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Transcranial Direct Current Stimulation (tDCS) paired with a decision-making task reduces risk-taking in a clinically impulsive sample

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ABSTRACT

Background: Impulsivity is a multidimensional personality trait observed across a variety of psychiatric disorders. Transcranial direct current stimulation (tDCS) applied over dorsolateral prefrontal cortex (DLPFC) has shown promise as an intervention to reduce impulsivity.
Objective: To investigate the effects of tDCS paired with a decision-making task on risk-taking in Veterans with a clinical history of impulsive behavior.
Methods: This was a randomized, single-blind, sham-controlled study. Participants performed the Balloon Analogue Risk Task (BART) while concurrently receiving either active or sham tDCS (right anodal/left cathodal over DLPFC) twice a day for five days. To evaluate generalization, the Risk Task was performed before and after the complete course of intervention. To evaluate durability, the BART and Risk Task were administered again at one and two month follow-up sessions.
Results: Thirty Veterans participated: 15 received active tDCS and 15 received sham tDCS. For the trained BART task, individual growth curve analysis (IGC) examining individual variation of the growth rates over time showed no significant variations in individual trajectory changes over time ($\beta = 0.02$, $p > 0.05$). For the untrained Risk Task, IGC showed that the active tDCS group had a significant 46% decrease in risky choice from pre-to post-intervention, which persisted through the one and two month follow-up sessions. The sham tDCS group showed no significant change in risky choice from pre-to post-intervention.
Conclusions: tDCS over DLPFC paired with a decision-making task effectively reduced risk-taking behavior in a group of Veterans with clinically-relevant impulsivity. Results suggest that this approach may be an effective neuroplasticity-based intervention for patients affected by impulsivity.

Introduction

Impulsivity is a multifaceted personality trait characterized by sensation-seeking, lack of premeditation, and impaired cognitive control [1]. Impulsivity includes a variety of behaviors that are typically inappropriate to the situation and done without consideration [2], including insufficient attention to relevant stimuli, inability to delay gratification, deficient action planning, and increased risk-taking [3–5].

Impulsivity is observed in a number of psychiatric disorders, including substance use disorders [6], gambling disorder [7], attention deficit hyperactivity disorder (ADHD) [8], bipolar disorder [9], post-traumatic stress disorder (PTSD) [10,11], binge eating disorder [12], and personality disorders [13]. The construct of impulsivity in psychiatric illness is important because impulsiveness has been shown to correlate significantly with destructive, suicidal, and aggressive behavior [14–16], is related to poor treatment program adherence [17], and is an important aspect of violence risk assessment and management in clinical outpatient settings [18]. These relationships are particularly important for military Veterans and service members, as impulsivity has been linked to combat exposure [19], depression [20], PTSD [11,21],

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traumatic brain injury (TBI) [20,22], substance use disorders [23], and aggression [24] in these populations.

While impulsivity is a common clinical trait, it has been difficult to treat and manage. Given that impulsivity is found in a myriad of psychiatric disorders, it presents a compelling target for treatment. Cognitive-Behavioral Therapies (CBT) have been used to target impulsive behaviors within the context of various disorders with some success [25,26]. Psychopharmacological treatments e.g. Refs. [27–29] have shown some promising effects with regard to impulsive behaviors, however results remain equivocal (e.g. Refs. [30,31]), and they each have adverse effect profiles that must be considered before administration. There remains a need for a novel, well-tolerated, neuroplasticity-based intervention that targets both the cognitive control issues associated with impulsivity, as well as its underlying neural dysfunction. Transcranial Direct Current Stimulation (tDCS) is a promising, low-risk, non-invasive neuromodulation technique that can modulate brain networks by inducing neural excitability with potentially enduring effects. When paired with an appropriate cognitive task, tDCS has potential as a low-risk method for affecting brain connectivity and psychiatric symptoms [32].

From a neurobiological perspective, impulsivity derives from dysfunction within thalamo-cortico-striatal neurocircuitry [33], with impairments in the higher order thalamic relay supporting the cortex in cognition [34], combined with excess engagement from the striatum (nucleus accumbens, putamen/caudate) driving the impulsive behaviors, and insufficient top-down control from the cortices, particularly prefrontal regions [35]. The prefrontal cortex plays a key role in cognitive control, modulating functions such as inhibitory control, attention, planning, risk taking, and delay discounting [36–39]. Thus, prefrontal cortex hypoactivity may result in deficits in these functions and lead to greater cognitive and motor impulsivity [5,40].

Previous studies involving healthy subjects have applied tDCS over prefrontal cortex, resulting in significant reduction of different aspects of impulsivity [see Ref. [40] for a review], such as inhibitory control [41–43], planning [44], and risk-taking [45–47]. Fecteau and colleagues investigated the effects of tDCS, in a single session, on risk-taking behavior as measured by the Balloon Analogue Risk Task (BART) [45] or the Risk Task [46]. Participants received either active or sham tDCS stimulation concurrent with task performance. Risk-taking in the BART was reduced with bilateral stimulation of dorsolateral prefrontal cortex (DLPFC), regardless of anode/cathode connection pattern (i.e. right anode/left cathode or left anode/right cathode), compared to either unilateral tDCS or sham [45]. Risk-taking in the Risk Task was reduced with right anode/left cathode over DLPFC (compared to left anode/right cathode and sham) [46]. Both Cheng and Lee [47] and Shen et al. [48] found reduced risk-taking and delay discounting, respectively, with single-session prefrontal tDCS, that was correlated with baseline impulsivity, such that the effect was larger in more impulsive individuals (in healthy samples). Finally, Ditye et al. [43], combined anodal tDCS over right frontal cortex with training on the Stop Signal Task for four consecutive days, resulting in an improvement in the ability to inhibit responses after active tDCS compared to sham.

tDCS has also been used to target impulsive behaviors within the context of specific clinical populations. A single DLPFC stimulation has been shown to reduce craving in alcohol use disorder (AUD) participants [49,50] and in chronic cannabis users [51]. Multiple tDCS sessions over DLPFC combined with an approach bias training have reduced craving in individuals with hazardous drinking and shown promising trends in improving treatment outcome [52,53]. There are encouraging findings of lower relapse incidence in AUD participants [54]. Also, there has been some success in using tDCS to reduce impulsive behaviors in ADHD patients [55,56], although success is not consistent [57].

These results suggest that tDCS may be a valuable therapeutic approach that can enhance executive function in clinical populations characterized by impulsivity. However, the long-term durability of this intervention in clinical populations is still unknown. The current study investigated the combination of tDCS with a decision-making training task over multiple sessions as a method of reducing impulsive behavior in a clinical population of Veterans. Further, we investigated the durability of the effects of combining tDCS and a task out to two months post-intervention. We hypothesized that 1) the active tDCS group would show a greater reduction in impulsive behavior on risk-taking tasks compared to the sham tDCS group, and 2) this reduction in impulsive behavior would persist to one month and two month follow-up sessions.

Material and methods

Participants

Thirty Veterans receiving outpatient services in the Minneapolis Veterans Affairs Health Care System (MVAHCS) participated. Participants were referred from clinical staff, posted flyers, and patient lists from clinics within the MVAHCS based on the participant's clinical history of impulsive behavior. Upon enrollment into the study, participants were randomized into either the active tDCS group or sham tDCS group (details below in *Intervention* section). There were 15 Veterans in the active tDCS group (mean age 60.4 ± 6.6 years, 1 woman), and 15 Veterans in the sham tDCS group (mean age 58.3 ± 7.6 years, 2 women). Participants were blinded to which study condition (active or sham) they were in, while research staff were not. Groups did not differ on age ($t(28) = 0.84$, $p > 0.05$). Consistent with the demographics of Minnesota, the sample was primarily Caucasian (20 Caucasian, 5 African-American, 5 Other/Unreported).

Participants' clinical history of impulsivity (Table 1) was gleaned from medical record review, as well as by assessment of neuropsychiatric symptoms via the MINI International Neuropsychiatric Interview (MINI 5.0) [58] given to participants at their baseline session. Additionally, all participants self-reported a history of exposure to sub-concussive or concussive events at some point in their lives, with 18 participants meeting criteria for having sustained a mild TBI (active tDCS: 10 participants, sham: 8

Table 1
Impulsivity Characteristics of the Sample.

	n	Percent of sample (N=30)
Alcohol Dependence/Abuse	26	86.7
Non-Alcohol Substance Dependence/Abuse	19	63.3
Suicidality [a]	16	53.3
Legal Problems [a]	9	30.0
Financial Problems [a]	7	23.3
Aggression	6	20.0
Interpersonal Issues [a]	4	13.3
ADHD/CD [a]	3	10.0
Impulse Control Disorder	3	10.0
Number of Impulsivity Characteristics per Participant		
1	1	3.3
2 - 3	20	66.7
4 - 6	9	30.0

[a] Suicidality: those meeting criteria for Suicidality per the MINI were all determined to be at low current suicide risk (all ≤ 2 on a scale of 1-46). Legal Problems include DWI, arrests for assault, robbery, disorderly conduct, drug possession, soliciting sex Financial Problems include impulsive spending, bankruptcy, gambling problems. Interpersonal Issues include history of multiple marriages/divorces, conflicts with commanding officers, inappropriate social interactions. ADHD/CD: Attention Deficit Hyperactivity Disorder and/or Conduct Disorder.

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