

Enhancing Pressurized Esports Performance: A Pilot Study on the Combined Effects of Transcranial Direct Current Stimulation and Arousal Reappraisal

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Abstract

This pilot study explored the combined impact of an arousal reappraisal intervention, shown previously to enable individuals to hold a more constructive interpretation of physiological arousal, and a single session of transcranial direct current stimulation (tDCS) targeting the left dorsolateral prefrontal cortex (PFC), demonstrated to increase the efficacy of psychological interventions, on measures of state anxiety, challenge and threat appraisals, and action performance under a high pressure esports context. Following a fully repeated measures study design, seventeen male Counter-Strike competitors received four different experimental interventions: tDCS with arousal reappraisal, tDCS with active control, sham stimulation with arousal reappraisal, and sham stimulation with active control. The findings tentatively suggest that arousal reappraisal effectively reduces cognitive anxiety, promotes favourable challenge appraisals versus threat, and enhances esports performance. This effect is more pronounced when combined with anodal tDCS. Combining arousal reappraisal and tDCS may be a promising intervention for esports competitors facing performance pressure.

Keywords: Anxiety, Challenge, Threat, Stress, Counter-Strike

Introduction

In esports, sporting, or occupational settings, individuals frequently encounter diverse pressurized circumstances, which significantly influence performance and mental well-being (e.g., Brimmell et al., 2019; Leis et al., 2024; McGrath et al., 2011). From a neuroscientific perspective, pressure is associated with physiological responses, including changes in heart rate (HR), HR variability, and cortisol secretion due to the activation of allostatic systems (Carnevali et al., 2018). Specifically, exposure to pressure activates the sympathetic system, suppresses the parasympathetic system (Castaldo et al., 2015), and engages the hypothalamic-pituitary-adrenal axis (Carnevali et al., 2020). These physiological responses interact with factors such as trait anxiety, self-confidence, and coping resources, influencing performance based on individual perceptions of stressors (Hanton et al., 2008; Seery, 2011; Seery et al., 2013). For instance, athletes who perceive pressure as a hindrance may experience significant performance declines (Behnke et al., 2020; Trotman et al., 2018).

In esports, the pressurized environments common to competitive play are linked to reduced attentional control, as evidenced by shorter quiet eye durations and increased search rates, which negatively affect timing and accuracy (Sharpe et al., 2024a). Beyond performance, negative perceptions of pressure are correlated with mental health challenges,

such as social phobia anxiety (Smith et al., 2022), and contribute to high rates of mental ill-health among esports athletes (Birch et al., 2024). Given these adverse effects, this pilot study focuses on two novel interventions: arousal reappraisal and transcranial direct current stimulation (tDCS), which aim to mitigate negative perceptions of pressure by leveraging theoretical insights from stress and neuroscience.

Approaches to Pressure: Theoretical Perspectives

The complexity of pressure and its effects are best understood through established theoretical frameworks. The Cognitive Appraisal Theory (Lazarus & Folkman, 1984) suggests an initial process of stress evaluation, wherein individuals assess situational demands (e.g., performance expectations, social evaluation, or incentives) and determine potential coping strategies, followed by ongoing reappraisal as the situation unfolds. This model emphasizes the subjective nature of stress appraisal, highlighting the critical role of perceived coping efficacy. Building on this foundation, the Biopsychosocial Model of Challenge and Threat (Tomaka et al., 1993) examines how individuals perceive situational demands and available resources, proposing that performance outcomes are contingent on psychological appraisals. According to this model, individuals who appraise situations as challenges tend to perceive sufficient resources to meet demands, leading to more adaptive cardiovascular responses and enhanced performance outcomes. In contrast, threat appraisals occur when individuals perceive demands as exceeding their available resources (Blascovich, 2008). These theories converge in the Integrative Framework of Stress, Attention, and Visuomotor Performance (Vine et al., 2016), which focuses on high-pressure visuomotor tasks.

This framework posits that appraisals of stressors as challenges versus threats influence attentional focus and performance outcomes. This framework extends previous models by explicitly linking cognitive appraisals to attentional mechanisms and motor performance. Specifically, challenge states are associated with efficient goal-directed attention and superior motor control, while threat states typically result in disrupted attentional control and degraded motor performance. The framework also emphasizes how these relationships can create self-reinforcing cycles, where initial appraisals influence attention and performance, which in turn affect subsequent appraisals. It further suggests that stress responses lie on a bipolar continuum rather than as distinct mechanisms, offering nuanced insights into performance variability (Blascovich, 2008; Britton et al., 2019). Despite the insights provided by these frameworks, interventions that explicitly target how individuals interpret their physiological responses to stress remain underexplored. One promising approach, arousal reappraisal, involves reframing physiological responses—such as increased HR or muscle tension—as facilitative rather than debilitating. Arousal reappraisal

interventions have demonstrated effectiveness across various domains, including single-trial tasks under pressure, where they enhanced performance and emotional regulation (Jamieson et al., 2013; Sammy et al., 2017; Moore et al., 2015). Within esports, such interventions have successfully promoted adaptive stress responses and challenge appraisals, leading to improved performance metrics like shooting accuracy (Sharpe et al., 2024b). Specifically, Sharpe et al. (2024b) demonstrated that arousal reappraisal interventions improved competitive Counter-Strike performance by reducing threat-related attention bias and enhancing visual search efficiency. Counter-Strike is a tactical first-person shooter game where two teams compete to complete objectives such as eliminating the opposition, while aiming to achieve core objectives (see Sharpe et al., 2022 for detailed overview). However, this work suggested that the effectiveness of psychological interventions might be limited by individual differences in emotion regulation capacity.

From a neuroscientific standpoint, negative responses to pressure may result in overactivation of brain regions associated with threat detection, such as the salience network, which includes the anterior cingulate cortex and amygdala (Corbetta & Shulman, 2002). The Attentional Control Theory (Eysenck et al., 2007) posits that anxiety under pressure redirects attentional resources away from goal-directed systems toward threat-related stimuli, potentially impairing performance unless compensatory strategies are employed (Wood et al., 2016). Similarly, the Neurovisceral Integration Model highlights the role of the prefrontal cortex (PFC) in regulating stress responses. Specifically, the dorsolateral PFC oversees high-order cognitive functions and exerts top-down control over emotional and autonomic systems (Thayer & Lane, 2009). Disruptions in PFC activity have been linked to anxiety disorders (Maksymetz et al., 2019), underscoring its centrality in stress management. One innovative technique for modulating PFC activity is transcranial direct current stimulation (tDCS), a non-invasive neuromodulation method that delivers a weak electric current to cortical regions to enhance excitability (Priori et al., 1998). tDCS has shown promise in improving cognitive functions, emotion regulation, and anxiety outcomes (Brunoni, Ferrucci, et al., 2013; Nasiri et al., 2020). In esports, tDCS has been proposed as a method to amplify the effects of psychological interventions like arousal reappraisal (Sharpe et al., 2024b). For example, anodal tDCS over the dorsolateral PFC has demonstrated favorable effects on HR variability and cortisol regulation during stress-inducing tasks (Brunoni, Vanderhasselt, et al., 2013; Machado et al., 2022).

Study Aim

This pilot study investigates the combined effects of tDCS and arousal reappraisal on performance, anxiety, and stress appraisals in esports. While previous research has examined

an arousal reappraisal intervention separately, this study represents the first attempt to combine neuromodulation with psychological intervention in an esports context. By targeting both neural and psychological mechanisms simultaneously, we hypothesize that this combined approach may overcome the limitations of single-modality interventions identified in previous research. Specifically, participants underwent either anodal tDCS targeting the left dorsolateral PFC or sham stimulation before engaging in an arousal reappraisal intervention and completing a high-pressure, domain-specific task. By comparing these conditions, this exploratory research seeks to determine whether the combined approach surpasses the effects of arousal reappraisal or tDCS alone in fostering adaptive stress responses and enhancing performance. The findings of this pilot study aim to inform future large-scale research, representing a novel contribution to the field by integrating theoretical insights and empirical evidence to address the challenges faced by athletes in pressurized environments.

Method

Study Design

This study served as a pilot investigation aimed at exploring preliminary trends and the practical feasibility of conducting a larger-scale study. A within-subject design was employed, allowing participants to serve as their own control, thus reducing variability associated with individual differences. This design was necessitated by resource limitations, including the availability of competitors within the region, as outlined by Lakens (2022). As such, the sample size was chosen based on logistical constraints and the exploratory nature of this pilot study. Future studies should implement formal sample size calculations using data derived from this investigation. Data collection for this study was carried out by a doctoral student (Male), under the supervision of one of the project authors (either the project lead, Male, cognitive scientist, or co-author, Female, biological scientist), to ensure adherence to standardized experimental protocols and to address health and safety considerations. The student was blinded to the experimental conditions during data collection (see Stimulation Blinding below). Ethical approval for the study protocol was given by the lead institution [BLINDED FOR REVIEW].

Participants

Seventeen male participants, aged 18 to 24 years (M age = 21.10, SD = 2.38), participated in this study. All participants were native English speakers from Western European countries, offering a culturally homogenous sample. Participants reported an average of 5.80 years (SD = 1.64) of general gaming experience, with 3.50 years (SD = 1.57) specifically in First-Person Shooter (FPS) games. Their prior Counter-Strike experience ranged from 209 to 1670 hours (M hours = 796.60, SD = 374.45). At the time of data collection,

all actively engaged in university-level competition with aspirations to advance to national competition, and were considered non-elite (Poulus et al., 2024).

Eligibility Criteria

Participants were required to meet the following criteria: be actively involved in university-level Counter-Strike competition; have no known psychiatric or neurological disorders; possess normal or corrected vision; be free of metal or electronic implants, history of head trauma, or spinal surgeries that could contraindicate tDCS; and exhibit prior competitive gaming experience with a minimum of one cross-university tournament (M tournaments = 3.60, SD = 1.49). The exclusive focus on male participants was driven by known structural and functional differences in male and female brain responses to interventions such as transcranial direct current stimulation (see Bhattacharjee et al., 2022; Weller et al., 2023). These differences preclude generalizations across genders and ensure that results remain specific to the population studied. Future research will aim to include female participants to address the broader applicability of findings.

Pressure Manipulation

The pressurised experimental environment came from prior research, where full task details and results are available (Sharpe et al., 2024a; Trotter et al., 2023). Adapted from prior research (Moore et al., 2012) and repeatedly demonstrated to elicit perceptions of anxiety and evaluations of threat within an esports sample, pressure was introduced before each experimental round, with verbal, pre-recorded instructions emphasizing the importance and difficulty of the task, comparison with others through a leader board, public observation via a public streaming service, and the possibility of post-task interviews for low performers. These manipulations were based on prior research indicating game-specific worry, performance expectations, and audience pressure as stressors experienced by esports competitors (Leis et al., 2022; Poulus et al., 2022; Smith et al., 2022). The instructions emphasized the high degree of difficulty and highlighted the performance of prior participants. Instructions were repeated before each round. The instructions were provided through pre-recorded videos that were one minute in duration.

Arousal Reappraisal Intervention

The arousal reappraisal instructions were adapted by incorporating an esports component into the original framework to ensure relevance within an esports context. No further modifications were made to preserve the integrity of the core theoretical elements underlying arousal reappraisal interventions, as established in prior research (Moore et al., 2015; Sammy et al., 2017). The arousal reappraisal group heard the following instructions, as

presented in a pre-recorded video, closely resembling those employed by Moore et al. (2015) and Sammy et al. (2017), which was originally adapted from prior authors (Jamieson et al., 2012, 2013), as follows: *“In stressful situations, like esports competitions, our bodies react in very specific ways. The increase in arousal you may feel during stressful situations is not harmful. In fact, recent research has shown that this response to stress can be beneficial and aid performance in stressful situations. Indeed, this response evolved because it helped our ancestors survive by delivering oxygen to where it was needed in the body to help address stressors. Therefore, before and during the upcoming counter-strike task, we encourage you to reinterpret your bodily signals and any increases in arousal as beneficial and remind yourself that they could be helping you perform well.”* This strategy allows individuals to reconceptualize pressure as a coping mechanism (Jamieson et al., 2016) and has been found to stimulate a challenge state and improve performance (Jamieson et al., 2010, 2012, 2013).

The active control group and subsequent instructions were designed to engage participants in reflective introspection regarding their evolving thoughts and emotions. Participants were encouraged to transcribe these ruminations onto a provided sheet of paper, in accordance with the methodology outlined by Pennebaker and Smyth (2016). This practice of introspecting on one's cognitive and affective experiences has been established as yielding modest yet consistent beneficial outcomes (effect size, $d = 0.07$) in enhancing psychological well-being, including emotional responses, as corroborated by a meta-analysis (Frattaroli, 2006). To enhance the robustness of future interpretations and align expectancy and response demands across interventions, we intentionally employed a strategy known to produce favorable effects. Additionally, an active control was selected over a passive control to enable a more rigorous comparison by incorporating procedural elements similar to those in arousal reappraisal. This approach ensures that observed effects are attributable to the specific intervention context (AR vs. AC) rather than to general placebo or procedural factors. Both interventions were conducted within a 2-minute window before task performance.

Transcranial direct current stimulation

Participants were assigned randomly to either the active or sham condition of anodal tDCS administered over the left dorsolateral PFC with an extracephalic position (Bai et al., 2014; Qi et al., 2024), as per the International EEG 10-20 system. In the case of anodal stimulation, a current intensity of 2 mA was applied for a duration of 20 minutes through the utilization of saline-soaked sponges measuring 5×7 cm. Prior to the commencement of testing, a Multimeter (Crenova MS8233D) was employed to verify the device's accurate output of milliamperes (mA). To isolate the influence of directional current flow on the targeted brain region of interest and to mitigate potential confounding effects stemming from distal brain

alterations linked to reference electrode placement over cortical areas that might impact pain perception and/or cognitive processing (Scheldrup et al., 2014), the anode was situated at the F3 location, while the cathode was positioned on the right upper arm. The anodal and cathodal electrodes were secured using elastic bands and connected to the neuroConn DC-stimulator Plus. The identical electrode arrangement was adopted for the sham stimulation condition; however, the stimulator was deactivated after a brief interval to uphold participant blinding. To minimize the likelihood of participants distinguishing the sham stimulation from the active condition, a 2-minute ramping period was implemented, incorporating a gradual decrease in current to 0 mA over a 10-second fade-out period (O'Connell et al., 2012). Consequently, participants could have experienced the initial tingling or itching sensation characteristic of the onset of electrical stimulation, albeit without any ongoing current – however, no such experiences were noted by participants. It is noteworthy that the procedural aspects, current density, and overall charge administered through the parameters adhere to established safety guidelines within the existing research literature (Bikson et al., 2016; Fregni et al., 2015).

Randomization Procedure and Stimulation Blinding

Multiple randomization procedures were employed throughout the study. For condition assignment, a computer-generated randomization sequence was created using R (version 4.1.2) to determine the order of interventions (AR vs. AC) for each participant. This sequence was stratified by participant ID to ensure balanced allocation across conditions. For tDCS administration, the apparatus was equipped with a blinding mechanism that employed preconfigured 5-digit codes to dictate the allocation of either active or sham stimulation. This ensured participants were assigned using a blocked randomization scheme (block size = 4) to ensure equal distribution between active and sham conditions. The distinct experimental conditions were generated by associating the relevant codes (either sham or active) with each experimental block. Following this, the compilation of codes was subjected to randomization utilizing the Excel "rand" function, thereby ensuring that none of the researchers involved in the data collection process or the participants were aware of the group assignment.

Measures and Questionnaires

Challenge and Threat Appraisal (DRES)

Challenge and threat appraisals were assessed using two items adapted from the Cognitive Appraisal Ratio (Tomaka et al., 1993). The competition demands were assessed using the question, '*What is your expectation of the demands of the upcoming competition?*'. Personal coping resources were measured by the question, '*What is your perceived ability to cope with the demands of the upcoming competition?*' Both items were rated using a 6-point Likert scale, with anchors ranging from '*Not at all*' (scored as 1) to '*Extremely*' (scored as 6).

Previous studies have employed a ratio approach for evaluating demands and resources by dividing the evaluated demands by resources (Feinberg & Aiello, 2010). However, this ratio has been found to be non-linear and inconsistent with the concept of challenge, and threat states exist on a single bipolar continuum (Seery, 2011). As an alternative, a demand-resource evaluation score (DRES) was calculated by subtracting demands from resources, with a more positive score indicating a challenge state and a more negative score reflecting a threat state (e.g., Arthur et al., 2019; Brimmell et al., 2019). As prior, a percentage change from baseline score was then generated.

Perceived Anxiety

Competitive state anxiety was accessed using the Immediate Anxiety Measurement Scale (IAMS; Thomas et al., 2002). The IAMS provided definitions of cognitive anxiety and somatic anxiety, after which participants completed questions relating to measuring the intensity of anxiety (e.g., *'To what extent are you experiencing cognitive anxiety right now'*). The IAMS provides the following information for participants prior to completion of the questionnaire pertaining to the term cognitive and somatic anxiety: 'The mental component of anxiety and maybe characterised by thoughts such as concerns or worries about your upcoming task, for example about the way you will perform or the importance of the event' and 'your perception of your physical state and maybe characterised by symptoms such as physical nervousness, butterflies in the stomach, tense muscles, and increases in heart rate', respectively. The intensity of the anxiety experienced was rated using a 7-point Likert scale anchored from 1 (Not at all) to 7 (Extremely). Percentage changes from baseline scores were then generated. This resulted in two distinct measures, each of which was analysed separately.

Action Performance

Action performance was assessed based on two primary metrics: the total time required to accomplish the simulated Counter-Strike time-trial and the accuracy represented as a percentage of successful hits versus misses. In the realm of esports, action performance denotes the attributes such as accuracy that are instrumental in influencing the overall outcome, for instance, winning or losing (Sharpe et al., 2022). Each participant engaged in a singular virtual task, involving negotiating the appearance of the targets (i.e., player animations) while traversing the virtual map from the starting point to the endpoint. Throughout the trials, participants adhered to a standardized script, ensuring consistency of the task across all individuals. Notably, all variables associated with the task remained uniform across participants. The performance indicators encompassed the overall time taken to accomplish the task (measured in seconds) and the percentage representing the ratio of accurately

executed shots to total shots fired, rendered as a percentage. The technological parameters encompassing screen resolution (1280 x 960), aspect ratio (16:10), and refresh rate (144 Hz) remained consistent throughout the testing conditions for all participants. Furthermore, the player's crosshair configuration and in-game settings were the same throughout the testing phase. Each round of engagement concluded after a period of three minutes if the participant did not complete the trial within that timeframe. Percentage change from baseline scores were then generated for time-trial and accuracy performance. Participants performed standardized tasks on a simulated Counter-Strike map, ensuring uniformity in equipment, settings, and environment.

Adverse Effects Questionnaire

Adverse effects stemming from the stimulation were evaluated through a comprehensive questionnaire encompassing a spectrum of 10 potential side effects, namely itching, tingling, burning, scalp pain, neck pain, headache, dizziness, sleepiness, difficulty concentrating, and nausea. Respondents were afforded the opportunity to indicate the presence and intensity of these effects using a rating scale that ranged from 0 (absent) to 3 (markedly present). No such negative side effects were noted across all testing conditions, beyond retrospective comments regarding a tingling sensation. Additionally, the questionnaire incorporated an inquiry pertaining to the perceived intensity and discomfort associated with the stimulation, rated on a 10-point scale. No statistically significant differences were observed between conditions ($F(3, 48) = 1.429, p = .246, \eta p^2 = .08$).

Procedures

All participants took part in the pressurised condition with differing interventional approaches per visit (see Figure 1). Before taking part, participants were provided an information sheet that described the purpose of the study, inform of their ethical rights (e.g., confidentiality, anonymity, right to withdraw), and provided a detailed description of tDCS usage. Once informed consent was provided, and demographic information (e.g., age, gender) was gathered, data collection took 40 minutes ($SD = 5.10$) per session per participant. Data collection was carried out in daytime hours (9am-4pm), and participants were asked to attend the sessions having not consumed caffeine-based drinks in the 24-hours prior to testing due to the noted impact of acute intake on shooting accuracy in esports tasks (Sainz et al., 2020).

Session one of testing consisted of participants being given 20 minutes to warm up on an aim-training map that was unrelated to the primary performance task (as typical for esports competitors) before familiarizing themselves with the primary performance task for one round. Once completed, all participants underwent four rounds of the action performance task after

being exposed to the pressurised manipulation and completing subsequent subjective measurements (i.e., IAMS, and DRES), to provide a baseline measurement. Baseline measures were used to generate a percentage change from baseline score per condition following the completion of testing. This session took 30 minutes ($SD = 4.00$).

Once 48-hours had passed, participants were invited back for session two of testing. Here, participants experienced 20 minutes of real or sham tDCS stimulation immediately prior to participating in the first condition. During this time, participants were asked to warm up with the above-mentioned aim-training map for the 20 minutes. Participants were then randomized into one of two conditions: arousal reappraisal (AR) or active control (AC) before one round of familiarization. The order in which participants fell into two conditions were counterbalanced to avoid any potential order effects. As reports have demonstrated stimulation effects typically return to baseline within one hour of the tDCS being administered (Antal et al., 2004; Ardolino et al., 2005), participants were immediately re-exposed to the pressurised manipulation and completed subjective measures before undergoing an additional four rounds of the pressurised task for the opposing condition. Participants were provided 2-minutes of time to engage with the interventions. This session took 30 minutes ($SD = 4.00$).

To ensure a tDCS washout period, the within-subject design ensured 48-hours were provided between sessions (see Jo et al., 2009). As such, session three consisted of the same warm-up, familiarization, and experimental procedure with 20 minutes of real or sham tDCS stimulation (dependant on whether participants were exposed to real or sham in the session prior). This session took 30 minutes ($SD = 5.11$). Participants completed the adverse effects questionnaire after session two and three, before being asked if they thought they received real or sham tDCS stimulation – participants guessed correctly 47% of the time. Participants were only exposed to a single round of stimulation across the entire experiment.

Insert Figure 1 about here

Statistical Analyses

Statistical analyses were completed in JASP version 0.16.4 (JASP, 2023). A series of repeated measures analyses of variance (ANOVA) were conducted evaluate the influence of intervention (4 levels; AR-tDCS, AC-tDCS, AR-Sham, and AC-Sham) on IAMS, DRES, and action performance. To decrease the significance threshold and avoid Type 1 errors, a Bonferroni adjustment was employed when multiple comparisons were performed (McLaughlin & Sainani, 2014). Violations of sphericity were corrected by adjusting the degrees of freedom using the Greenhouse Geisser or Huynh-Feldt correction depending on epsilon (less than 0.75 or greater than 0.75, respectively; Girden, 1992). The alpha level (p) for statistical significance was set at 0.05, and partial eta squared (ηp^2) was used to measure

effect size for all ANOVA analyses with Cohen's d used for pairwise comparisons when appropriate (Cohen, 1988). Further, Bayesian repeated measures ANOVAs with priors kept at standard values (0.5 for the fixed effect) was used to provide probabilistic statements of effects. The Bayes factor adopted was BF_{10} , which quantified the evidence for the alternative hypothesis relative to the null hypothesis. With interpretation based on prior literature, the outcomes were classified as Anecdotal ($BF_{10} = 1-3$), Moderate (3-10), Strong (10-30), Very Strong (30-100), and Extreme (>100) favouring the alternative hypothesis (Wagenmakers, Love, et al., 2018; Wagenmakers, Marsman, et al., 2018). A Bayesian approach is often used to complement the p -values and further clarify results that are often difficult to interpret (Evelyn Malone & Coyne, 2020).

Results

Two-way repeated measured ANOVA, and supplemental Bayesian analysis, were conducted to examine the different intervention effects on all independent variables (see Table 1 for descriptive information).

Insert Table 1 about here

Challenge and Threat Appraisal

An analysis of DRES indicated significant within-subject effects regarding percentage change from baseline scores ($F(1.589, 25.431) = 30.253, p < .001, \eta p^2 = .65$), demonstrating extreme support in favour of the alternative hypothesis ($BF_{10} = 185$). The mean DRES scores transitioned towards a challenge appraisal away from a threat appraisal, with increases of 245%, 79%, 188%, and 10% for the AR-tDCS, AC-tDCS, AR-Sham, and AC-Sham groups, respectively. Specifically, post hoc analyses demonstrated that participants receiving AR-tDCS appraised the pressurised context as more as a challenge (as opposed to a threat) compared to those receiving AC-tDCS ($t = 5.576, p < .001, d = 1.35$), AC-Sham ($t = 3.114, p = .040, d = .76$), and AR-Sham ($t = 6.107, p < .001, d = 1.481$). Likewise, there were statistically significant differences between AC-tDCS and AR-Sham ($t = 4.810, p = .001, d = 1.17$) and AC-Sham ($t = 3.722, p = .011, d = .90$).

Perceived Anxiety

An analysis of the intensity of cognitive anxiety indicated significant within-subject effects regarding percentage change from baseline scores ($F(2.083, 33.336) = 7.172, p = .002, \eta p^2 = .31$), demonstrating very strong support in favour of the alternative hypothesis ($BF_{10} = 93.38$). The mean scores for cognitive anxiety intensity decreased by 39%, 27%, 10%, and 8% for the AR-tDCS, AC-tDCS, AR-Sham, and AC-Sham groups, respectively. Post hoc analyses demonstrated that participants receiving AR-tDCS perceived the intensity of their

cognitive anxiety as significantly lower compared to those receiving AC-Sham ($t = 4.322, p = .003, d = 1.05$), and AR-Sham ($t = 3.165, p = .036, d = .77$), but not those receiving AC-tDCS ($t = 2.085, p = .320, d = .51$). No statistically significant differences were present between AC-tDCS and AR-Sham ($t = 1.936, p = .424, d = .47$) or AC-Sham ($t = 2.298, p = .212, d = .56$).

No significant within-subject effects were demonstrated for the intensity of somatic anxiety regarding percentage change from baseline scores ($F(1.548, 24.763) = 1.602, p = .223, \eta p^2 = .09$), demonstrating no support in favour of the alternative hypothesis ($BF_{10} = .42$). Irrespective, mean scores for somatic anxiety intensity decreased by 21%, 14%, 21%, and 13% for the AR-tDCS, AC-tDCS, AR-Sham, and AC-Sham groups, respectively.

Performance Outcomes

Time trial performance indicated significant within-subject effects regarding percentage change from baseline scores ($F(3, 48) = 39.083, p < .001, \eta p^2 = .71$), demonstrating strong support in favour of the alternative hypothesis ($BF_{10} = 27.18$). Mean time trial performance decreased from baseline by 23%, 9%, and 13% for the AR-tDCS, AR-Sham, and AC-tDCS groups, respectively. Conversely, the AC-Sham group demonstrated an increase from baseline by 9%. Post hoc analyses demonstrated that participants receiving AR-tDCS completed the task quicker than those receiving AC-tDCS ($t = 5.497, p < .001, d = 1.33$), AR-Sham ($t = 4.903, p < .001, d = 1.189$), and AC-Sham ($t = 9.654, p < .001, d = 2.341$). There was no statistically significant difference between AC-tDCS and AR-Sham ($t = 1.269, p = .999, d = .31$); however, AC-tDCS and AC-Sham did exhibit statistical differences ($t = 5.007, p < .001, d = 1.21$).

The analysis of shooting accuracy similarly showed significant within-subject effects regarding percentage change from baseline scores ($F(3, 48) = 48.260, p < .001, \eta p^2 = .74$), demonstrating very strong support in favour of the alternative hypothesis ($BF_{10} = 96.76$). Mean shooting accuracy decreased from baseline by 22%, 1%, and 6% for the AR-tDCS, AR-Sham, and AC-tDCS groups, respectively. The AC-Sham group demonstrated an increase from baseline by 7%. Post hoc analyses revealed that participants who received AR-tDCS demonstrated significantly better shooting accuracy compared to those who received AC-tDCS ($t = 7.605, p < .001, d = 1.84$), AR-Sham ($t = 8.000, p < .001, d = 1.94$), and AC-Sham ($t = 9.587, p < .001, d = 2.325$). However, there was no statistically significant difference between AC-tDCS and AR-Sham ($t = 2.881, p = .065, d = .70$) or AC-Sham ($t = 2.602, p = .116, d = .63$). For ease of interpretation of action performance measures, raw data, probability density, and summary statistics are illustrated in Figure 2.

Insert Figure 2 about here

Discussion

The pilot study examined the effects of a single session of anodal transcranial direct current stimulation (tDCS) applied over the left dorsolateral prefrontal cortex (DLPFC) combined with an arousal reappraisal intervention, compared to active control and sham conditions. The analysis focused on the intervention's impact on state anxiety, challenge and threat appraisals, and action performance. Results indicated that the arousal reappraisal intervention significantly reduced perceptions of threat in a pressurized context relative to the active control condition. Specifically, the AR-tDCS condition produced a 245% shift toward challenge appraisal, compared to 79% for the AC-tDCS condition. Furthermore, cognitive anxiety intensity decreased by 39% from baseline in the AR-tDCS condition, surpassing reductions observed in other conditions (AC-tDCS: 27%, AR-Sham: 10%, AC-Sham: 8%). Performance metrics also demonstrated notable improvements under AR-tDCS, including a 23% reduction in time trial completion time and a 22% improvement in shooting accuracy from baseline. These performance gains were greater than those observed in AR-Sham (9% and 1%, respectively) and AC-tDCS (13% and 6%, respectively). These findings broadly supported our hypotheses. The combined intervention of arousal reappraisal and tDCS produced more substantial shifts toward challenge appraisals. While arousal reappraisal alone did not significantly reduce anxiety in prior literature (Sharpe et al., 2024b), the addition of tDCS enhanced its anxiety-reducing effects. Additionally, the combined intervention seemed to yield greater improvements in performance metrics.

The arousal reappraisal intervention appeared to prompt shifts from a threat appraisal toward challenge appraisal for participants, as did all conditions. These preliminary findings align with prior investigations exploring the efficacy of arousal reappraisal strategies in cognitive performance contexts (Jamieson et al., 2010, 2013) and competitive sporting environments (Moore et al., 2015; Sammy et al., 2017; Sharpe et al., 2024b). As the intervention aims to encourage individuals to interpret pressure-induced increases in physiological arousal constructively (Goyer et al., 2022), it was expected that AR-tDCS and AR-Sham would elicit the most favourable outcome, as demonstrated statistically. Likewise, disparities between AC-tDCS and AC-Sham were observed. Particularly given the active control instruction (i.e., introspecting on one's cognitive and affective experiences) has been shown to yield beneficial outcomes, particularly in aiding individuals to experience more favourable emotional responses (Frattaroli, 2006). The current **pilot** study did not aim to determine the most effective method for eliciting a challenge appraisal. However, future research could investigate whether anodal tDCS over the left dorsolateral PFC or the active control instruction alone may benefit esports performers. This is especially noteworthy considering that the active control instruction, much like arousal appraisal, appears in this preliminary investigation to be a

practical and cost-effective method for eliciting such beneficial changes in challenge and threat appraisal.

Acknowledging that the arousal reappraisal intervention is not primarily intended as an anxiety-reduction technique (Ginty et al., 2022), it was expected that there would not be a significant difference between the AR-Sham and AC-Sham conditions regarding the intensity of cognitive and somatic anxiety, as demonstrated statistically. However, the observed disparities between AR-tDCS and both AR-Sham and AC-Sham, along with the absence of differences with AC-tDCS, suggests preliminarily that the neuromodulation technique might have offered some advantage in participants' perception of cognitive anxiety intensity. In fact, such a finding, while not the primary focus of the investigation, may not be surprising, though further research is needed to confirm this effect. This is particularly evident considering the application of tDCS has shown promise in the treatment of psychiatric disorders (Brunoni, Ferrucci, et al., 2013). Most notably, anodal tDCS has been found to induce higher vagally mediated HRV and lower cortisol levels in contexts like those experienced during the current investigation (i.e., high-pressure tasks; Remue, Vanderhasselt, et al., 2016) and has shown promise in enhancing overall treatment outcomes for anxiety reduction interventions (Nasiri, Mashhadi et al., 2020). Future researchers might consider employing the tool independently as an anxiety reduction technique, as seen in previous esports literature (Machado et al., 2022). Alternatively, they could combine this technique with established psychological interventions to enhance their effectiveness (Leis et al., 2023; 2024; Poulus et al., 2023).

Based on the findings outlined above, it was expected that both performance measures would show a notable improvement regardless of stimulation. Specifically, conditions involving arousal reappraisal appeared in this pilot study to offer the most significant advantages in both time trial performance and shooting accuracy, with AR supplemented with tDCS demonstrating the greatest improvement from baseline. This preliminary observation is potentially consistent with prior studies indicating that individuals often experience enhanced performance following exposure to arousal reappraisal interventions in high-pressure situations (Sammy et al., 2017). With the anticipated increase in oxygenated blood flow to the brain and muscles following arousal reappraisal, as suggested previously (Jamieson et al., 2013; Moore et al., 2015), improvements in mouse control (i.e., accuracy) and keyboard proficiency (i.e., character movement) may have been expected, though causal mechanisms remain speculative at this stage. It is important to highlight that this **pilot** study represents the first investigation in esports to observe a significant enhancement in time trial performance following such intervention. In contrast, earlier research by Sharpe et al. (2024b) did not find any significant differences in time trial performance between arousal reappraisal and a passive control intervention, although significant differences were observed in shooting accuracy.

Tentatively, there were discernible differences in time trial performance between AC-tDCS and AC-Sham conditions, although shooting accuracy remained unaffected. Considering the role of the dorsolateral PFC in overseeing higher-order cognitive functions (Gianaros & Wager, 2015; Thayer & Lane, 2009), including working memory, selective attention, and outcome prediction (Curtis & D'Esposito, 2003), it is possible that modulating PFC excitability may have enhanced the proficiency of individuals executing intricate keyboard manoeuvres. Specifically, in tasks like time trial performance, which demand a nuanced understanding of virtual environments, including map navigation, processing speed, and strategic planning. Conversely, if the noted enhancements are solely attributed to improved motor performance, it's plausible that the stimulation inadvertently heightened excitability in neighbouring premotor and supplementary motor areas. Nevertheless, considering that shooting accuracy did not demonstrate similar benefits from tDCS between active control conditions, this scenario appears less likely. While our preliminary data from this pilot study may not offer a comprehensive understanding of the complete impact of an F3–extracephalic montage on action performance, it presents a starting point for future investigations. Subsequent researchers may find value in exploring the isolated effects of this technique on esports competitors with larger sample sizes and more robust designs.

Limitations

Several limitations warrant consideration when interpreting these results. First, the sample size ($n = 17$) limits statistical power and generalizability. While appropriate for a pilot study, future research requires larger samples to confirm these findings. Second, without additional neuroimaging techniques, we cannot definitively demonstrate that tDCS exerted the anticipated impact on brain activity across all participants, given the potential modulation of effects by inter-individual differences (Chew et al., 2015; Horvath et al., 2016). The study's ecological validity presents another limitation. The laboratory task, while controlled, may not fully replicate the competitive environment experienced by esports competitors, including external distractors, environmental complexities, and dynamic contextual information. While this standardized approach was necessary for experimental control, the findings may primarily reflect changes in individual action performance rather than comprehensive competitive ability. Our research design focused on controlled, individual performance metrics which, while valuable for establishing causal relationships, may not capture the full complexity of competitive esports environments. The social dynamics, team coordination, and strategic decision-making that characterize actual competition were necessarily excluded from our experimental paradigm. Additionally, the pressure manipulation, though effective in inducing anxiety responses, may not fully replicate the psychological demands of high-stakes tournament settings where career implications and substantial prizes are at stake. The

standardized equipment and settings, while ensuring internal validity, might not account for the variation in personal preferences and customized setups that players typically rely on during competition. These factors collectively suggest that while our findings demonstrate clear effects on fundamental performance metrics, their translation to comprehensive competitive success requires further investigation in more naturalistic settings.

Research Directions

Future investigations should prioritize several key areas to build on the findings of this study. First, replication and validation are critical, with larger-scale studies needed to confirm the effects observed in this pilot and investigations including diverse populations and skill levels to enhance generalizability. Additionally, researchers should examine potential gender differences in responses to these interventions. Understanding the mechanisms underlying these effects is another important avenue for research. Studies should explore the independent effects of transcranial direct current stimulation (tDCS) as an anxiety-reduction technique, as demonstrated in prior literature (Machado et al., 2022), and assess the efficacy of different tDCS montages and stimulation parameters. Further, the neural mechanisms driving the combined effects of arousal reappraisal (AR) and tDCS should be investigated. Potential interaction effects between psychological and neurological interventions also warrant detailed exploration, aligning with earlier findings (Leis et al., 2023; 2024; Poulus et al., 2023). To improve ecological validity and application, future studies should evaluate the interventions across varying levels of competitive pressure, determine their effectiveness in different gaming contexts and genres, and investigate their longitudinal impacts through repeated applications. Expanding the scope to include naturalistic competitive settings and non-esport activities, such as traditional sports or high-stakes academic testing, could provide insights into broader applicability. Optimization and refinement of these interventions are also essential. Research should focus on identifying the optimal timing and duration of the interventions, exploring individual difference factors influencing their success, and developing standardized protocols for practical implementation.

Practical Implications

The findings of this study suggest promising applications for enhancing esports performance, but several practical considerations must be addressed to ensure safe and effective implementation. Proper assessment and screening are essential, including thorough checks for contraindications to tDCS, individual evaluations of anxiety and stress responses, and the establishment of baseline performance measurements. Implementation should be guided by clear protocols and well-trained practitioners to ensure the accurate administration of interventions and the effective combination of psychological and neurostimulation

techniques. Regular monitoring of athletes' responses and overall well-being should remain a priority throughout the intervention process. Ethical considerations are equally critical. Practitioners must obtain informed consent and provide education about the potential effects of the interventions. Balancing performance enhancement with athlete welfare is crucial to maintaining ethical standards, particularly given the stressors faced by esports competitors (Leis et al., 2024; Smith et al., 2022) and the high prevalence of mental health issues among them (Birch et al., 2024). Fair play considerations should also be addressed to prevent any competitive imbalance. As such, until findings are replicated with larger samples, we recommend refraining from applying these techniques in competitive environments. Authors must act responsibly in their use of participants and avoid premature implementation. Consequently, this paper will not be making applied applications.

Conclusion

Our findings provide initial support for the efficacy of combining arousal reappraisal with anodal tDCS in reducing cognitive anxiety, promoting challenge appraisals, and enhancing action performance in esports competitors. While these results are promising, the limitations in sample size and ecological validity underscore the need for further research to confirm and expand upon these findings. Future investigations should focus on larger-scale validation, examination of different tDCS montages, and application in more naturalistic competitive settings before implementing these techniques in high-stakes competitive environments.

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Table 1

Descriptive information for all outcome variables of interest.

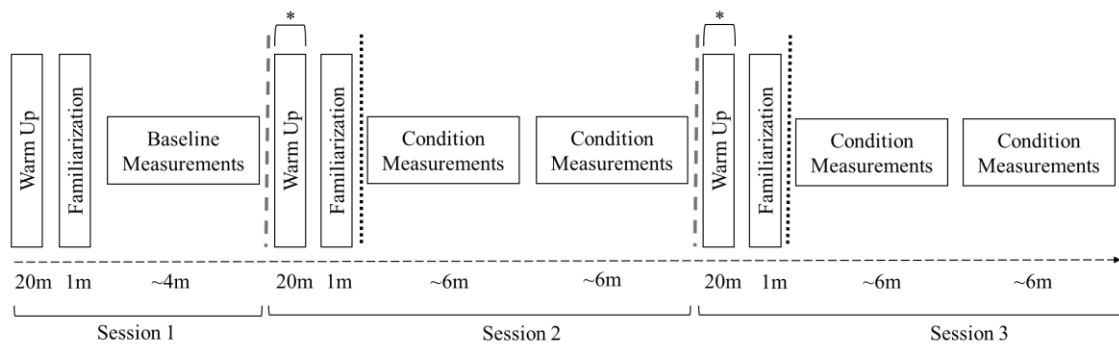
Session 1	Session 2-3
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	Baseline	AR-tDCS	AC-tDCS	AR-Sham	AC-Sham
Cognitive Anxiety Intensity	4.29 ± 1.32	2.47 ± 0.70	2.94 ± 0.87	3.65 ± 0.90	3.71 ± 1.13
Somatic Anxiety Intensity	4.24 ± 1.35	3.24 ± 1.00	3.65 ± 1.28	3.18 ± 0.78	3.71 ± 1.36
C/T Appraisal	-2.71 ± 1.18	2.94 ± 0.87	-0.35 ± 1.33	2.06 ± 1.43	-2.29 ± 1.32
Time Trial Performance (s)	59.91 ± 10.11	45.50 ± 7.32	52.70 ± 8.17	49.26 ± 8.88	65.76 ± 10.62
Shooting Accuracy (%)	73.03 ± 11.35	87.26 ± 4.30	72.40 ± 7.65	76.00 ± 5.30	67.15 ± 7.32

Note: All figures are presented as Mean ± SD.

Figure 1

Experimental protocol.



Note: Grey dotted line demonstrates 48-hour washout period, *Black* dotted line indicates the introduction of the pressurised context, ‘Condition Measurements’ depending on participant order may refer to any of the four experimental conditions, and * indicates sham/stim tDCS.

Figure 2

Illustration of raw data, probability density, and summary statistics through boxplots for action performance measures.

