The Effects of Acute Transcranial Direct Current Stimulation on Attentional Bias in Pedophilic Disorder: A Pre-registered Pilot Study

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Abstract

Objectives. Individuals with Pedophilic Disorder (PD) experience personal and interpersonal difficulties and are at risk of sexually offending against children. As such, innovative and empirically validated treatments are needed. Recent studies have indicated that men who have sexually offended against children (SOC) with PD display an automatic attention bias for child-related stimuli as well as reduced activity in the dorsolateral prefrontal cortex (dlPFC), a brain area involved in cognitive control, including control over sexual arousal. In this pre-registered pilot study, we are the first to investigate whether acutely increasing prefrontal activity could reduce the putative pedophilic attention bias. **Materials and Methods**. We delivered a single 20-minute session of active anodal vs. sham transcranial direct current stimulation (tDCS) over the left dlPFC to 16 SOC with PD and 16 matched healthy controls, while they performed a task requiring controlled attention to computer-generated images of clothed and nude children and adults. We collected responses unobtrusively by recording eye movements. **Results**. Our results did not support the presence of the expected automatic attention bias across outcome measures. Nonetheless, we found a response facilitation with child targets in patients and, unexpectedly, in controls, likely due to unwanted salience effects. Active vs. sham tDCS reduced this bias across groups, as indicated by a significant group*condition interaction (p = .04). However, no attentional bias and no tDCS effects on attentional responses to child and adult images emerged following tDCS. **Conclusions**. These results suggest enhanced cognitive control in response to salient stimuli during active tDCS. Thus, to assist future studies on neuromodulation in PD, we provide suggestions for design improvement.

The Effects of Acute Transcranial Direct Current Stimulation on Attentional Bias in Pedophilic Disorder: A Pre-registered Pilot Study

Pedophilia is characterized by recurrent and intense sexual fantasies, urges, or behaviors involving prepubescent children, and Pedophilic Disorder (PD) is associated with marked distress or impairment as a result ([1]). PD is an important risk factor for sexual offending against children ([2]). Indeed, it has been estimated that approximately half of individuals convicted for sexual offenses against children have PD ([3],[4]). Despite the personal and societal cost of PD, the efficacy of available treatments is debated. Behavioral conditioning protocols, such as aversion therapy, have been shown to reduce pedophilic sexual arousal, but only in the short term ([5]), and empirical research on cognitive behavioral approaches remains inconclusive ([6]). Although pharmacological interventions may be effective ([7]), their side effects often result in noncompliance. For example, sexual dysfunctions associated with the use of antiandrogen agents and selective serotonin reuptake inhibitors (SSRIs, [8]) might impede sexual relationships with adult partners for those with nonexclusive PD. Moreover, the efficacy of combined treatment for self-referred PD patients from the community has been questioned recently ([9]). As a result, new therapeutic avenues should be explored.

An intriguing possibility is to use recent evidence regarding possible cognitive and neurobiological alterations in PD to inform the development of novel treatments. A growing number of studies have shown that men with PD display an automatic attention bias for images depicting children, whether computer-generated ([10],[11]) or photographic ([12]). This automatic attention bias can be detected using attention-based (i.e., “indirect”) measures of sexual interest ([13]). Such indirect measures of sexual interest require respondents to view sexually relevant stimuli and rate their attractiveness or, alternatively, to complete attentional tasks in the presence

of distracting sexual content, while viewing times are unobtrusively recorded. These are referred to as task-relevant and task-irrelevant, respectively, and have been shown to successfully detect sexual interest in children ([13],[14],[15],[16]). In their simplest form, task-irrelevant indirect measures involve categorizing stimulus characteristics, such as stimulus location. It is expected that preferred sexual content will interfere with task completion ([17]) due to increased attentional capture by preferred stimuli. One example of a more sophisticated task-irrelevant indirect measure is an adaptation of the antisaccade test, a measures of cognitive control of eye movements ([18]), which are considered a valid proxy for attentional processes ([19]). In this task, respondents are instructed to look towards or away from certain stimuli, and it is expected that stimulus content will influence their saccades ([20]). In healthy men, faster and more accurate saccades towards sexually preferred relative to non-preferred stimuli as well as more accurate saccades away from sexually non-preferred relative to preferred stimuli have been observed ([21]). In sum, prior evidence suggests that viewing times ([12],[13]) as well as saccade latency and accuracy ([22],[23]) can be used to detect an automatic attention bias for sexually preferred stimuli.

Research has further indicated that, in men with PD, the automatic attention bias for child stimuli might be associated with impaired cognitive control over sexual responses ([11]). In support of this, decreased activity in frontal regions such as the left dorsolateral prefrontal cortex (dlPFC) has been found in men who have sexually offended against children (SOC) with PD compared to healthy controls in response to sexual images ([24],[25],[26]). Reduced functional connectivity between the left dlPFC and subcortical regions involved in the processing of sexual information has also been observed in this population ([27]). Since the dlPFC is highly implicated in cognitive control and inhibition, including the control and regulation of sexual responses ([28]), its reduced activity

and functional connectivity with subcortical brain areas might constitute neural features underlying the pedophilic attentional bias.

In light of these findings, it may be hypothesized that increased prefrontal activity could decrease the automatic attention bias for child stimuli in SOC with PD. This possibility can be explored using non-invasive brain stimulation techniques such as transcranial direct current stimulation (tDCS, [29]). Through electrodes placed on the scalp, tDCS delivers a weak constant direct current that can enhance or reduce neuronal excitability potentials, with anodal or cathodal stimulation, respectively. In healthy volunteers, acute anodal tDCS over the left dlPFC has been associated with increased executive control ([30]). In disorders characterized by poor cognitive control, such as substance use disorders, anodal tDCS over the left dlPFC has been found to reduce craving symptoms immediately after stimulation with a moderate effect size ([31]). A case study has shown that five daily sessions of anodal tDCS of the dlPFC reduced disinhibited sexual responses in a manic patient, albeit in combination with medication ([32]). In healthy participants, repetitive transcranial magnetic stimulation (TMS) over the right dlPFC has been found to reduce self-reported sexual arousal during exposure to pornographic videos ([33]). In participants preoccupied with their sexual risk taking, increased dlPFC excitability induced by theta burst stimulation (TBS, [34]) was found to modulate electroencephalographic (EEG)-indexed alpha activity during anticipation and receipt of direct stimulation of the genitalia ([35]). However, to the best of our knowledge, no previous study has addressed the possibility of modulating cortical activity during sexual information processing in individuals with PD.

In the current study, we assessed whether acute anodal tDCS of the left dlPFC would modulate attentional responses to two task-irrelevant indirect measures of sexual interest in men with and without PD. Using eye-tracking, we measured response latency and accuracy on the

antisaccade test as well as response times on a test requiring participants to indicate the location of visual stimuli (here referred to as the "viewing time" test). In the two tests, stimuli were children and adults from computerized and photographic picture sets, respectively. We tested four hypotheses: First (H1), we hypothesized that male SOC with PD would display an automatic attention bias for child stimuli during sham tDCS. We operationalized this as shorter response latency and higher response accuracy (antisaccade test), as well as longer viewing times (viewing time test) towards child compared to adult targets. Conversely, we expected teleiophilic men (i.e., sexually attracted to adults) to show an automatic attention bias for adult targets. Second (H2), in both groups, we hypothesized that acute anodal tDCS over the left dlPFC would reduce the automatic attention bias for sexually preferred stimuli compared to sham tDCS. Third (H3), in both groups, we hypothesized that the tDCS-induced reduction in the automatic attention bias would persist following tDCS, as evidenced during the viewing time test. Lastly (H4), given the functional brain anomalies that have been observed in SOC with PD, we hypothesized that active tDCS would have a greater effect in reducing the attentional bias in patients relative to controls.

Method

The present study was approved by the Research Ethics Board at The Royal Ottawa Health Care Group, in accordance with the 1964 Declaration of Helsinki. All participants provided written informed consent to their voluntary participation in the study. To enhance transparency, facilitate replicability, and prevent positive publication bias, we pre-registered this study on the Open Science Framework before data collection. The pre-registered project is publicly available at osf.io/pnr59. The anonymized dataset, annotated scripts for analyses, and output files are also available at the project's webpage (osf.io/7udwf).

Participants

Recruitment

The power calculation using G*Power ([36]) indicated that a sample size of 16 participants per group would provide 80% statistical power to detect group differences with a large effect size (Cohen's f = .40, corresponding to eta squared η^2 = .14; [37]) in a two-factor (tDCS condition [active/anodal vs. sham] * group [PD vs. controls]) analysis of variance (ANOVA) approach, with repeated measures on the tDCS factor, at the conventional type I error rate of 5% and assuming a small correlation between measures of r = .20. Accordingly, we recruited 16 male SOC, diagnosed with PD and admitting being or having ever been sexually interested in prepubertal children aged 10 or younger, and 16 teleiophilic male controls. Patients were recruited from an outpatient sexual behaviors clinic at the Royal Ottawa Mental Health Centre. Patients were either on bail, probation, or parole for contact, noncontact, or both forms of sexual offenses against children under age 16. Before testing, we coded pertinent information (i.e., basic demographics, diagnosis, and criminal history) from clinical records, and we administered a self-report version of the Screening Scale for Pedophilic Interests, Version 2 (SSPI–2, [38]), a behavioral life-history measure designed for SOC. Controls were recruited from the community via online advertising.

Inclusion and Exclusion Criteria

Exclusion criteria for all participants were potential contraindications for tDCS, including prior head injury with loss of consciousness >5min, neurological diagnosis including epilepsy, prior medical conditions with central nervous system sequelae, metallic implants inside the head, electrical medical devices in the body, as well as visual and hearing impairments potentially interfering with testing. Seventeen patients volunteered to participate but had to be screened out. Almost half of the volunteers who were screened out (n = 7/17) reported a history of traumatic

brain injury with loss of consciousness >5min, in line with the elevated prevalence of traumatic brain injury often observed among offenders ([39]).

We addressed the presence of *DSM-5* disorders using a semi-structured interview based on questions from the Structured Clinical Interview for *DSM-5*, Research Version (SCID-5, RV, [40]). Most patients (n = 11/16) had comorbid depression, often co-occurring with anxiety (n = 7/11). At the time of testing, six patients were medicated with antidepressants and an additional two with leuprolide acetate, a synthetic gonadotropin-releasing hormone that can reduce sexual urges in PD ([41]). For controls, any criminal history (self-reported), a history of any clinically significant psychiatric condition in the last six months, and current psychoactive medication use constituted exclusion criteria.

Participant Characteristics

Groups were matched on age, years of education, hand dominance, and overall attention (outlined below). Patients were 21 to 65 years old (M = 43.2, SD = 12.8) and controls were 25 to 62 years old (M = 43.4, SD = 10.9). Patients had 8 to 18 years of education (M = 12.00, SD = 3.02) and controls 11 to 15 years (M = 13.07, SD = 1.16). A group difference existed in sexual orientation, as measured with the Kinsey Scale ([42], controls: M = 6.88, SD = 0.34; PD: M = 5.56, SD = 1.82; [t(16.05) = 2.83, p = .01, d = 1.00]). All controls (n = 16) and most patients (n = 12) reported predominant or exclusive sexual attraction to females. The remaining patients reported attraction to males occasionally (n = 3) or exclusively (n = 1). We found no group difference in hand dominance, as assessed with the Edinburgh Handedness Inventory ([43], p > .10, two-tailed Fisher-Exact-Test). Most participants were right-handed, except for one patient and two controls.

Overall attention was measured at baseline using the Attention Network Test (ANT, [44]) programmed using E-prime professional by Psychology Software Tools, version 2.0. Based on

reaction times, using the subtraction procedures provided by Fan and colleagues ([45]), we obtained four indices of attention. A two-way ANOVA (2 groups [controls vs. PD, as between factor] * 4 indices [alerting, alerting2, orienting, executive control, as within factor]) with mixed design showed no group differences in overall attention [$Q(1, 15.36) = 0.75$, $p = .40$, $\xi^1 = .02$].

Task Stimuli

Four different picture sets were employed in the present study.

The "Virtual People Set" (VPS, [46]) and the "Not Real People" set (NRP, [47]) were used in the task administered during tDCS. These picture sets include images of computer-generated female and male individuals varying in terms of explicitness (clothed, in swimsuits, and nude), and Tanner stage of sexual maturity ([48]). We chose validated computer-generated images due to ethical concerns with the use of sexually explicit child images. Two rather than one picture sets were used in order to reduce the number of presentations of the same image and, thus, also reducing the risk of habituation to the images. We selected 68 images displaying a complete lack of secondary sex characteristics as child stimuli (Tanner stage I) and 68 images displaying full sexual maturity as adult stimuli (Tanner stages IV and V). We excluded Tanner stages II and III because detecting possible hebephilic interests (i.e., sexual attraction to early adolescents) was not the scope of the present investigation.

Since participants viewed the computer-generated images threee times during the first task, we created a novel picture set to use in a second task, thus further preventing habituation. This picture set included 160 photographs of female and male individuals wearing swimsuits, circumventing concerns related to the use of nudes. We selected photographs available from the

[1] Explanatory measure of effect size for Yuen's dependent sample trimmed means t-test.

internet under universal Creative Commons licenses, depicting female and male prepubescent children and adults (~6-10 and ~20-40 years old, respectively, as evaluated by two independent raters), and varying in terms of apparent body mass index and ethnicity.

The fourth picture set included 20 neutral images from the International Affective Picture System (IAPS, [49]), which were used in practice blocks (details below).

To control for low-level visual features, we pre-processed the four picture sets separately to match images for luminance and complexity using Matlab® version 2017a, Spectrum, Histogram, Intensity Normalization and Equalization toolbox (SHINE, [50]). We further removed background colors for all but IAPS images used for practice.

Transcranial Direct Current Stimulation Procedure

The study included two testing sessions, one to nine days apart (M = 3.53, SD = 2.65, time of day was consistent within but not between participants), during which participants received either active or sham tDCS in a double-blind, within-subject design with block randomization. We asked participants to abstain from alcohol and drugs since the night before testing, as well as from caffeine and nicotine for 3 hours prior to testing. This was confirmed by self-report. In addition, we assessed participants' mood before and after tDCS using the Positive and Negative Affect Schedule (PANAS;[51]). Stimulation was applied using a battery-driven constant-current regulator (Oasis Pro, Edmonton, Alberta, Canada). One conductive saline-soaked rubber electrode, super-imposed on a sponge plate, was placed on the scalp at site F3 (active/anode electrode, 4.4×4.4cm), corresponding to a scalp region approximately overlaying the left dlPFC, according to the 10–20 International System for Electrode Placement. A second electrode was placed on the contralateral supraorbital area (reference/cathode electrode, 5.1×10.2cm). Stimulation was delivered by a research assistant not otherwise involved in task

administration or data analysis. Stimulation would not begin until impedance was within an acceptable range as indicated on the device display. Direct current was increased in a ramp-like fashion over 10s, until reaching 2mA, and similarly decreased at the end of stimulation. Stimulation was maintained for 20 minutes in the active tDCS condition and turned off after 15 seconds in the sham condition. During the experiment, participants sat in a dimly lit and sound-attenuated room, positioned about 60 centimeters from the computer monitor. Research personnel operated the computer and monitored and communicated with participants from a separate room. Following stimulation, in line with available guidelines ([52]), we asked participants to report what type of stimulation they believed they had received, and to rate adverse effects on a scale from 1 (“no symptoms at all”) to 5 (“severe symptoms”).

Measures

While receiving tDCS, participants completed the antisaccade test ([18]) and, within 10 minutes following tDCS, they completed a viewing time test (see Figures 1 and 2, respectively). During both tests, participants’ eye movements were recorded using a contactless remote-controlled eye tracking device (SMI RED 250 eye tracker; SensoMotoric Instruments GmBH, Germany). This device recorded the corneal reflection caused by an infrared light, stored coordinates of gaze position on the screen with 250 Hz frequency, automatically excluded blinking or off-screen gazes, and automatically compensated for minor head movements.

Antisaccade Test

The antisaccade test included 202 trials. One practice block of 10 trials (neutral stimuli) was administered before tDCS. The remaining 192 test trials with sexually relevant stimuli from the VPS and NRP picture sets were administered during tDCS. During each trial, two images appeared on the computer monitor, one of a child and one of an adult. Stimuli were always

matched by sex (both females or both males) and sexual relevance (both clothed/in swimsuits or both nude). One of the two stimuli was always surrounded by a cue, namely, a white frame. Trials were divided in two block types, which alternated during each testing session in ABBA fashion. Instructions were provided at the beginning of each block. In prosaccade blocks, participants were instructed to look towards the stimulus surrounded by the visual cue. In antisaccade blocks, they had to look towards the opposite stimulus. Across trials, the location of the visual cue (left/right) as well as the age (child/adult) and sex (female/male) of the target were counterbalanced. We created two versions of the test, with different combinations of images and counterbalanced block order, for use in the two testing sessions. Every image was presented 3 times per session. Each trial began with a blank screen for 1700-2300ms (average: 2000ms) followed by a fixation cross, presented at the center of the screen for 1250-1750ms (average: 1500ms). Then, two stimuli were presented for 2000-2500ms (average: 2250ms). The entire test took approximately 25 minutes to complete, including short breaks (<1min) between blocks. Based on participant's eye movements, we extracted two outcome measures: response latency (i.e., time from stimuli appearance to first fixation towards target), and response accuracy (i.e., accuracy of first fixation). Latency was computed across correct and incorrect trials (i.e., when first fixation was towards the distracter but followed by a saccade towards the target). Latency could not be extracted from trials when participants did not ever gaze at the target (coded as missing data).

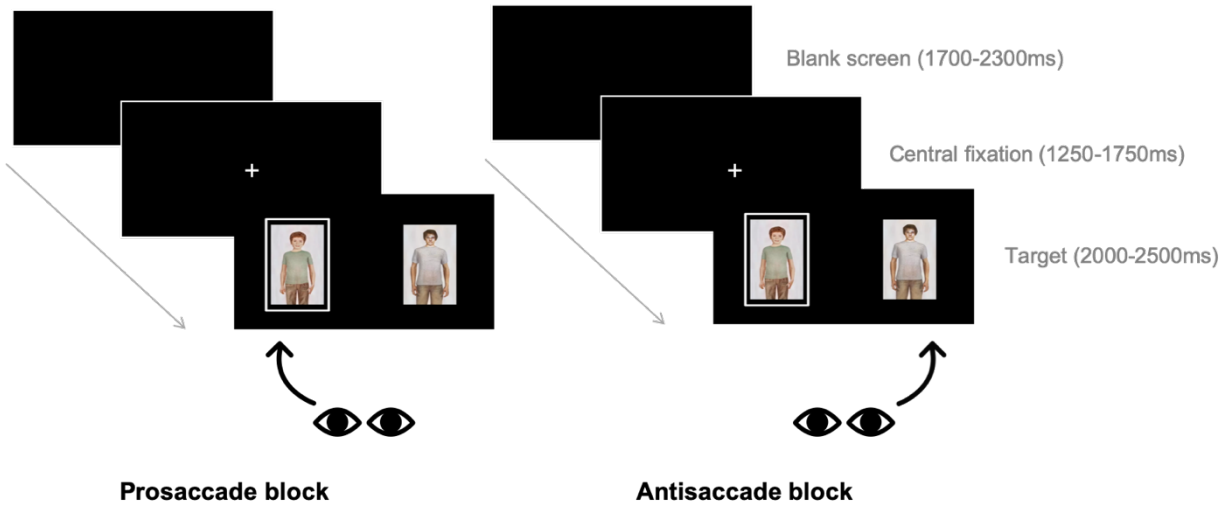

Figure 1. Antisaccade test. The computerized antisaccade test was performed during active and sham transcranial Direct Current Stimulation. To complete test trials, participants had to look at either of two computer-generated images of clothed and nude female and male children (Tanner stage I) and adults (Tanner stages IV and V) simultaneously appearing on the computer monitor. The test included two types of blocks: prosaccade and antisaccade, during which participants were instructed to look, respectively, towards the image marked by a visual cue (white frame) or towards the other image. Responses were collected using an eye-tracking device.

Viewing Time Test

The subsequent viewing time test consisted of 80 trials divided into 4 blocks of 20 trials. During each trial, participants viewed an image selected from the swimsuit picture set. Images were presented to the left or the right side of the screen in a randomized fashion. Participants had to indicate the location of each image, by pressing either a left or a right key on the keyboard. Across trials, the age (child/adult) and sex (female/male) of the target was counterbalanced. We created two versions of the test, one per testing session, using a different set of images, so that every image was presented once in the whole experiment. Each trial began with a blank screen, presented for 1250-1750ms (average: 1500ms), which was followed by a central fixation cross (1700-2300ms, average: 2000ms). Then, a target stimulus was shown until the participant responded (right or left presentation). Completing the test took approximately 10 minutes, including short breaks (<1min) between blocks. Participant's response times were used as a proxy of viewing times. We used the software BeGaze version 3.0 (SensoMotoric Instruments GmbH, Germany) to program and administer both the antisaccade and viewing time tests.

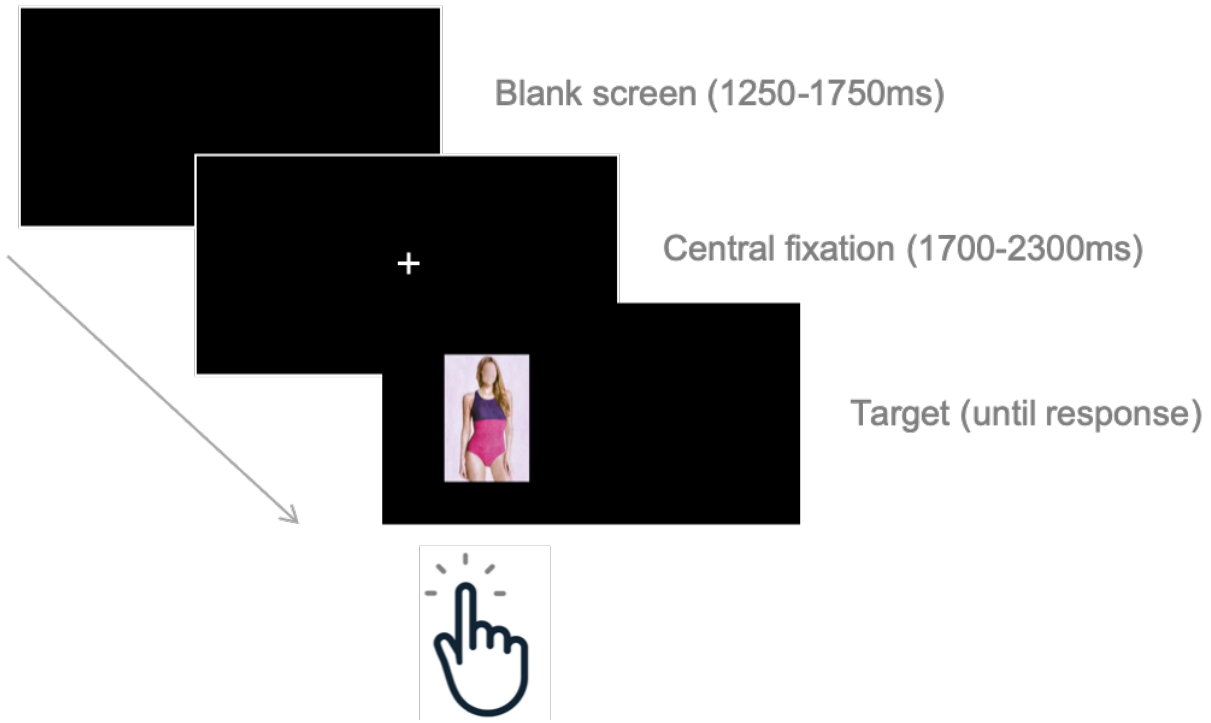

Figure 2. Viewing time test. The viewing time test was performed within the 10 minutes following active and sham transcranial Direct Current Stimulation. To complete the test, participants had to indicate the location (left vs. right) where advertising photographs of female and male children (aged ~6-10) and adults (aged ~20-40) wearing swimsuits appeared, by pressing one of two keys on the computer keyboard. Faces were visible to participants but have been blurred for publication.

Statistical Analyses

We prepared data for statistical analyses by removing outliers and inspecting missing data. For each outcome measure, we defined outliers as values > ±3 SDs than the mean across all participants. This resulted in the deletion of 8% of total data points for latency, 0% for accuracy, and 3% for viewing times. With respect to missing data, we calculated the proportion of missing data points for each participant and, then, the mean proportion of missing data points across participants. Next, we inspected whether any participant had a proportion of missing data > 3 SDs than this mean value, indicating that multiple imputation could be preferred ([53]). No participant met this criterion for latency and one participant met this criterion for accuracy. Since results were consistent when removing and imputing data collected from this participant, we removed it from the analyses. No missing data points existed in the viewing time test, which required a response to each trial.

We tested H1 with a three-way ANOVA (2 groups [PD vs. controls, as between-subjects factor] * 2 self-reported sexual preferences [preferred vs. non-preferred] * 2 blocks [prosaccade vs. antisaccade]) with mixed design on response latency and accuracy from the antisaccade test, and a two-way ANOVA (2 groups [PD vs. controls, as between-subjects factor] * 2 self-reported sexual preferences [preferred vs. non-preferred]) with mixed design on viewing times. Sexual preference was determined in terms of both sex and age, based on self-reports. Only outcome measures collected in the sham tDCS condition were used to address this hypothesis.

Next, based on each participant's reported sexual preference, we calculated the difference in outcome measures (i.e., mean response latency and accuracy from the antisaccade test, mean viewing times from the viewing time test) between trials with preferred and non-preferred targets for each of the sham and active tDCS conditions. The three resulting difference measures were

used as indices of automatic attention bias. To test the remaining hypotheses (H2-H4), we performed a mixed two by two (2 groups [PD vs. controls] * 2 tDCS conditions [active vs. sham]) ANOVA on the three indices of automatic attention bias. To test H2, we examined the effects of active vs. sham tDCS on the response latency and accuracy indices. To test H3, we further tested the effects of active vs. sham tDCS on the viewing time index. Robust estimation was used for this index as its values were not normally distributed ([54]). To test H4, we inspected group differences on the effect of active vs. sham tDCS on the three indices.

In addition to the pre-registered analyses, we conducted exploratory analyses using three-way mixed ANOVAs (2 groups [PD vs. controls] * 2 target age [child vs. adult] * 2 tDCS conditions [active vs. sham]) on the three raw outcome measures. The main difference between these and the pre-registered ANOVAs was that we analysed responses irrespective of self-reported sexual preferences for sex and age. Rather, we analysed the responses to child and adult targets, averaging across target sexes.

Lastly, we inspected other effects potentially associated with tDCS by performing a three-way ANOVA (2 groups [controls vs PD, as between factor] * 2 testing days [day 1 vs day 2], * 2 time [before vs after tDCS session]) on positive and negative affect measured with the PANAS, as well as a two-way ANOVA (2 groups [PD vs. controls, as between factor] * 2 tDCS conditions [active vs. sham]) with mixed design on participants' perceived adverse effects, and two-tailed Fisher's exact tests on their guesses regarding active or sham stimulation.

Statistical analyses were performed in the *R* environment for statistical computing, version 3.6.0, using the packages effsize, version 0.7.6 ([55]), emmeans, version 1.4.3.01 ([56]), ez, version 4.4-0 ([57]), nlme version 3.1-139 ([58]), psych, version 1.9.12 ([59]), and WRS2, version 1.0-0 ([60]). Both the pre-registered and exploratory analyses were also conducted using Linear Mixed-

Effects Models (LMMs), yielding consistent results. Therefore, results of the ANOVAs were reported here, for consistency with prior literature, and results of the LMMs are available in the output file at the project webpage. We included both η^2 and partial eta squared estimates (η_p^2) as measures of effect size to facilitate comparisons between studies ([61],[62]).

Results

Automatic Attention Bias

We performed the first set of ANOVAs on the outcome measures collected during the sham tDCS condition to address the presence of an automatic attention bias for stimuli of the preferred sex and age according to self-reports (see Table 1).

Antisaccade Test

With respect to latency, only the main effect of block was significant [$F(1, 30) = 22.21$, $p < .001$, $\eta^2 = .06$, $\eta_p^2 = .43$], with shorter latencies in prosaccade relative to antisaccade blocks. We found no main effect of sexual preference [$F(1, 30) = 0.45$, $p = .51$, $\eta^2 < .01$, $\eta_p^2 = .01$], group [$F(1, 30) = 3.18$, $p = .08$, $\eta^2 = .08$, $\eta_p^2 = .10$], or a group * sexual preference interaction on latency [$F(1, 30) = 2.64$, $p = .11$, $\eta^2 = .01$, $\eta_p^2 = .08$]. Despite non-significant results, we conducted the post-hoc comparisons meant to address the pre-registered hypothesis (H1). These indicated significantly shorter latencies in patients relative to controls overall ($p < .01$), to adult targets ($p = .01$), and to preferred targets in particular (i.e. shorter latencies to child targets in patients vs. adult targets in controls; $p < .01$).

Regarding accuracy, we again observed a significant main effect of block [$F(1, 29) = 6.19$, $p = .02$, $\eta^2 = .02$, $\eta_p^2 = .18$], with increased accuracy in prosaccade vs. antisaccade blocks. Additionally, we found a main effect of group [$F(1, 29) = 4.81$, $p = .04$, $\eta^2 = .11$, $\eta_p^2 = .14$], with increased overall accuracy in controls vs. patients. Although no main effect of sexual preference

emerged [$F(1, 29) = 0.04$, $p = .85$, $\eta^2 < .01$, $\eta_p^2 < .01$], the group * sexual preference interaction was significant [$F(1, 29) = 4.38$, $p = .05$, $\eta^2 = .01$, $\eta_p^2 = .13$]. Post-hoc analyses indicated that controls were more accurate to preferred (i.e., adult) targets than patients to non-preferred (i.e., adult) targets ($p = .01$). Controls were also more accurate to non-preferred (i.e., child) targets than patients to preferred (i.e., child stimuli; $p = .01$). In sum, controls were not only more accurate than patients with adult targets ($p = .01$), but also with child targets.

Viewing Time Test

There was no main effect of group [$F(1, 30) = 1.10$, $p = .75$, $\eta^2 < .01$, $\eta_p^2 < .01$], sexual preference [$F(1, 30) = 1.65$, $p = .21$, $\eta^2 < .01$, $\eta_p^2 = .05$] or group * sexual preference interaction [$F(1, 30) = 0.\ 04$, $p = .83$, $\eta^2 < .01$, $\eta_p^2 < .01$] on viewing times.

Transcranial Direct Current Stimulation (tDCS) Effects

The second set of ANOVAs sought to address the impact of active vs. sham tDCS on indices of automatic attention bias. Following the pre-registered analysis plan, we computed the indices based on self-reported sexual preferences (see Table 2), and, across groups, expected a reduced bias during (H2) and following (H3) active vs. sham tDCS, as well as a larger reduction in patients compared to controls (H4).

Antisaccade Test

Regarding the latency index based on self-reported sexual preferences, we found no main effect of group [$F(1, 30) = 1.79$, $p = .19$, $\eta^2 = .02$, $\eta_p^2 = .06$] or tDCS condition [$F(1, 30) = 0.12$, $p = .73$, $\eta^2 < .01$, $\eta_p^2 < .01$]. We observed a significant group * tDCS condition interaction [$F(1, 30) = 4.68$, $p = .04$, $\eta^2 = .09$, $\eta_p^2 = .14$] but post-hoc comparisons were non-significant.

With respect to the accuracy index based on self-reported preferences, we observed a main effect of group [$F(1, 29) = 8.91$, $p = .01$, $\eta^2 = .12$, $\eta_p^2 = .24$], reflecting a larger positive

index in patients relative to controls, who showed a negative index. Since the index was computed by subtracting accuracy for non-preferred targets from accuracy for preferred targets, this was consistent with the above-documented bias for preferred targets in patients and non-preferred targets in controls. No main effect of tDCS condition [$F(1, 29) = 0.69$, $p = .41$, $\eta^2 = .01$, $\eta_p^2 = .02$] or group * tDCS condition interaction [$F(1, 29) = 0.18$, $p = .67$, $\eta^2 < .01$, $\eta_p^2 = .01$] existed.

Viewing Time Test

The ANOVA on the viewing time index based on self-reported preferences showed no main effect of group $Q(1, 17.92) = 0.14$, $p = .71$, $\xi = .06$], tDCS condition [$Q(1, 15.92) = 0.06$, $p = .82$, $\xi = .04$], or group * tDCS condition interaction [$Q(1, 15.92) = 0.39$, $p = .54$, $\xi = .06$].

Additional Exploratory Analyses

We carried out another set of exploratory analyses to determine the presence and direction of any tDCS effects on the three outcome measures, irrespective of the self-reported sexual preferences for sex and age. The ANOVA on response latency on the antisaccade test indicated a main effect of tDCS [$F(1, 30) = 653.81$, $p < .01$, $\eta^2 < .02$, $\eta_p^2 = .19$], with longer latencies during active vs. sham tDCS overall. The ANOVA on response accuracy on the antisaccade test indicated a main effect of target age [$F(1, 30) = 653.81$, $p = .05$, $\eta^2 < .01$, $\eta_p^2 = .12$]. Participants were significantly more accurate to child vs. adult stimuli overall ($p = .02$). No significant effect emerged from the ANOVA on responses at the viewing time test.

Affect

The ANOVA on the PANAS indicated a main effect of time on both positive affect [$F(1, 30) = 8.10$, $p = .01$, $\eta^2 = .02$, $\eta_p^2 = .21$] and negative affect [$F(1, 30) = 7.79$, $p = .01$, $\eta^2 = .02$, $\eta_p^2 = .21$], with lower affect scores following tDCS, irrespective of stimulation type. For negative

affect, we also observed a main effect of testing day [$F(1, 30) = 12.29$, $p < .001$, $\eta^2 = .03$, $\eta_p^2 = .29$], with lower negative affect on the second session, as well as a time * testing day interaction [$F(1, 30) = 6.17$, $p = .02$, $\eta^2 = .01$, $\eta_p^2 = .17$], with lower negative affect before stimulation on the second relative to the first session.

Adverse Effects and Blinding

The ANOVA on the questions on adverse events showed a main effect of group [$F(1, 28) = 6.94$, $p = .01$, $\eta^2 = .13$, $\eta_p^2 = .20$], with controls reporting more adverse effects than patients, and a main effect of tDCS condition [$F(1, 28) = 6.24$, $p = .02$, $\eta^2 = .08$, $\eta_p^2 = .18$], with participants reporting more jitteriness, dull headache, and mild nausea after active vs. sham tDCS. The percentage of correct guesses was higher in the active vs. sham condition (68% vs. 33%, $p = .02$, two-tailed Fisher-Exact-Test), indicating incomplete blinding. No group was more accurate than the other in guessing the condition ($p > .10$, two-tailed Fisher-Exact-Test).

Table 1

Mean Response Latency, Accuracy, and Viewing Times for Preferred and Non-preferred Targets

	Response Latency		Response Accuracy		Viewing times	
	Preferred	Non-preferred	Preferred	Non-preferred	Preferred	Non-preferred
Patients (*n* = 16)	345.68 (92.31)	354.73 (68.09)	80 (0.18)	78 (0.16)	439.33 (103.64)	432.72 (85.77)
Controls (*n* = 16)	405.27 (89.09)	383.58 (73.22)	87 (0.11)	90 (0.09)	430.47 (93.88)	421.23 (79.44)

Note: Response latency and viewing times are measured in ms, response accuracy in percentage of correct responses. Standard deviations are reported in parentheses. Preference is defined in terms of both sex and age and based on self-reports.

Table 2

Transcranial Direct Current Stimulation Effects on the Indices of Attentional bias

	Latency Index		Accuracy Index		Viewing Times Index	
	Sham	Active	Sham	Active	Sham	Active
Patients (*n* = 16)	-13.21 (59.00)	6.72 (27.70)	2.40 (8.30)	0.14 (5.12)	6.60 (40.61)	9.41 (28.52)
Controls (*n* = 16)	22.57 (40.50)	-4.90 (23.57)	-3.08 (5.91)	-3.81 (6.91)	9.24 (28.00)	47.67 (136.26)

Note: Indices were computed as the difference in outcome measures (i.e., response latency, response accuracy, and viewing times) between trials with targets congruent and incongruent with each participant's self-reported sexual preferences for sex and age. An automatic attention bias for sexually preferred targets is indicated by a negative index value for latency and by a positive index value for accuracy and viewing times. Response latency and viewing times are measured in ms, response accuracy in percentage of correct responses. Standard deviations are reported in parentheses. Active = active tDCS condition, Sham = sham (placebo) tDCS condition.

Discussion

PD is a source of distress for patients and a risk factor for sexual offending against children. Hence, developing successful evidence-based therapeutic interventions is crucial. A growing body of evidence has shown that SOC with PD display an automatic attention bias for child stimuli (10), as well as decreased activity and disrupted connectivity profiles in brain areas involved in cognitive control over sexual responses (for a review, see [63]). In light of this evidence, this pre-registered pilot study was the first to explore the effects of acute tDCS on attention bias to sexually relevant stimuli in SOC with PD.

Gaze-Based Measures of Automatic Attention Bias for Sexually Preferred Stimuli

First, we examined the presence of an automatic attention bias for child vs. adult images in SOC with PD and for adult vs. child images in teleiophilic controls (H1). This prediction was not supported, as statistical analyses indicated no main effect of sexual preference on any of the outcome measures. It is possible that our pilot study was underpowered to detect an automatic attention bias. Accordingly, while our power analysis estimated the sample size needed to detect main effects with a large effect size, only small-to-medium post-hoc effect size estimates were found when testing the first hypothesis. Nevertheless, the interaction of group by sexual preference on response accuracy during the antisaccade test was statistically significant. Specifically, both groups displayed an automatic attention bias to child targets. There are at least three possible interpretations for this finding. First, the bias could reflect different attentional processes in the two groups, as computerized child stimuli might have been sexually attractive for patients and unsettling or distressing for controls. At the same time, computerized adult stimuli might have been sexually unattractive and less salient than the computerized child stimuli across groups. A second, unlikely, possibility is that both groups were sexually attracted to child

images, and a third explanation is that, in both groups, attentional responses reflected an unwanted salience artefact rather than sexual preferences. Since we did not ask participants to rate stimuli in terms of valence and arousal, we could not address this possibility directly.

It is also conceivable that one of the two tasks was more apt than the other to detect an automatic attention bias, thus explaining some of the inconsistency between outcome measures. Both the antisaccade test and viewing time-based measures have been successfully employed in the indirect assessment of sexual interest ([21], [13]). However, other protocols, such as the Choice Reaction Time task (CRT, [14]) and the Approach–Avoidance Task (AAT, [64]), have also been proposed. Consequently, research aimed at evaluating and comparing the psychometric properties of indirect measures of sexual interest, and gaze-based measures, in particular, is warranted to establish appropriate standards. For instance, the test-retest reliability of such measures is presently unclear ([17]). It should also be noted that indirect measures assume a link between measurable behaviour (e.g., longer viewing times) and a construct of interest (e.g., sexual attraction) which cannot be directly measured and is inferred ([65]). As our results suggested, this link may not hold in all circumstances ([66]) and might be especially weak in the case of task-irrelevant measures that do not require participants to pay attention to the sexual features of the stimuli ([17]). Moreover, the group effects observed in the present study indicate that normative standards in non-forensic populations are warranted ([65]) and might provide a reference for the use of indirect measures in forensic settings.

Transcranial Direct Current Stimulation in Pedophilic Disorder

Next, we aimed to investigate whether acute anodal vs. sham tDCS applied over the left dlPFC could reduce the automatic attention bias for sexually preferred stimuli measured by the antisaccade test (H2). We further predicted that this effect would be greater in patients relative to

controls (H3). Since no main effect of sexual preference emerged in the sham condition and controls did not show the expected bias for adult stimuli, we could not address these specific research questions. Nevertheless, in compliance with our pre-registered analytical plan, we computed indices reflecting participants' self-reported sexual preference.

Statistical analyses indicated no main effect of tDCS condition on those indices. However, the interaction of group by tDCS condition was significant for response latency on the antisaccade test, suggesting that active vs. sham tDCS reduced the automatic attention bias for child targets in both groups. Therefore, across participants, modulating brain areas involved in cognitive control by means of tDCS did appear to reduce the automatic attention bias towards salient stimuli. Additional exploratory analyses on the antisaccade test, conducted regardless of self-reported sexual preferences, further indicated increased overall latencies during active vs. sham tDCS, suggesting enhanced cognitive control. In other words, increased latencies during active vs. sham tDCS might result from participants' effort to complete the task while resisting potentially distracting/highly salient content. However, exploratory analyses did not further indicate increased accuracy during active vs. sham tDCS.

Several methodological factors might account for the inconsistent results across outcome measures. First, behavioural effects are more reliably observed with repeated rather than single tDCS sessions ([67]). Thus, repeated administrations might induce greater changes. Second, while some studies have found adequate blinding with standard ramp up/down and stimulation times $\leqslant$30s for the sham condition ([68]), others have not ([69]). Based on participants' self-reports, our protocol did not appear to result in effective blinding, potentially confounding our results. Third, our montage and electrode size might have been sub-optimal. Electrode placement was guided by a 10–20 system positioning cap rather than by computational models simulating current

distribution, more apt to identifying the optimal montage per participant (e.g., [70]). The use of comparably large active/anode and reference/cathode electrodes might have created an electrical field over the prefrontal cortex wider than intended and, as a result, we might have modulated multiple regions recruited by the antisaccade test. To prevent this, smaller and more focal active electrodes might be preferred. Also, placing the reference electrode over the contralateral supraorbital area might have induced opposite effects in contralateral areas. Lastly, although we ensured that impedance was acceptable prior to stimulation, we did not record its values throughout stimulation. In future studies, devices that provide this information should be preferred to ensure that impedance remains below 5k ohms as per tDCS guidelines ([71]).

In line with the pre-registered analytical plan, we also addressed whether the reduction in the automatic attention bias expected with active vs. sham tDCS persisted during a second test administered immediately following stimulation (H4). This prediction was not supported, as no significant main or interaction effects emerged after stimulation in either group. The nonsignificant main effect following tDCS may be unsurprising given that single-stimulation effects are known to be short-lived ([72]). Some of the above-mentioned methodological issues were also at play, such as the confound due to the use of different stimuli and tasks during and after tDCS, and imperfect blinding. Moreover, we were unable to disentangle whether the persistence and/or the generalization of tDCS effects were unsupported give relatively subtle tDCS effects on the antisaccade test. Furthermore, the antisaccade and viewing time tests might have engaged different brain networks, differently responsive to active tDCS. Indeed, while performance on the antisaccade test has been repeatedly associated with dlPFC activity ([73],[20]), the extent and exact localization of the frontal engagement during the viewing time test is less clear. Since neuromodulation is dependent on ongoing brain activity, tDCS may have small or no

effects when the targeted brain area is not implicated in the behavioural task at hand. Altogether, these results indicate that tDCS effects on viewing time-based measured of sexual interest should be further examined.

Lastly, we observed significant tDCS effects on affect, irrespective of stimulation type. We found an overall down-regulation in positive and negative affect after (vs. before) tDCS, which may result from sitting calmly and completing simple tasks. We also found lower negative affect on the second (vs. first) tDCS session, particularly before (vs. after) stimulation, which may be due to participants having clearer expectations regarding study procedures.

Limitations

Albeit intriguing, our findings should be interpreted in the context of limitations. We have already noted our main methodological concerns above. In addition, when recruiting healthy volunteers, we relied on self-reports of sexual interest. According to available estimates, about 1% of men in the general population might have a sexual interest in prepubertal children ([4]). Therefore, we cannot rule out that some control participants concealed a pedophilic interest. Similarly, we cannot rule out potential confounds due to patients being sexually attracted to both children and adults. Indeed, *exclusive* sexual interest in children is uncommon ([74]).

While we screened for mental health conditions in the control group, we did not exclude comorbid depression and anxiety in the patient group. As a result, altered dlPFC activity, often associated with depression ([75]), might have introduced within-group variation modulating the expected tDCS effect. Also, all patients were involved in some form of cognitive behavioral therapy designed to target PD, and two further received medication to reduce their sexual urges, which might have further confounded the anticipated tDCS effects.

Our sample included men only and, conceivably, different results might be expected for women who are sexually attracted to children. Nevertheless, very little is known about the prevalence and features of pedophilia in women ([63]), and even less about potential therapeutic avenues for them.

Lastly, all of our patients had a history of sexual offending against children. According to previous research, SOC with PD present reduced inhibitory control compared to men with PD but no offence history ([76],[77]). Thus, impaired inhibitory control might increase the risk of offending, and different levels of impairment might be associated with contact compared to noncontact or no offending. Based on this evidence, our sample of SOC with PD had the highest potential of showing inhibitory impairments and, thus, tDCS-induced improvements. With only 16 patients, however, we were unable to compare those with contact, noncontact, or both kinds of sexual offences. Consequently, future studies should clarify whether tDCS effects vary depending on status (presence/absence) and type of offense, with the ultimate goal to improve patient symptomatology while assisting crime prevention.

Conclusion

The present pre-registered pilot study investigated, for the first time, whether increased prefrontal activity putatively induced by acute anodal vs. sham tDCS could reduce the automatic attention bias for child vs. adult images in SOC with PD. Since teleiophilic controls showed a response facilitation to child stimuli, which likely captured their attention in unintended ways, the presence of the expected automatic attention bias was not supported, and a direct test of this hypothesis was precluded. Nevertheless, across groups, we found that active vs. sham tDCS reduced the automatic attention bias for child stimuli, although no attentional bias and no tDCS effects were found following stimulation. Overall, these findings suggested that modulating areas

involved in cognitive control has the potential to improve attentional features associated with PD. Given these encouraging preliminary results, we have discussed several methodological improvements that can inform future research on brain stimulation in PD.

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