Transcranial Direct Current Stimulation on Dorsolateral Prefrontal Cortex as a possible tool to improve Attention in a healthy sample and how Mind Wandering, Sluggish Cognitive Tempo and multiple Psychopathological variables are related.

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Abstract

Objectives: The present study has been divided in two parts. The aim of the first study was to find if anodal transcranial direct current stimulation (tDCS) over the right dorsolateral prefrontal cortex (DLPFC) in young healthy adults could enhance some attentional variables. The objective of the second study was to analyze the relationship between Mind Wandering (MW) and Sluggish Cognitive Tempo (SCT), and with some psychiatric symptoms. **Methodology:** We administrated a sociodemographic formulary which also included three scales (Adult Concentration Inventory (ACI), Mind Excessively Wandering Scale (MEWS) and DSM-5 Self-Rated Level 1 Cross-Cutting Symptom Measure — Adult (CCSM)), to a communitarian sample (n=43) of young adults. Ten of those forty-three participants were included in the tDCS study, where they received a single session of active (n=5) or sham (n=5) tDCS. Before and after the stimulation participants performed Conners' Continnuous Performance Test (CPT-3) and Attention Network Task (ANT). **Results:** Those participants who received active tDCS uniquely showed a large and significant reduction of the variability of block change reaction time in the CPT-3 task. No significant differences were found in the three attentional networks, although the sham group showed a decrease in the efficiency of the executive network. Regarding the second study, we found a significant moderate correlation between ACI and MEWS, and weak correlations between CCSM and both ACI and MEWS. **Conclusions:** tDCS over DLPFC could improve sustained attention and prevent a reduction of the executive network efficiency. Moreover, as we expected, SCT, MW and emotional dimensions were related.

Keywords: tDCS; DLPFC; attention, Sluggish Cognitive Tempo; Mind Wandering.

Introduction

Attention is not a unitary concept since is composed by a variety of components. According to the model described by Petersen & Posner (2012, 1990) it is possible to identify three differentiated networks, which interact between them: the alerting, orientating and executive or conflict networks.

Alertness depends on the arousal level of the brain and is referred to the capacity to generate and maintain an optimal level of vigilance and performance during a task. Some of the areas that participate in its functioning are the nucleus coeruleus, which is the source of norepinephrine (NE), and its projections to the frontal cortex and parietal areas related to the dorsal but not the ventral visual pathways. Orienting is defined as the ability to select a sensory input and redirect the focus of attention to a target stimulus. This network includes the frontal eye fields (FEF), the superior coliculus, the temporal parietal junction, and the superior parietal cortex. Finally, the executive system is involved in the detection, the monitoring and/or the resolution of conflicts, which implies to withhold a dominant but incorrect response to perform a subdominant response. Precisely, this explanation corresponds to what is defined as inhibitory control (Roberts, Fillmore, & Milich, 2011), which represents a collection of different cognitive processes implicated in the cognitive control (Botvinick, Braver, Barch, Carter, & Cohen, 2001). The executive network contains the anterior cingulated cortex (ACC), the midline regions of the medial frontal cortex and usually the bilateral midline and anterior insula. Moreover, it has been found activity in these areas during different operations or demands, such as perception of physical or social pain, processing of reward and theory of mind. The same authors suggest that this system could be useful in top-down regulation processes.

Another area that plays an important role in the functioning of the executive attention network is the dorsolateral prefrontal cortex (DLPFC). This area mediates cognitive control to prevent future conflicts through an enhancement of the attentional resources relevant for a task. Likewise, literature shows that there is a lateralization of the DLPFC (Nejati, Salehinejad, Nitsche, Najian, & Javadi, 2017; Vanderhasselt, de Raedt, & Baeken, 2009). On the one hand, left DLPFC seems to be more associated to executive control functions (working memory, interference inhibition), whereas right DLPFC is closely involved in inhibitory control.

Apparently, inhibitory control plays a crucial role during the neurodevelopment. For example, in the attention deficit hyperactivity disorder (ADHD), which is characterized by the presence of symptoms of inattention, impulsivity and hyperactivity that are inadequate for the age, the appropriate development of this ability is essential for the correct performance of other areas as working memory, internalization of speech, self-regulation of affect-motivation-arousal, reconstitution, and motor control-fluency-syntax (Barkley, 1997). Structurally, in their meta-analytic review Dickstein, Bannon, Castellanos, & Milham (2006) examined neuroimaging literature of ADHD and results revealed that the most consistent findings were deficits in neural activity within fronto-striatal and fronto-parietal circuits.

In a more recent meta-analysis, Kelly et al. (2012) also found that in children with ADHD, additionally to the fronto-parietal network there was also a hypoactivation of the ventral attentional network, despite that some of its structures were also hyperactivated, as well as the default and somatomtor networks. The first two networks are involved in the executive and attention functioning respectively. Likewise, while ADHD adult individuals also displayed a hypoactivation of the fronto-parietal network, they showed hyperactivity in the visual, dorsal attention, and default mode networks. According to this last network, some studies emphasize the role played by the default mode network (DMN) and its interaction with other networks to explain attentional dysfunctions (Castellanos & Proal, 2012; Sonuga-barke & Castellanos, 2007). DMN is usually deactivated during the performance of a high central demand tasks that requires an attentional engagement to external stimuli, whereas is activated when attentional focus is disengaged ceasing the conscious supervision of a task and during Mind Wandering (Andrews-Hanna, Smallwood, & Spreng, 2014; Mason et al., 2007).

Related with inattention, Mind Wandering (MW) is defined as those set of processes characterized by focusing the attention into internal stimuli or self-generated thoughts usually in absence of external demands. In contrast with healthy population, whose DMN activity display negative correlations between the fronto-parietal and dorsal attention networks (Chai, Castañón, Öngür, & Whitfield-Gabrieli, 2012; Kucyi, Hodaie, & Davis, 2012), ADHD individuals exhibit a reduced or even an absence of negative correlation between the activation of these networks and within the DMN connectivity, when the brain is at a resting state (Castellanos et al., 2008; Mattfeld et al., 2014). This indicates an excessive inappropriate DMN activity and, consequently, MW during tasks that require attentional resources. Moreover, unlike healthy people, those with a diagnosis of ADHD showed positive correlations between cerebellar DMN and generalized areas of salience, dorsal attention, sensoriomotor, fronto-parietal and visual networks (Kucyi, Hove, Biederman, Van Dijk, & Valera, 2015).

Sluggish Cognitive Tempo (SCT) is another psychological dimension, closely related to the inattentive ADHD subtype, where attention is one of the main affected components, as well as a motor and cognitive slowdown (Carlson, 1986). In this case, the symptoms of inattention are related but differ from those included on the DSM-5 criteria for ADHD. These are daydreaming, staring, mental fogginess and confusion, hypoactivity, sluggishness or slow movement, lethargy, apathy, and sleepiness (Barkley, DuPaul, & McMurray, 1990; Carlson & Mann, 2002; Milich, Balentine, & Lynam, 2001).

Some authors suggest that MW and SCT are maybe related factors, in the sense that SCT constitute a pathological form of MW, characterized by a particular kind of attentional dysfunction that does not depend on the task (Barkley, 2014). Both factors share an interesting feature: they may be reflecting an alteration on the attentional functioning without the requisite of being implicated in a specific disorder. In other words, they are transdiagnostic dimensions. This means that all people present a greater or lesser MW and SCT degree, without necessarily supposing a significant clinical alteration. However, in some cases, extreme scores on some of these factors, or when they occur concomitantly with another disorder, might modify or even aggravate its symptoms. Despite ADHD is the most common comorbid disorder with both factors (Carlson & Mann, 2002; Seli, Smallwood, Cheyne, & Smilek, 2015), SCT (Becker & Langberg, 2013) and MW (Deng, Li, & Tang, 2014) are also specially related with internalizing symptoms, as anxiety or depression. Thus, research focused on MW and SCT, mainly follows two pathways: analyze its relationship with other psychopathological disorders and the efficacy of different procedures to reduce or regulate its influence over attentional mechanisms.

Nowadays, evidence based treatments addressed to improve deficits exclusively include those recommended for ADHD, including pharmacological therapy, behavioral parent training and classroom behaviour management (Toplak, Connors, Shuster, Knezevic, & Parks, 2008), being the first the unique that has been well established as able to directly improve attentional deficits. Other treatments are the Neural-based interventions. One of the most prominent is the neurofeedback, a method that uses monitoring devices to provide instantaneous information of an individual about the state of its brain functioning, through the displaying of an auditory or visual stimulus that will change depending on the type of brain activity, reinforcing the participant if he focuses on the desired pattern of waves. Some studies have found that neurofeedback could be useful to reduce ADHD symptoms, but is still requiring more research to be considered as effective treatment for ADHD (Sonuga-Barke et al., 2013).

Another neurophysiological technique that has received a growing interest during the last years, as a possible tool to improve cognitive dysfunctions, including attentional and executive deficits, is the transcranial direct current stimulation (tDCS). tDCS is a neuromodulatory, non-invasive technique which consists on supplying low intensity current to cortical areas, which facilitates or inhibit spontaneous neuronal activity (Brunoni et al., 2012). There are two types of tDCS: anodic tDCS (atDCS) or cathodic tDCS (ctDCS). Concretely, anodic stimulation increases the cortical excitability potential, while cathodic stimulation decreases it. To improve attention deficits using tDCS, some studies have focused on the stimulation of the DLPFC, due to its implication in the inhibitory control, an ability that plays an essential role in the appropriate development and performance of a lot of other cognitive areas, being particularly important for the executive attention network. Soltaninejad, Nejati, & Ekhtiari (2015), found that in a sample of 20 high school students with ADHD, a single 15 minute ctDCS session at 1.5 mA on the left DLPFC improved inhibitory capacity during the performance of a "go-don't go" task, while, a session of atDCS on the same region implied an improvement in the performance of the "go" phase of the task. These authors argue that a decrease in the levels of activity of the left DLPFC can induce an increase of the activity of the same region in the right hemisphere, due to an effect of interhemispheric mediation, which would result in an improvement of the inhibitory control capacity. By contrast, Cosmo et al. (2015) observed that atDCS of the left DLPFC, where the cathode was placed over the respective area of the right hemisphere, did not produce significant improvements in the inhibitory control capacity, also using a sample composed by adult patients with ADHD diagnosis. Rubia (2018) proposed that these results could be explained because left DLPFC is an area that does not seem to be involved in the inhibitory control, unlike right DLPFC, which would have that function. Besides the positive effects that seem to have on inhibitory control, (Brunoni et al., 2012) point out some other aspects that make tDCS attractive for clinical research: there is a well-documented theoretical clinical basis that places tDCS as a possible substitute treatment of pharmacotherapy, which could be something to consider in those patients with a low tolerance to the some drugs or in those where prescribed drugs interact between them; tDCS can be used as an augmentative treatment and the low costs of the tDCS make it attractive in localities with lack resources.

Even though medication has shown its effectiveness improving ADHD symptoms, some studies have found several limitations (Fredriksen, Halmøy, Faraone, & Haavik, 2013; Spencer et al., 2006) including that 1) the gains last as long as the drug is taken, 2) is not effective in among a 30% of the children, 3) may produce some side effects, 4) long term effects are not well established yet and 5) so many people refuse to take it, because the drug is an amphetamine derivate. Those are some of the main reasons why non-pharmacological alternatives have been investigated, such as neurofeedback and, recently, tDCS. Nevertheless, tDCS is a relatively new technique with disparate results, probably due to methodological problems and the lack of available standardized protocols. Therefore, it might be helpful to increase tDCS research to analyze its effectiveness, possible side effects and to develop unified intervention protocols. Moreover, regarding attention and executive functioning is essential establish the role played by the different involved structures and related factors, in order to design better treatments. Attending to all of these aspects, we have decided to divide the present work in two related studies.

The aim of the first study was to find if the atDCS applied over the right DLPFC in young healthy adults could enhance some of the three attentional networks described in the Posnerian theory (Posner & Petersen, 1990) or some of the different areas that are usually affected in ADHD (vigilance, sustained attention, inattention or impulsivity). Our hypothesis was that compared to the sham condition, those individuals who would have received real atDCS over the right DLPFC, were going to improve executive attention network functioning due to the targeted area is associated with inhibitory control.

Relative to the second study, the primary objective was to analyze the relationship of two dimensions related with the attentional functioning, such as MW and SCT, with some psychopathological symptoms. We hypothesized that we were going to find positive correlations between MW and SCT, as well as with the emotional related psychopathological dimensions (anxiety, depression, obsessive or repetitive thoughts and dissociation), even in a community sample.

Methodology

Participants and recruitment

As regards the ***first study***, the target population were young adults with ages between 18 and 39 years. Individuals that were diagnosed by chronic pain, a major psychiatric disorder, alcohol abuse or who had consumed psychoactive substances in the previous 6 months were excluded from the study. Furthermore, exclusion criteria also included individuals with epilepsy, neurological impairment and/or with tDCS contraindications such as metallic head implants or an implanted medical device. Recruitment consisted in the spreading of an announcement that indicated how to participate in the tDCS study through social networks, such as Whats App, Facebook and Instagram. Fifteen individuals were interested in participating in the tDCS study, but finally four of them refused it for personal reasons, and another one was excluded because he was experiencing severe cervical pain due to a traffic accident. Finally, the sample included ten healthy participants between 22-32 years (mean age 25.71 ± 2.83), which were proportionally and randomly distributed among the active (n = 5; 2 females, 3 males) and sham (n = 5; 2 females, 3 males) tDCS groups. Although participants did not know to which group they were assigned, the investigator knew to which condition each one belonged, so this was a single blind study.

In the ***second study***, the target population were also young adults with ages between 18 and 39 years. Only participants whose ages were above or below the established age limits were excluded. The sample included forty-three people between 21-32 years (mean age 25.44 ± 2.26; 25 females, 18 males).

In both studies, the sample was mainly composed by college students of the University of the Balearic Islands (UIB).

Ethics statements

This study is part of the research project nºIB 3681/18 PI, which has been registered with the code PSI2017-88388-C4-1-R, by IUNICS principal researcher Pedro Montoya Jiménez, of the UIB. This project has been approved by the Research Ethics Committee of the Balearic Islands, receiving the necessary quality and safety guarantees to be carried out.

Following the guidelines for human medical research, provided in the declaration of Helsinki (Carlson, Boyd, & Webb, 2004), each participant of the tDCS study received a copy with the followed protocol and the informed consent, which they should read and sign if they were going to participate.

Procedure

As regards the ***first study***, during the active or sham tDCS session, the participants remained without doing any task, sited on a chair inside a quiet room while the investigator who applied the tDCS was supervising the process. Participants of both groups performed ANT and CPT-3 tasks before and after the session. When the session ended, all the participants answered a questionnaire about possible noticed sensations or side effects.

Regarding the ***second study***, a Google Docs formulary that contained three tests and a few questions to asses some sociodemographic variables, was distributed through social networks, such as Whats App, Facebook and Instagram. The ten participants of the tDCS study also answered the formulary.

Cognitive tasks

Attention Network Task (ANT). ANT is a computerized task based on the theoretical model presented by Posner & Petersen (1990) that it was designed by Fan, McCandliss, Sommer, Raz, & Posner, (2002) to evaluate the three attention networks in children and adults: alertness, orientating and executive control. In the present study it has been used the child version adapted by Rueda et al., (2004), where arrows were replaced by fishes and visual feedback by auditory feedback. The test is divided into 3 blocks of 5 minutes. During the task, series of visual stimuli appears in each trial, consisting of one or five yellow fishes situated against a blue background that may point left or right. Participants must determine where middle target fish points and then press as quickly as they can the “S” button if it points to the left and the “L” button if it points to the right. After each answer, participants receive auditory feedback, listening to a joyful sound if it is correct and a noisy beep if it is incorrect. While the test is performed, a cross occupies the center of the screen, representing the fixation point, so the central fish may appear above or below it (see Figure 1.b).

Central fish may or may not be surrounded by two more flanker fishes on both sides. Hence, there are three kinds of conditions: in the “neutral” condition, middle target fish is presented in an isolated way, without being surrounded by any flanker; “congruent” condition is when central target fish is surrounded by two flankers on each side which points at the same direction; and by contrast in the “incongruent” condition the four flanker fishes points the opposite direction of the central fish (see Figure 1.a).

Moreover, each trial may or may not be preceded by four different types of cue warning conditions, which are represented by asterisks: “no cue” (NC) condition, in which none asterisk precedes the trial; “center cue” (CC), in which an asterisk appears on the fixation point location just before a trial without providing information about where the target will appear; “double cue” (DC) when appears an asterisk above and below the central cross, and as in the previous case, it warns that a trial is above to start without offering any kind of information about the location of the target; and “spatial cue” (SC) where asterisk may appear above or below the fixation point, indicating the exactly position where the central target fish will be situated (see Figure 1.c).

To obtain the representative scores for each of the three attentional networks, we have calculated the mean of the RT median values for the different conditions. Higher scores reflect a worse efficiency of its performance (Forns et al., 2014). The subtractions to calculate each one of the attentional network efficiency scores are included in the Figure 1.d.

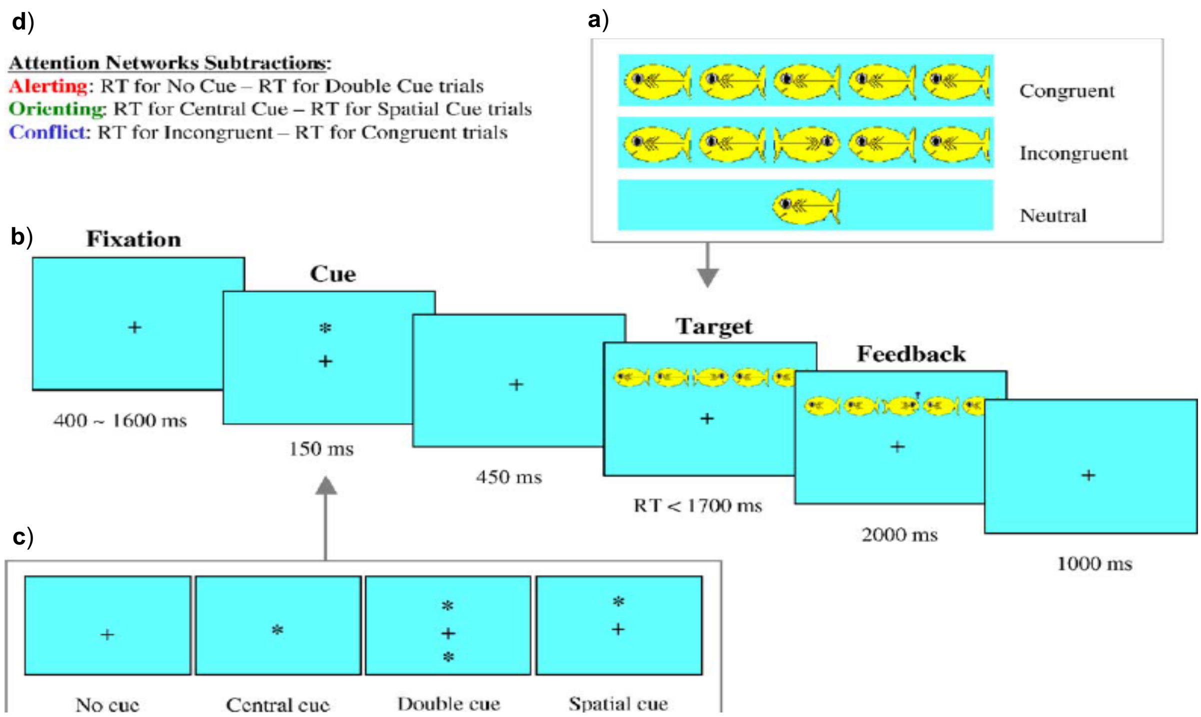

Figure 1. Description of ANT children version. The figure includes three of the six possible target conditions (the three remaining possibilities would be inversely disposed) (**a**), an example with the procedure of a trial (**b**), the four possible cue conditions (**c**) and the formulas to calculate the scores of the three attention networks (**d**).

Conners Continuous Performance Test (CPT-3). Continuous Performance Test was originally developed by Mackworth & Taylor (1963) to evaluate vigilance performance in radar operators. Subsequently was adapted to multiple versions to be applied to look for attention deficits. Nowadays is a widely used research and clinical tool, specially applied to diagnose ADHD. In the present study we used CPT-3 version of Conners (1994), where participants must respond pressing the space button to all the letters presented except the letter X, during an uninterrupted period of 15 minutes of duration. CPT-3 task allows assess attention related variables obtaining its representative functioning scores. A description of the analyzed measures is provided below in the **Table 1**.

Table 1

CPT-3 measures and definitions

Measure	Description
C response style (C_R)	C response style, based on the age of the subject.
HITS_R	Direct score of correct answers.
d'index (DPR_R)	Detectability attentional capacity index (d'), measures the ability to distinguish targets from non-targets.
Omissions (OMI_R)	Percentage of omissions is obtained from the failure to respond to targets
Commissions (COM_R)	Percentage of commissions is extracted from the number of responses to non-targets
Perseverations (PRS_R)	Percentage of perseverations refers to random or anticipatory responses.
Hit Reaction Time (HRT_R)	Mean RT of correct responses.
HRT Standard Deviation (HRTSD_nolog)	RT standard deviation of the hits.
Variability (VAR_nolog)	Intra-participant variability.
HRT Block Change (BLKCH_nolog)	Gradient of RT changing through the 6 blocks of the test.
HRT Interstimular interval Change (ISICH_nolog)	Gradient of RT changing as a function of the 3 interestimular intervals (1, 2 and 4 sec.).

Formulary

With the aim to obtain information about how some attentional and psychopathological variables were related in a young adult sample, a formulary was distributed through the Google Docs platform, which was divided in three parts. In the first one appeared an explanation of the study and how participants have to proceed. Each participant had to enter an invented 6-digit code to guarantee their anonymity. The second part contained some sociodemographic general questions about educational level, employment status, physical and psychological state, consumption of substances and drugs and the presence of stressors during the last 6 months. In the last part, there were three questionnaires, which are described below.

Mind Excessively Wandering Scale (MEWS). MEWS is a self-report scale initially developed to assess MW phenomenon in ADHD adults (Mowlem et al., 2019). This original measure contains 15 items that reflects the frequency of three conditions of this mental state: continuous thoughts, thoughts that changes from one topic to another and simultaneous lines of thoughts. Following Mowlem et al., (2019) recommendations for future research of this measure, we used the reduced 12-items scale, because they found that we could exclude three items without affecting its sensitivity of .89 or specificity of .90.

Adult Concentration Inventory (ACI). ACI is a 10-item self-reported measure, which was developed with the aim of asses 13 features identified as constitutive of the SCT factor (Becker et al., 2018).

DSM-5 Self-Rated Level 1 Cross-Cutting Symptom Measure — Adult (CCSM). This questionnaire is the adult version of a self-reported screening scale, which contains 23 items, used to evaluate 13 mental health or psychiatric domains, including depression, anger, mania, anxiety, somatic symptoms, suicidal ideation, psychosis, sleep problems, memory, repetitive thoughts and behaviours, dissociation, personality functioning and substance use. Each item inquires about how much or often each symptom interfered in the person's functioning during the last 2 weeks(American Psychiatric Association, 2013).

tDCS session

To allocate the electrodes on the scalp, the guidelines established by the International EEG Twenty System were followed. Therefore, the assembly consisted in introduce the electrodes inside two 5 x 7 sponges moistened with a saline fluid to reduce the impedance and subsequently place the anode over the F3 position and cathode over the F4, which correspond to the left and right DLPFC locations respectively (DaSilva, Volz, Bikson, & Fregni, 2011). To hold the electrodes, we used an elastic belt. Participants of tDCS group received an atDCS single session of 20 minutes over the right DLPFC, delivered at 2 mA of intensity, with a fade in and a fade out that lasted 30 seconds. In the case of the sham group, the process was exactly the same, excepting that when the fade in ended, we turned off the device without participants noticed it.

Statistical analysis

To proceed with the statistical analysis, we have used the *Statistical Package for the Social Sciences* (SPSS) software.

Regarding the ***first study,*** we analysed if the sample followed the patterns of a normal distribution, through the Kolmogórov-Smirnov test, for all the attentional variables in both groups, for the pre-intervention, post-intervention, changing, and intra-group punctuations. Since the null hypothesis was rejected for the most part of CPT-3 and ANT measures, we conducted a nonparametric analysis, obtaining the level of signification using the Mann-Whitney U test for the inter-group punctuations and Wilcoxon test for intra-group punctuations. Moreover, due to the reduced size of the sample (n=10), the information provided by the level of significance was insufficient. For that reason, it was considered appropriate to use the formula proposed by Fritz, Morris, & Richler (2011), to estimate effect sizes using nonparametric statistical tests, such as the Mann–Whitney and the Wilcoxon tests.

$$r = \frac{z}{\sqrt{n}}$$

ANT scores of one of the participants have been excluded from the analysis, because it has been a problem with the understanding of the instructions that caused an alteration of the values.

In the ***second study***, our purpose was to obtain the correlation coefficient between the ACI, MEWS and CCSM, using the non-parametric test of Sepearman. We also estimated the Z scores, p values and effect sizes (r) of the measures, between the female and male samples. To calculate the effect size scores we used the formula recommended by Fritz et al., (2011) for nonparametric analysis.

Results

Study 1

We analyzed if there were differences between active tDCS and sham groups regarding the scores of change (pre-intervention minus post-intervention scores). Result tables for both CPT-3 (Table 2) and ANT (Table 3) displays the obtained means (M), standard deviations (SD), Z values, p-value and effect sizes (r), on each measure.

Group comparisons of the scores of change on all the CPT-3 measures are displayed below, in the **Table 2**.

Table 2

Active and sham tDCS effects on the pre-post differences of the CPT-3 measures

	tDCS *M (SD)*	Sham *M (SD)*	*Z*	*p*	*r*
C_R	-0.12 (0.26)	-0.05 (0.15)	-0.42	.675	0.13
HITS_R	0.40 (2.30)	-0.40 (1.14)	-0.43	.669	0.14
DPR_R	0.34 (0.42)	0.29 (0.23)	-0.21	.834	0.07
OMI_R	-0.21 (0.53)	0.14 (0.40)	-0.98	.329	0.31
COM_R	11.11 (9.00)	5.56 (4.28)	-1.28	.202	0.40
PRS_R	0.06 (0.30)	0.06 (0.12)	-0.39	.700	0.12
HRT_R	-22.24 (21.50)	-26.33 (15.54)	-0.10	.917	0.03
HRTSD_nolog	8.52 (45.53)	-6.83 (13.96)	-0.31	.754	0.10
VAR_nolog	11.96 (43.55)	-1.79 (6.27)	-0.10	.917	0.03
BLKCH_nolog	-5.14 (1.83)	0.97 (5.58)	-1.98	**.047***	0.63
ISICH_nolog	3.97 (7.34)	2.77 (14.80)	-0.10	.917	0.03

Note. Measures of change have been calculated subtracting pre vales to the post values (*post – pre*). C_R = C response style; HITS_R = number of correct responses; DPR_R = d' index; OMI_R = percentage of omissions; COM_R = percentage of commissions; PRS_R = percentage of perseverations; HRT_R = Hit Reaction Time; HRTSD_nolog = HRT Standard Deviation; VAR_nolog = intra-participant variability; BLKCH_nolog = HRT Block Change; ISICH_nolog = HRT ISI Change.

*. p< .05 (bilateral).

Results indicated that the two groups did not differ in the majority of the factors. Uniquely those participants who received active tDCS showed a large and significant reduction in the variability of block change RT. tDCS group, decreased omission and increased commissions moderately, despite those differences were not significant compared to sham group.

As regards intra-group differences, both tDCS and sham groups participants revealed a significant and moderated reduction in the RT for the correct responses (Z = -2.02, p = .043, r = 0.64) (see **Table A1** and **Table A2** of the annexes).

Group comparisons of the scores of change on all the ANT measures are displayed below, in the **Table 3**.

Table 3

Active and sham tDCS effects on the pre-post differences of the ANT measures

	tDCS *M (SD)*	Sham *M (SD)*	*Z*	*p*	*r*
Alerting	25.50 (11.27)	7.40 (19.19)	-1.72	.085	0.57
Orientating	4.75 (16.76)	-3.60 (19.56)	-0.74	.462	0.25
Executive	-6.50 (15.72)	12.80 (16.56)	-1.47	.142	0.49

According to the results obtained for the three attentional networks, there were not significant differences between the active tDCS and sham groups, in the scores of change obtained after the session of stimulation. Despite this, we obtained large higher values of change after stimulation in the tDCS condition respecting the sham condition for the alerting network. As regards the orientating network efficiency, statistical analysis revealed small differences among the two groups, where the scores of changes followed a growing trend in the tDCS condition, whereas the sham group shows a decreasing tendency. Finally, for the executive network efficiency, differences were moderate but nearly large.

Specifically, attending the directionality of the changes observed in the executive network, tDCS group showed a small reduction after stimulation (Z = -0.37, p = .715, r = 0.12), while in the case of the sham group, after the session, scores experimented a large growing tendency (Z = -1.75, p = .080, r = 0.58) (see **Table A3** and **Table A4** of the annexes).

Study 2

The correlation indexes (r) between the ACI, MEWS and CCSM scores have been included in the **Table 4**.

Table 4

Correlations among the total scores of the different scales

	ACI	MEWS	CCSM
ACI	-	-	-
MEWS	**.66****	-	-
CCSM	**.46****	**.48****	

Note. ACI = Adult Concentration Inventory; MEWS = *Mind Excessively Wandering Scale*; CCSM = *DSM-5 Self-Rated Level 1 Cross-Cutting Symptom Measure — Adult.*
**. *p*< .01 (bilateral).

Spearman analysis indicates a significant and moderate level of correlation between ACI and MEWS, ACI and CCSM, as well as MEWS and CCSM.

Next, **Table 5** shows the correlation rates of ACI and MEWS with the different Level 1 of DSM-5 factors.

Table 5

Correlations between each factor of the CCSM with the total scores of ACI and MEWS measures

CCSM factors	ACI	MEWS
Depression	**.37***	**.40****
Rage	.25	.29
Mania	.14	**.34***
Anxiety	**.37***	**.54****
Somatic symptoms	.14	.11
Suicidal ideation	.23	.20
Psychosis	.21	.25
Sleep problems	**.41****	**.34***
Memory	**.45****	**.39***
Obsessive patterns	**.53****	**.43****
Dissociation	**.55****	**.55****
Personality functioning	**.58****	**.49****
Substance use	.21	**.37***

Note. ACI = Adult Concentration Inventory; MEWS = *Mind Excessively Wandering Scale;* CCSM = *DSM-5 Self-Rated Level 1 Cross-Cutting Symptom Measure — Adult.*
*. p< .05 (bilateral).
*. p< .01 (bilateral).

Specifically, we found that ACI and MEWS showed similar correlations with the majority of the CCSM factors. Both measures coincided displaying significant and moderate correlations with the same seven CCSM factors. Additionally, MEWS was moderately correlated with substance use and mania. Moreover, the means of the significant correlations were similar: r = .46 for ACI and r = .43 for MEWS.

On the **Table 6** are presented ACI, MEWS and CCSM scores, separated by gender.

Table 6

Gender differences for each scale

	Female	Male	Z	p	r
ACI	8.64 (6.41)	17.56 (11.07)	-2.66	**0.008****	0.41
MEWS	6.76 (5.93)	14.44 (11.10)	-2.31	**0.021****	0.35
CCSM	13.40 (7.44)	24.00 (20.34)	-1.55	0.120	0.24

Note. ACI = Adult Concentration Inventory; MEWS = *Mind Excessively Wandering Scale*; CCSM = *DSM-5 Self-Rated Level 1 Cross-Cutting Symptom Measure — Adult.*
*. p<.05 (bilateral).
**. p<.01(bilateral).

According to the gender variable, men scores were significantly higher than the women ones, with a moderate size effect for both ACI and MEWS.

Discussion and conclusions

Study 1

The aim of this study was to determinate if right DLPFC was involved in the functioning of some attentional variables, focusing on the inhibitory control which, as it has been found its correct development is necessary to a good performance of other cognitive areas. Despite that for the CPT-3 HRT scores showed a large significant reduction after the session, we cannot attribute these results to the stimulation effects, since they are present in both active and sham tDCS group. Nevertheless, uniquely participants who belonged to the active tDCS group showed a large significant reduction in mean response speed across blocks. This fact could reflect a better efficiency when a task progresses, indicating an increase of sustained attention.

As regards ANT, results were not significant in any of the cases. Despite this, effect size analysis revealed that alerting and orienting networks, impaired its performance in the active tDCS group. The impairment of the alerting network was also observed in the sham group, although it was lower than for the active tDCS condition, whereas the orientating network displayed a small improvement. However, contrary to our initial hypothesis, active tDCS group did not improve executive network efficiency. Even so, their performance did not get worse and remained relatively stable, while participants of the sham condition showed higher values after the session, indicating a worsening performance. A possible explanation could be that while executive network decreased its efficiency due to the effect of the fatigue in the sham group, the atDCS over the right DLPFC prevented this effect, maintaining its correct functioning. Other studies have found improvements in inhibitory control after a single session of atDCS on the right DLPFC or ctDCS on the left DLPFC in ADHD samples (Rubia, 2018; Soltaninejad et al., 2015). While they found more significant differences, the use of a healthy sample might have limited the scope of our results.

Study 2

In the line of our hypothesis, the obtained results have provided evidences that MW and the SCT are related factors, as some authors supposed. Barkley (2014) proposed that SCT might be a pathological form of MW, but both dimensions were similarly associated with the presence of psychopathology.

More specifically, as we predicted, MW was moderately associated with the measures of anxiety, dissociation, depression, mania, sleep problems, obsessive patterns, substance use, memory problems and personality functioning. This is congruent with the findings of Deng et al., (2014), where MW was positively correlated with depression.

Regarding SCT, our results were consistent with previous research. As Becker & Langberg (2013) we found that SCT was associated with internalizing symptoms, such as dissociative symptoms, obsessive patterns, depression and anxiety. Moreover, high SCT scores were significantly related with problems in personality functioning, memory and to sleep. Saxbe & Barkley (2014) hypothesized about the possibility to link the cognitive symptoms of SCT with the sleep problems that are usually present, as hypersomnia.

This fact provides more evidence that some disorders or dysfunctional patterns are associated with attentional deficits, as literature has found for depression (Gotlib & Joormann, 2010; Lonigan & Vasey, 2009), anxiety (Armstrong & Olatunji, 2012; Lonigan & Vasey, 2009) eating disorders (Dobson & Dozois, 2004) or chronic pain (Crombez, Van Ryckeghem, Eccleston, & Van Damme, 2013; Todd, van Ryckeghem, Sharpe, & Crombez, 2018). This could help to develop more specific and adequate treatments for all of this and other disorders, with the aim to achieve great improvements, both functional and cognitive level. It might be interesting to examine whether tDCS has any effect on MW or SCT.

In contrast to Barkley (2013) who did not find significant gender differences in SCT scores or other studies which found that were higher in women (Becker et al., 2018), our results showed that men were more likely to experience SCT symptoms. In the same way, we found men scored significantly higher in MW compared to women group, while in the Burdett, Charlton, & Starkey (2016) study there was no difference in reported MW between men and women.

Limitations and future directions

Obtained results should be treated with caution, since studies present some limitations. The most remarkable aspect is the reduced size of the sample, which is detrimental for the statistical analysis of the data, in both studies. In the same way, in the first study would have been recommendable to crossover the sample so that all participants go through both experimental conditions, but due to the availability difficulties that some of them had, to return twice to the laboratory, we decided to distribute them in two groups and perform a single session. Regarding characteristics of the participants, the fact that we have used a healthy sample, could explain why the improvements have been reduced or even null for the most measures. Perhaps, if their attentional networks work properly, it was difficult to expect an improvement after an anodal tDCS session, which technically promotes an increase of the excitatory potential of the stimulated area and, therefore, a better performance of the associated functions. However, we decided to use this kind of sample to increase external validity, attending that attentional dysfunctions are widely extended among a considerable heterogeneity of disorders. Another limitation is that we conducted a single blind study, when it would have been preferable if the researcher would also have ignored the condition to which each participant belonged, but it was not possible because of the tDCS device did not dispose of that option. One last considerable aspect is that the size of the electrodes was too big, so it cannot be assured that only the target area was being stimulated.

According to Rubia (2018), the amount of available studies testing tDCS as a tool aimed to enhance cognitive deficits is limited. That is why further high-quality studies, avoiding the limitations of the present one, are still being necessary to establish the efficacy of the tDCS to improve attention, as well as to assess the role of right DLPFC in inhibitory control. These investigations could have a good impact for those who suffer any disorder characterized by attentional deficits and offer a non-pharmacological therapeutic alternative. Furthermore, other studies could analyse the possible benefits of tDCS on the dimensions of MW and SCT.

Conflict of interest

The author confirm that this master’s thesis content has no conflict of interest.

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Annexes

Table A1

Pre-post analysis of the CPT-3 measures for the active tDCS group

	Pre M (SD)	Post M (SD)	*Z*	*p*	*r*
C_R	-0.95 (0.31)	-1.07 (0.32)	-0.73	.465	0.23
HITS_R	286.60 (2.19)	287.00 (0.71)	-0.18	.854	0.06
DPR_R	-3.39 (0.87)	-3.05 (1.00)	-1.46	.144	0.46
OMI_R	0.42 (0.62)	0.21 (0.19)	-0.82	.414	0.26
COM_R	26.11 (15.26)	37.22 (22.38)	-1.84	.066	0.58
PRS_R	0.06 (0.12)	0.11 (0.25)	-0.45	.655	0.14
HRT_R	408.03 (21.63)	385.80 (40.08)	-2.02	**.043***	0.64
HRTSD_nolog	75.08 (13.23)	83.60 (47.52)	-0.41	.686	0.13
VAR_nolog	24.32 (8.79)	36.27 (46.28)	-0.41	.686	0.13
BLKCH_nolog	3.21 (3.11)	-1.93 (2.57)	-2.02	**.043***	0.64
ISICH_nolog	7.59 (11.05)	11.56 (9.18)	-0.94	.345	0.30

Note. C_R = C response style; HITS_R = number of correct responses; DPR_R = d' index; OMI_R = percentage of omissions; COM_R = percentage of commissions; PRS_R = percentage of perseverations; HRT_R = Hit Reaction Time; HRTSD_nolog = HRT Standard Deviation; VAR_nolog = intra-participant variability; BLKCH_nolog = HRT Block Change; ISICH_nolog = HRT ISI Change.

*. p< .05 (bilateral).

Table A2

Pre-post analysis of the CPT-3 measures for the sham tDCS group

	Pre M (SD)	Post M (SD)	*Z*	*p*	*r*
C_R	-0.88 (0.20)	-0.93 (0.29)	-0.73	.465	0.23
HITS_R	287.40 (0.89)	287.00 (1.22)	-0.82	.414	0.26
DPR_R	-3.73 (0.89)	-3.44 (0.92)	-1.83	.068	0.58
OMI_R	0.14 (0.19)	0.28 (0.45)	-0.82	.414	0.26
COM_R	19.44 (17.62)	25.00 (21.38)	-1.84	.066	0.58
PRS_R	0.06 (0.12)	0.11 (0.25)	-1.00	.317	0.32
HRT_R	408.16 (60.90)	381.83 (60.52)	-2.02	**.043***	0.64
HRTSD_nolog	69.93 (11.32)	63.10 (17.44)	-1.21	.225	0.38
VAR_nolog	19.51 (2.19)	17.72 (4.4)	-0.14	.893	0.04
BLKCH_nolog	0.2 (2.5)	1.17 (5.48)	-0.41	.686	0.13
ISICH_nolog	13.60 (4.35)	16.37 (10.80)	-0.14	.893	0.04

Note. C_R = C response style; HITS_R = number of correct responses; DPR_R = d' index; OMI_R = percentage of omissions; COM_R = percentage of commissions; PRS_R = percentage of perseverations; HRT_R = Hit Reaction Time; HRTSD_nolog = HRT Standard Deviation; VAR_nolog = intra-participant variability; BLKCH_nolog = HRT Block Change; ISICH_nolog = HRT ISI Change.

*. p< .05 (bilateral).

Table A3

Pre-post analysis of the ANT measures for the active tDCS condition.

	Pre *M (SD)*	Post *M (SD)*	*Z*	*p*	*r*
Alerting	25.25 (19.10)	50.75 (16.01)	-1.83	.068	0.61
Orientating	13.00 (9.63)	17.50 (15.84)	-0.73	.465	0.24
Executive	27.00 (11.97)	20.75 (23.81)	-0.37	.715	0.12

Table A4

Pre-post analysis of the ANT measures for the sham tDCS condition

	Pre *M (SD)*	Post *M (SD)*	*Z*	*p*	*r*
Alerting	48.00 (30.17)	55.60 (18.45)	-0.94	.345	0.31
Orientating	29.60 (16.94)	26.20 (16.13)	-0.41	.686	0.14
Executive	35.60 (11.78)	48.60 (17.42)	-1.75	.080	0.58