *7*(1), 41219. https://doi.org/10.1038/srep41219

Adenzato, M., Manenti, R., Gobbi, E., Enrici, I., Rusich, D., & Cotelli, M. (2019). Aging, sex and cognitive theory of mind: A transcranial direct current stimulation study. *Scientific Reports*, *9*(1), 18064. https://doi.org/10.1038/s41598-019-54469-4

Aksu, S., Soyata, A. Z., Mursalova, Z., Eskicioğlu, G., & Tükel, R. (2022). Transcranial direct current stimulation does not improve clinical and neurophysiological outcomes in panic disorder: A randomized sham-controlled trial. *Psychiatry and Clinical Neurosciences*, *76*(8), 384–392. https://doi.org/10.1111/pcn.13378

Alotaiby, T., El-Samie, F. E. A., Alshebeili, S. A., & Ahmad, I. (2015, 1). A review of channel selection algorithms for EEG signal processing. *EURASIP Journal on Advances in Signal Processing*, *2015*(1). https://doi.org/10.1186/s13634-015-0251-9

Amatachaya, A., Jensen, M. P., Patjanasoontorn, N., Auvichayapat, N., Suphakunpinyo, C., Janjarasjitt, S., Ngernyam, N., Aree-Uea, B., & Auvichayapat, P. (2015). The short-term effects of transcranial direct current stimulation on electroencephalography in children with autism: A randomized crossover-controlled trial. *Behavioural Neurology*, *2015*, 928631. https://doi.org/10.1155/2015/928631

Andric, S., Maric, N. P., Knezevic, G., Mihaljevic, M., Mirjanic, T., Velthorst, E., & van Os, J. (2016). Neuroticism and facial emotion recognition in healthy adults. *Early Intervention in Psychiatry*, *10*(2), 160–164. https://doi.org/10.1111/eip.12212

Başar, E. (2013). Brain oscillations in neuropsychiatric disease. *Dialogues in Clinical Neuroscience*, *15*(3), 291–300. https://doi.org/10.31887/DCNS.2013.15.3/ebasar

Başar, E., & Güntekin, B. (2012). A short review of alpha activity in cognitive processes and in cognitive impairment. *International Journal of Psychophysiology: Official Journal of the International Organization of Psychophysiology*, *86*(1), 25–38. https://doi.org/10.1016/j.ijpsycho.2012.07.001

Başar, E., & Güntekin, B. (2013). Review of delta, theta, alpha, beta, and gamma response oscillations in neuropsychiatric disorders. *Supplements to Clinical Neurophysiology*, *62*, 303–341. https://doi.org/10.1016/b978-0-7020-5307-8.00019-3

Behere, R. V. (2015). Facial emotion recognition deficits: The new face of schizophrenia. *Indian Journal of Psychiatry*, *57*(3), 229–235. https://doi.org/10.4103/0019-5545.166641

Berryhill, M. E., & Martin, D. (2018). Cognitive effects of transcranial direct Current stimulation in healthy and clinical populations: An overview. *The Journal of ECT*, *34*(3), e25–e35. https://doi.org/10.1097/YCT.0000000000000534

Biasiucci, A., Franceschiello, B., & Murray, M. M. (2019). Electroencephalography. *Current Biology: CB*, *29*(3), R80–R85. https://doi.org/10.1016/j.cub.2018.11.052

Boonstra, T. W., Nikolin, S., Meisener, A. C., Martin, D. M., & Loo, C. K. (2016). Change in mean frequency of resting-state electroencephalography after transcranial direct Current stimulation. *Frontiers in Human Neuroscience*, *10*, 270. https://doi.org/10.3389/fnhum.2016.00270

Boudewyn, M., Roberts, B. M., Mizrak, E., Ranganath, C., & Carter, C. S. (2019). Prefrontal transcranial direct current stimulation (tDCS) enhances behavioral and EEG markers of proactive control. *Cognitive Neuroscience*, *10*(2), 57–65. https://doi.org/10.1080/17588928.2018.1551869

Boudewyn, M. A., Scangos, K., Ranganath, C., & Carter, C. S. (2020). Using prefrontal transcranial direct current stimulation (tDCS) to enhance proactive cognitive control in schizophrenia. *Neuropsychopharmacology: Official Publication of the American College of Neuropsychopharmacology*, *45*(11), 1877–1883. https://doi.org/10.1038/s41386-020-0750-8

Brennan, S., McLoughlin, D. M., O'Connell, R., Bogue, J., O'Connor, S., McHugh, C., & Glennon, M. (2017). Anodal transcranial direct current stimulation of the left dorsolateral prefrontal cortex enhances emotion recognition in depressed patients and controls. *Journal of Clinical and Experimental Neuropsychology*, *39*(4), 384–395. https://doi.org/10.1080/13803395.2016.1230595

Buhagiar, F., Fitzgerald, M., Bell, J., Allanson, F., & Pestell, C. (2020). Neuromodulation for mild traumatic brain injury rehabilitation: A systematic review. *Frontiers in Human Neuroscience*, *14*, 598208. https://doi.org/10.3389/fnhum.2020.598208

Cavinato, M., Genna, C., Formaggio, E., Gregorio, C., Storti, S. F., Manganotti, P., Casanova, E., Piperno, R., & Piccione, F. (2019). Behavioural and electrophysiological effects of tDCS to prefrontal cortex in patients with disorders of consciousness. *Clinical Neurophysiology: Official Journal of the International Federation of Clinical Neurophysiology*, *130*(2), 231–238. https://doi.org/10.1016/j.clinph.2018.10.018

Cavlak, U., Altuğ, F., Ünal, A., Kara, G., Yazıcıoğlu Şener, F. G. (2019). *Evidence-based neuromodulation applications in neurological rehabilitation: Evidence-Based Approaches in Physiotherapy and Rehabilitation.*

Clausi, S., Lupo, M., Funghi, G., Mammone, A., & Leggio, M. (2022). Cerebellum and mental state recognition: A transcranial direct current stimulation study in healthy subjects.*Scientific Reports*. https://doi.org/10.21203/rs.3.rs-1734553/v1

Demenescu, L. R., Mathiak, K. A., & Mathiak, K. (2014). Age- and gender-related variations of emotion recognition in pseudowords and faces. *Experimental Aging Research*, *40* (2), 187–207. https://doi.org/10.1080/0361073X.2014.882210

Donaldson, P. H., Kirkovski, M., Yang, J. S., Bekkali, S., & Enticott, P. G. (2019). High-definition tDCS to the right temporoparietal junction modulates slow-wave resting state power and coherence in healthy adults. *Journal of Neurophysiology*, *122*(4), 1735–1744. https://doi.org/10.1152/jn.00338.2019

Dong, G., Wang, Y. &., & Chen, X. (2020). Anodal occipital tDCS enhances spontaneous alpha activity. *Neuroscience Letters*, *721*, 134796. https://doi.org/10.1016/j.neulet.2020.134796

Ekman, P. (1992). An argument for basic emotions. *Cognition and Emotion*, *6*(3–4), 169–200. https://doi.org/10.1080/02699939208411068

Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods*, *41*(4), 1149–1160. https://doi.org/10.3758/BRM.41.4.1149

Faul, F., Erdfelder, E., Lang, A. G. &., & Buchner, A. (2007). G*Power 3: A flexible sta-tistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175–191. https://doi.org/10.3758/BF03193146

Ferrucci, R., Giannicola, G., Rosa, M., Fumagalli, M., Boggio, P. S., Hallett, M., Zago, S., & Priori, A. (2012). Cerebellum and processing of negative facial emotions: Cerebellar transcranial DC stimulation specifically enhances the emotional recognition of facial anger and sadness. *Cognition & Emotion*, *26*(5), 786–799. https://doi.org/10.1080/02699931.2011.619520

Frings, C., Brinkmann, T., Friehs, M. A., & van Lipzig, T. (2018). Single session tDCS over the left DLPFC disrupts interference processing. *Brain and Cognition*, *120*, 1–7. https://doi.org/10.1016/j.bandc.2017.11.005

Ge, Y., Su, R., Liang, Z., Luo, J., Tian, S., Shen, X., Wu, H., & Liu, C. (2022). Transcranial direct current stimulation over the right temporal parietal junction facilitates spontaneous micro-expression recognition. *Frontiers in Human Neuroscience*, *16*, 933831. https://doi.org/10.3389/fnhum.2022.933831

Ghafoor, U., Yang, D., & Hong, K.-S. (2022). Neuromodulatory effects of HD-tACS/tDCS on the prefrontal cortex: A resting-state fNIRS-EEG study. *IEEE Journal of Biomedical and Health Informatics*, *26*(5), 2192–2203. https://doi.org/10.1109/JBHI.2021.3127080

Gordon, P. C., Zrenner, C., Desideri, D., Belardinelli, P., Zrenner, B., Brunoni, A. R., & Ziemann, U. (2018). Modulation of cortical responses by transcranial direct current stimulation of dorsolateral prefrontal cortex: A resting-state EEG and TMS-EEG study. *Brain Stimulation*, *11*(5), 1024–1032. https://doi.org/10.1016/j.brs.2018.06.004

Güntekin, B., & Başar, E. (2014). A review of brain oscillations in perception of faces and emotional pictures. *Neuropsychologia*, *58*, 33–51. https://doi.org/10.1016/j.neuropsychologia.2014.03.014

Güntekin, B., & Başar, E. (2016). Review of evoked and event-related delta responses in the human brain. *International Journal of Psychophysiology: Official Journal of the International Organization of Psychophysiology*, *103*, 43–52. https://doi.org/10.1016/j.ijpsycho.2015.02.001

Güntekin, B., Emek-Savaş, D. D., Kurt, P., Yener, G. G., & Başar, E. (2013). Beta oscillatory responses in healthy subjects and subjects with mild cognitive impairment. *NeuroImage Clinical*, *3*, 39–46. https://doi.org/10.1016/j.nicl.2013.07.003

Han, Y. M. Y., Chan, M. M. Y., Shea, C. K. S., Lai, O. L.-H., Krishnamurthy, K., Cheung, M.-C., & Chan, A. S. (2022). Neurophysiological and behavioral effects of multisession prefrontal tDCS and concurrent cognitive remediation training in patients with autism spectrum disorder (ASD): A double-blind, randomized controlled fNIRS study. *Brain Stimulation*, *15*(2), 414–425. https://doi.org/10.1016/j.brs.2022.02.004

Hanley, C. J., Singh, K. D., & McGonigle, D. J. (2016). Transcranial modulation of brain oscillatory responses:

A concurrent tDCS-MEG investigation. *Neuroimage: Reports*, *140*, 20–32. https://doi.org/10.1016/j.neuroimage.2015.12.021

Hayes, G. S., McLennan, S. N., Henry, J. D., Phillips, L. H., Terrett, G., Rendell, P. G., Pelly, R. M., & Labuschagne, I. (2020). Task characteristics influence facial emotion recognition age-effects: A meta-analytic review. *Psychology and Aging*, *35*(2), 295–315. https://doi.org/10.1037/pag0000441

Heberlein, A. S., Padon, A. A., Gillihan, S. J., Farah, M. J., & Fellows, L. K. (2008). Ventromedial frontal lobe plays a critical role in facial emotion recognition. *Journal of Cognitive Neuroscience*, *20*(4), 721–733. https://doi.org/10.1162/jocn.2008.20049

Herrmann, C. S., Strüber, D., Helfrich, R. F., & Engel, A. K. (2016). EEG oscillations: From correlation to causality. *International Journal of Psychophysiology: Official Journal of the International Organization of Psychophysiology*, *103*, 12–21. https://doi.org/10.1016/j.ijpsycho.2015.02.003

Higgins, W. C., Ross, R. M., Langdon, R., & Polito, V. (2023). The "Reading the mind in the eyes" test shows poor psychometric properties in a large, demographically representative U.S. Sample. *Assessment*, *30*(6), 1777–1789. https://doi.org/10.1177/10731911221124342

Hızlı Sayar, G., Öztekin, E., & Ve Tarhan, N. (2012). Transkraniyal Doğru Akım Uyarımı: Bir Gözden Geçirme. *Np Akademi*, *1*(2), 43–48.

Iarrobino, I., Bongiardina, A., Dal Monte, O., Sarasso, P., Ronga, I., Neppi-Modona, M., Actis-Grosso, R., Salatino, A., & Ricci, R. (2021). Right and left inferior frontal opercula are involved in discriminating angry and sad facial expressions. *Brain Stimulation*, *14*(3), 607–615. https://doi.org/10.1016/j.brs.2021.03.014

Imbert, L., Moirand, R., Bediou, B., Poulet, E., & Brunelin, J. (2022). P249. A single session of bifrontal tDCS can improve facial emotion recognition in Major depressive disorder: An exploratory Pilot study. *Biological Psychiatry*, *91*(9), S188. https://doi.org/10.1016/j.biopsych.2022.02.483

Jacobson, L., Ezra, A., Berger, U., & Lavidor, M. (2012). Modulating oscillatory brain activity correlates of behavioral inhibition using transcranial direct current stimulation. *Clinical Neurophysiology: Official Journal of the International Federation of Clinical Neurophysiology*, *123*(5), 979–984. https://doi.org/10.1016/j.clinph.2011.09.016

Kadak, M., Demir, T., & Dogangun, B. (2013). Recognition of face and emotional facial expressions in Autism. *Psikiyatride Guncel Yaklasimlar – Current Approaches in Psychiatry*, *5*(1), 15. https://doi.org/10.5455/cap.20130502

Kalaycıoğlu, O., & Akhanlı, S. E. (2020). The importance and main principles of power analysis in health research: Application examples on medical case studies. *Türkiye Halk Sağlığı Dergisi*, *18*(1), 103–112. https://doi.org/10.20518/tjph.602400

Kaya, Ö. E. (2017). Nörogörüntüleme Çalışmalarında Etik Meseleler. *Turkish Psychological Articles*, *20*(39), 39–50.

Kayalar, D. D., & Sazak, N. (2018). The interaction with musictypes of the brain wave Astetha, Alpha, SMR; a work of the Nexus-10 EEG. *Online Journal of Music Sciences*, *3*(1), 149–165. https://doi.org/10.31811/ojomus.435201

Keeser, D., Padberg, F., Reisinger, E., Pogarell, O., Kirsch, V., Palm, U., Karch, S., Möller, H.-J., Nitsche, M. A., & Mulert, C. (2011). Prefrontal direct current stimulation modulates resting EEG and event-related potentials in healthy subjects: A standardized low resolution tomography (sLORETA) study. *Neuroimage: Reports*, *55*(2), 644–657. https://doi.org/10.1016/j.neuroimage.2010.12.004

Kessels, R. P. C., Montagne, B., Hendriks, A. W., Perrett, D. I., & Haan, E. H. F. (2014). Assessment of perception of morphed facial expressions using the emotion recognition task: Normative data from healthy participants aged 8-75. *Journal of Neuropsychology*, *8*(1), 75–93. https://doi.org/10.1111/jnp.12009

Kim, J. H., Chul Min Kim, C. M., & Yim, M. S. (2020). An investigation of insider threat mitigation based on EEG signal classification. *Sensors*, *20*(21), 6365. https://doi.org/10.3390/s20216365

Klimm, N., Ehlis, A.-C., Häußinger, F., & Plewnia, C. (2015). P163. Reduction of excitability in the left inferior frontal gyrus by cathodal tDCS facilitates emotion recognition. *Clinical Neurophysiology*, *126*(8), e142. https://doi.org/10.1016/j.clinph.2015.04.229

Lee, J.-Y., Jang, J. H., Choi, A. R., Chung, S. J., Kim, B., Park, M., Oh, S., Jung, M. H., & Choi, J.-S. (2021). Neuromodulatory effect of transcranial direct current stimulation on resting-state EEG activity in internet gaming disorder: A randomized, double-blind, Sham-controlled parallel group trial. *Cerebral Cortex Communications*, *2*(1), tgaa095. https://doi.org/10.1093/texcom/tgaa095

Lee, Y.-S., Shim, M., Choi, G.-Y., Kim, S. H., Lim, W., Jeong, J.-W., Jung, Y.-J., & Hwang, H.-J. (2023). Neuromodulatory feasibility of a current limiter-based tDCS device: A resting-state electroencephalography study. *Biomedical Engineering Letters*, *13*(3), 407–415. https://doi.org/10.1007/s13534-023-00269-9

Lefaucheur, J.-P., Antal, A., Ayache, S. S., Benninger, D. H., Brunelin, J., Cogiamanian, F., Cotelli, M., De Ridder, D., Ferrucci, R., Langguth, B., Marangolo, P., Mylius, V., Nitsche, M. A., Padberg, F., Palm, U., Poulet, E., Priori, A., Rossi, S., Schecklmann, M., … Paulus, W. (2017). Evidence-based guidelines on the therapeutic use of transcranial direct current stimulation (tDCS). *Clinical Neurophysiology*, *128*(1), 56–92. https://doi.org/10.1016/j.clinph.2016.10.087

Lesser, R., & Picton, T. W. (1991). American electroencephalographic sciety guidelines for standard electrode position nomenclature. *Journal of Clinical Neurophysiology*, *11*(1), 111–113. https://doi.org/10.1097/00004691-199401000-00014

Mangia, A. L., Pirini, M. &., & Cappello, A. (2014). Transcranial direct current stimulation and power spectral parameters: A tDCS/EEG co-registration study. *Frontiers in Human Neuroscience*, *8*, 601. https://doi.org/10.3389/fnhum.2014.00601

Martin, A. K., Huang, J., Hunold, A., & Meinzer, M. (2017). Sex mediates the effects of high-definition transcranial direct current stimulation on "Mind-reading". *Neuroscience*, *366*, 84–94. https://doi.org/10.1016/j.neuroscience.2017.10.005

Martin, D. M., Teng, J. Z., Lo, T. Y., Alonzo, A., Goh, T., Iacoviello, B. M., Hoch, M. M., & Loo, C. K. (2018). Clinical pilot study of transcranial direct current stimulation combined with cognitive emotional training for medication resistant depression. *Journal of Affective Disorders*, *232*, 89–95. https://doi.org/10.1016/j.jad.2018.02.021

Moliadze, V., Andreas, S., Lyzhko, E., Schmanke, T., Gurashvili, T., Freitag, C. M., & Siniatchkin, M. (2015). Ten minutes of 1 mA transcranial direct current stimulation was well tolerated by children and adolescents: Self-reports and resting state EEG analysis. *Brain Research Bulletin*, *119*(Pt A), 25–33. https://doi.org/10.1016/j.brainresbull.2015.09.011

Navarro, E. (2022). What is theory of mind? A psychometric study of theory of mind and intelligence. *Cognitive Psychology*, *136*, 101495. https://doi.org/10.1016/j.cogpsych.2022.101495

Nejati, V., Khalaji, S., Goodarzi, H., & Nitsche, M. (2021). The role of ventromedial and dorsolateral prefrontal cortex in attention and interpretation biases in individuals with general anxiety disorder (GAD): A tDCS study. *Journal of Psychiatric Research*, *144*, 269–277. https://doi.org/10.1016/j.jpsychires.2021.10.034

Nejati, V., Khorrami, A. S., & Fonoudi, M. (2022). Neuromodulation of facial emotion recognition in health and disease: A systematic review. *Neurophysiologie Clinique = Clinical Neurophysiology*, *52*(3), 183–201. https://doi.org/10.1016/j.neucli.2022.03.005

Nitsche, M. A., Koschack, J., Pohlers, H., Hullemann, S., Paulus, W., & Happe, S. (2012). Effects of frontal transcranial direct current stimulation on emotional state and processing in healthy humans. *Frontiers in Psychiatry*, *3*, 58. https://doi.org/10.3389/fpsyt.2012.00058

Oakley, B. F. M., Brewer, R., Bird, G., & Catmur, C. (2016). Theory of mind is not theory of emotion: A cautionary note on the reading the mind in the eyes test. *Journal of Abnormal Psychology*, *125*(6), 818–823. https://doi.org/10.1037/abn0000182

Overman, M. J., Browning, M., & O'Shea, J. (2020). Inducing affective learning biases with cognitive training and prefrontal tDCS: A proof-of-concept study. *Cognitive Therapy and Research*, *45*(5), 869–884. https://doi.org/10.1007/s10608-020-10146-9

Palmisano, A., Bossi, F., Barlabà, C., Febbraio, F., Loconte, R., Lupo, A., Nitsche, M. A., & Rivolta, D. (2021). Anodal tDCS effects over the left dorsolateral prefrontal cortex (L-DLPFC) on the rating of facial expression: Evidence for a gender-specific effect. *Heliyon*, *7*(11), e08267. https://doi.org/10.1016/j.heliyon.2021.e08267

Parlikar, R., Vanteemar, S., Shivakumar, S., Narayanaswamy, V., C, J., Rao, P. N., & Ganesan, V. (2021). High-definition transcranial direct current stimulation (HD-tDCS): A systematic review on the treatment of neuropsychiatric disorders. *Asian Journal of Psychiatry*, *56*, 102542. https://doi.org/10.1016/j.ajp.2020.102542

Peirce, J., Gray, J. R., Simpson, S., MacAskill, M., Höchenberger, R., Sogo, H., Kastman, E., & Lindeløv, J. K. (2019). PsychoPy2: Experiments in behavior made easy. *Behavior Research Methods*, *51*(1), 195–203. https://doi.org/10.3758/s13428-018-01193-y

Pera-Guardiola, V., Contreras-Rodríguez, O., Batalla, I., Kosson, D., Menchón, J. M., Pifarré, J., Bosque, J., Cardoner, N., Soriano-Mas, C., & Urgesi, C. (2016). Brain structural correlates of emotion recognition in psychopaths. *PLOS One*, *11*(5), e0149807. https://doi.org/10.1371/journal.pone.0149807

Rassovsky, Y., Dunn, W., Wynn, J., Wu, A. D., Iacoboni, M., Hellemann, G., & Green, M. F. (2015). The effect of transcranial direct current stimulation on social cognition in schizophrenia: A preliminary study. *Schizophrenia Research*, *165*(2–3), 171–174. https://doi.org/10.1016/j.schres.2015.04.016

Rassovsky, Y., Dunn, W., Wynn, J. K., Wu, A. D., Iacoboni, M., Hellemann, G., Green, M. F., & van Os, J. (2018). Single transcranial direct current stimulation in schizophrenia: Randomized, cross-over study of neurocognition, social cognition, ERPs, and side effects. *PLOS one*, *13*(5), e0197023. https://doi.org/10.1371/journal.pone.0197023

Romero-Martínez, Á., Bressanutti, S., & Moya-Albiol, L. (2020). A systematic review of the effectiveness of non-invasive brain stimulation techniques to reduce violence proneness by interfering in anger and irritability. *Journal of Clinical Medicine*, *9*(3), 882. https://doi.org/10.3390/jcm9030882

Ruffman, T., Henry, J. D., Livingstone, V., & Phillips, L. H. (2008). A meta-analytic review of emotion recognition and aging: Implications for neuropsychological models of aging. *Neuroscience and Biobehavioral Reviews*, *32*(4), 863–881. https://doi.org/10.1016/j.neubiorev.2008.01.001

Ruggiero, F., Dini, M., Cortese, F., Vergari, M., Nigro, M., Poletti, B., Priori, A., & Ferrucci, R. (2021). Anodal transcranial direct current stimulation over the cerebellum enhances sadness recognition in parkinson's disease patients: A pilot study. *Cerebellum (London, England)*, *21*(2), 234–243. https://doi.org/10.1007/s12311-021-01295-y

Salehinejad, M. A., Paknia, N., Hosseinpour, A. H., Yavari, F., Vicario, C. M., Nitsche, M. A., & Nejati, V. (2021). Contribution of the right temporoparietal junction and ventromedial prefrontal cortex to theory of mind in autism: A randomized, sham-controlled tDCS study. *Autism Research*, *14*(8), 1572–1584. https://doi.org/10.31234/osf.io/zt5da

Saracli, O., Atasoy, N., & Karaahmet, E. (2012). Neurobiology of Intimate Relationships. *Psikiyatride Guncel Yaklasimlar – Current Approaches in Psychiatry*, *4*(4), 414. https://doi.org/10.5455/cap.20120425

Song, M., Shin, Y., & Yun, K. (2014). Beta-frequency EEG activity increased during transcranial direct current stimulation. *Neuroreport*, *25*(18), 1433–1436. https://doi.org/10.1097/WNR.0000000000000283

Spitoni, G. F., Cimmino, R. L., Bozzacchi, C., Pizzamiglio, L. &., & DiRusso, F. (2013). Modulation of spontaneous alpha brain rhythms using low-intensity transcranial direct-current stimulation. *Frontiers in Human Neuroscience*, *7*, 529. https://doi.org/10.3389/fnhum.2013.00529

Thair, H., Holloway, A. L., Newport, R., & Smith, A. D. (2017). Transcranial direct current stimulation (tDCS): A beginner's guide for design and implementation. *Frontiers in Neuroscience*, *11*, 641. https://doi.org/10.3389/fnins.2017.00641

Vecchio, F., Babiloni, C., Lizio, R., Fallani, F. D. V., Blinowska, K., Verrienti, G., Frisoni, G., & Rossini, P. M. (2013). Resting state cortical EEG rhythms in Alzheimer's disease: Toward EEG markers for clinical applications: A review. *Supplements to Clinical Neurophysiology*, *62*, 223–236. https://doi.org/10.1016/b978-0-7020-5307-8.00015-6

Vecchio, F., DiIorio, R., Miraglia, F., Granata, G., Romanello, R., Bramanti, P., & Rossini, P. M. (2018). Transcranial direct current stimulation generates a transient increase of small-world in brain connectivity: An EEG graph theoretical analysis. *Experimental Brain Research*, *236*(4), 1117–1127. https://doi.org/10.1007/s00221-018-5200-z

Vimolratana, O., Aneksan, B., Siripornpanich, V., Hiengkaew, V., Prathum, T., Jeungprasopsuk, W., Khaokhiew, T., Vachalathiti, R., & Klomjai, W. (2024). Effects of anodal tDCS on resting state eeg power and motor function in acute stroke: A randomized controlled trial. *Journal of NeuroEngineering and Rehabilitation*, *21*(1), 6. https://doi.org/10.1186/s12984-023-01300-x

Wang, Y., Liu, W., Wang, Y., Ouyang, G., & Guo, Y. (2024). Long-term HD-tDCS modulates dynamic changes of brain activity on patients with disorders of consciousness: A resting-state EEG study. *Computers in Biology and Medicine*, *170*, 108084. https://doi.org/10.1016/j.compbiomed.2024.108084

Willis, M. L., Murphy, J. M., Ridley, N. J., & Vercammen, A. (2015). Anodal tDCS targeting the right orbitofrontal cortex enhances facial expression recognition. *Social Cognitive and Affective Neuroscience*, *10*(12), 1677–1683. https://doi.org/10.1093/scan/nsv057

Wilson, J., Trumbo, M., & Tesche, C. (2021). Transcranial direct current stimulation (tDCS) improves empathy and recognition of facial emotions conveying threat in adults with autism spectrum disorder (ASD): A randomized controlled pilot study. *NeuroRegulation*, *8*(2), 87–95. https://doi.org/10.15540/nr.8.2.87

Wingenbach, T. S. H., Ashwin, C., Brosnan, M., & Urgesi, C. (2016). Validation of the amsterdam dynamic facial expression set – bath intensity variations (ADFES-BIV): A set of videos expressing low, intermediate, and high intensity emotions. *PLOS One*, *11*(1), e0147112. https://doi.org/10.1371/journal.pone.0147112

Winker, C., Rehbein, M. A., Sabatinelli, D., Dohn, M., Maitzen, J., Wolters, C. H., Arolt, V., & Junghofer, M. (2018). Noninvasive stimulation of the ventromedial prefrontal cortex modulates emotional face processing. *Neuroimage: Reports*, *175*, 388–401. https://doi.org/10.1016/j.neuroimage.2018.03.067

Wirth, M., Rahman, R. A., Kuenecke, J., Koenig, T., Horn, H., Sommer, W., & Dierks, T. (2011). Effects of transcranial direct current stimulation (tDCS) on behaviour and electrophysiology of language production. *Neuropsychologia*, *49*(14), 3989–3998. https://doi.org/10.1016/j.neuropsychologia.2011.10.015

Wysokiński, A., Szczepocka, E., & Szczakowska, A. (2023). Improved cognitive performance, increased theta, alpha, beta and decreased delta powers after cognitive rehabilitation augmented with tDCS in a patient with post-COVID-19 cognitive impairment (brain-fog). *Psychiatry Research Case Reports*, *2*(2), 100164. https://doi.org/10.1016/j.psycr.2023.100164

Xing, X., Li, Z., Xu, T., Shu, L., Hu, B., & Xu, X. (2019). SAE+LSTM: A new framework for emotion recognition from multi-channel EEG. *Frontiers in Neurorobotics*, *13*, 37. https://doi.org/10.3389/fnbot.2019.00037

Yamada, Y., Inagawa, T., Hirabayashi, N., & Sumiyoshi, T. (2021). Emotion recognition deficits in psychiatric disorders as a target of non-invasive neuromodulation: A systematic review. *Clinical EEG and Neuroscience*, *53*(6), 506–512. https://doi.org/10.1177/1550059421991688

Yamada, Y., Sueyoshi, K., Yokoi, Y., Inagawa, T., Hirabayashi, N., Oi, H., Shirama, A., & Sumiyoshi, T. (2022). Transcranial direct current stimulation on the left superior temporal sulcus improves social cognition in schizophrenia: An open-label study. *Frontiers in Psychiatry*, *13*, 862814. https://doi.org/10.3389/fpsyt.2022.862814

Yıldırım, E. A., Kaşar, M., Güdük, M., Ateş, E., Küçükparlak, İ., & Özalmete, E. O. (2011). Gözlerden Zihin Okuma Testi'nin Türkçe Güvenirlik Çalışması. *Türk Psikiyatri Dergisi*, *22*(3), 177–186.

Zemestani, M., Hoseinpanahi, O., Salehinejad, M. A., & Nitsche, M. A. (2022). The impact of prefrontal transcranial direct current stimulation (tDCS) on theory of mind, emotion regulation and emotional-behavioral functions in children with autism disorder: A randomized, sham-controlled, and parallel-group study. *Autism Research*, *15*(10), 1985–2003. https://doi.org/10.1002/aur.2803