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The Effect of Forehead Cortex Electric Current Stimulation on Inhibitory Control and Working Memory in Children with Attention Deficit and Hyperactivity Disorder

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Abstract

This study aimed at determining the effect of forehead cortex electric current stimulation on inhibitory control and working memory in people with attention deficit and hyperactivity disorder (ADHD), using TDCS device. The method used was quasi-experimental research with pretest-posttest control group design. The participants were 24 children with attention deficit and hyperactivity disorder aged 7-11 who referred to Baqiyatallah Hospital in 1397. Children were randomly divided into experimental (n = 12) and control (n = 12) groups. The experimental group was intervened in 10 sessions, 3 times a week, and each session was 20 minutes. Assessments were performed in 3 steps, a day before the intervention, and a day after the intervention ended, and finally at the follow-up phase, two months after the intervention was accomplished. Go/no Go and N-back tests were used to evaluate inhibitory control and working memory, respectively. A repeated measurement method was applied to analyze the data. Findings revealed that brain electric stimulation program improves working memory and inhibitory control in children with attention deficit hyperactivity disorder. Therefore, brain electric stimulation program can be used to enhance the working memory and inhibitory control of children with attention deficit hyperactivity disorder.

Keywords: Attention deficit and hyperactivity disorder, brain electrical stimulation, forehead cortex, inhibitory control, working memory

Introduction

Having at least one child inflicted with attention deficit hyperactive disorder in each class has led this disorder to be classified as one of the most commonly occurring behavioral disorders. Attention deficit hyperactive disorder is one of the most rampant disorders of childhood, affecting almost 5% of students in different countries of the world (Richa et al., 2014). Attention deficit hyperactive disorder is a nervous-psychiatric disorder which is abundant among childhood disorders and known mostly with problems of negligence, hyperactivity and attention deficit (American Psychological Association, 2000). Attention deficit hyperactive disorder is a common behavioral disorder that now affects 3 to 5 percent of the world's children (American Psychological Association, 1994; quoted by Nejati, 2012). In Iran, the prevalence of attention deficit hyperactive disorder has been reported differently from 2.7 to 12.3 (Salehi et al., 2011). These children persistently exhibit high levels of negligence, impulsivity, and hyperactivity, which are not commensurate with their evolutionary step. Coupled with, they have difficulty with curbing their actions in situations where they are asked to sit quietly or concentrate on their assignments (Alipour et al., 2013). This disorder often hurts the function of a person in a

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variety of fields such as education, attention and concentration, social communication and cognitive domains, including executive functions (Nelson & Israel, 2003). Once, it was thought that the disorder is extirpated with puberty, but long-term studies challenged this belief. Clinical manifestations of this disorder may change during an individual's development. But, at least half of the children with hyperactivity attention deficit disorder as adults have a permanent functional disorder. Since this disorder is a heterogeneous one (Nigg, Willcut, Doyle & Sounga-Barke, 2005), experts do not agree on the primary cause of the disorder. Hence, new etiology models emphasize the interaction of genetic, biomedical, environmental, psychosocial and chemical nerve factors (Castellanos, 1997).

In recent years, experts have come up with miscellaneous influential fields in relation to these people; most studies have shown that the disorder is associated with problems such as abnormalities of brain waves, motor, social, emotional and behavioral drawbacks; all of these problems can have adverse effects on areas such as attention and concentration, executive functions and, consequently, the well-being of these individuals (Hackel, Heckel, Barry, McCarthy & Selikowitz, 2009). Also, working memory plays an important role in this regard, as well as a common ground between these two cognitive functions exists (Bobova et al. 2009). Since consideration of the past and future assessment and prediction are interconnected, we may be able to reduce the rate of delayed effect of individual rewards in the future by increasing one's ability to remind past events and reinforcing memory, and consequently mitigate risky decisions in impulsive individuals (Bickel et al., 2011). Problems with working memory are presumably the result of a large number of disturbances in various processes, and different developmental disabilities may be caused by a failure in a variety of working memory categories (Zelazo & Mueller, 2002) .

In addition to working memory, another psychological skill that children with hyperactivity and attention deficit are mattering to is inhibitory control. Inhibitory control refers to the ability to alter behavior in order to adapt to changes and demands of the environment. Inhibitory control is conceptualized broadly and has various forms of inhibition in the perceptual/attention, cognitive and movement domains (Nejati & Shiri, 2013).

Given the current state of life, promoting working memory and inhibitory control for people who are not severely disrupted is also very helpful. Endeavors to enhance these functions had long been a pragmatic goal of researches, which have benefited methods such as behavioral training, neurofeedback, etc., (Fioravante Capone et al., 2014). Considering that a wide range of cognitive and therapeutic researches have investigated the effectiveness of various therapies such as medication (Biederman, Spencer & Wilens, 2004), behavioral therapy (Pelham & Fabiano, 2008), and cognitive-behavioral therapy (Hinshaw, 2006) neurofeedback therapy (Zoefel, Huster & Herman, 2011) have addressed the improvement of mentioned disorder's symptoms. Direct electric stimulation from the skull is one of these neurological therapies that imposes a current directly or weakly into cortical regions and facilitates or inhibits self-stimulated neural activity (Brunoni et al., 2012). Direct brain electric stimulation has been widely tested over the past decade and is a non-invasive, inexpensive, and safe alternative to changing the irritability of cerebral cortex, which acts by altering the resting potential of cerebral cortical's neural cells. This weak and direct current through the connection of two electrodes with opposite poles usually consisting of an anode and a cathode at different points on the surface of the skull stimulates the lower neurons. The cathode stimulation reduces the brain's irritability, while the stimulation of an anode and a cathode at different points on the skull surface leads to irritation of lower neurons. Cathode stimulation appeases brain's irritability, whereas anode stimulation increases brain's irritability (DaSilva et al., 2011). In transcranial Direct Current Stimulation (tDCS), the position of the electrodes is very important. Studies in this area indicate the effects of inhibition and facilitation.

Due to umpteen problems of attention deficit hyperactivity disorder and its underlying causes, namely defects in the forehead and brain's neurotransmitters, cognitive rehabilitation as a non-pharmacological and psychological treatment method to improve the executive function of these individuals is underway. Among all, brain's electric stimulation through the skull using a device called tDCS dates back long. Although numerous cognitive rehabilitation programs have been used to strengthen cognitive functions of the brain, there is a shortage of research in this area and finding a method which can non-invasively make the human brain more productive requires more research. Therefore, this study sought to evaluate the effect of the cognitive rehabilitation program on brain electric stimulation through the skull using a tDCS device as an effective way to improve risky decision-making and impulsivity and working memory. Considering the importance of working memory and inhibitory control in the diurnal life of humans and heighten brain capacities, the core aim of the current study was to see how stimulating forehead cortical electric current affects inhibitory control and working memory in children with attention deficit hyperactivity disorder?

Method

This research, owing to its nature and purpose, was conducted based on quasi-experimental research of pre-test post-test control group design .

Participants

The statistical population included children with attention deficit hyperactivity disorder who had visited a psychiatrist in Baqiyatollah Hospital in spring and summer of 2018 and were exposed to medical treatment (Ritalin). Based on random sampling and exclusion and inclusion criteria, 24 patients were selected and randomly assigned into two groups of experiment and control. The criteria for entering the study were the diagnosis of attention deficit hyperactivity disorder by the psychiatrist, having a minimum age of 7 years old, lacking other disorders such as mental retardation, learning disorder, right-handedness and dearth of metal parts in the body. Study's exit criteria were reluctance to continue treatment, seizure experience and failure to follow up treatment sessions for more than two consecutive sessions. The procedure was followed by the participation of children in the study after having the disorder diagnosed by the psychiatrist, completing consent and Conners' forms by the parents. Samples were randomly divided into experimental and control groups .

Instruments

N-Back Test: This test is applied to evaluate working memory and is one of the most widely used culture-free tools. In this test, a number of visual stimuli appear sequentially on the computer screen, and the subject must press "1" key, if it is similar to the preceding one and "2" vice versa. In this assignment, the subject must remember only one stimulus (preceding step stimulus is intended). Additionally, while a new stimulus replaces the stimulus ahead of itself, updating to the rule of working memory is imperative. This assignment is designed such that at all steps people have to respond to all the stimuli. Therefore, this assignment requires continuous control and updating of information in working memory. In this test, a series of hundreds of linear images has been used. This test has a strong reputation and is now universally used in clinical and empirical studies and shown to be validated by several other tests assaying working memory (Kane, Conway, Miura & Colflesh, 2007). Reliability and validity of the test in Iran has been investigated by Hadianfard, Najarian, Shekarkan and Mehrabizadeh Honarmand. They have reported the coefficients of retest reliability for different parts of the test ranging from 0.59 to 0.93 (Nejati, Barzegar & Pourgaldooz, 2013).

Go-no Go Test: This task comprised one hundred (aircraft) stimuli that the person should have pressed same-direction cursor button on the computer keyboard by viewing every aircraft and after having beeb sound of the aircraft presented, the subject should have refuted to press the cursor key. In this test, the number of correct and incorrect answers given by the individual during the delivery of stimulus, motion without stop stimulus (Go step), and the average time between the correct and incorrect answers, the number of correct and incorrect answers given by the person when delivering motion stimulus with stop one (Go-no Go) as well as the average duration of these responses were measured. The coefficient of validity and re-test of this test was reported to be higher than 80% (Hopko, & Miehel, 2006, quoted by Safaryazdi & Nejati, 2012).

Procedure

Activadose device was used to run this research. Device's maximum current and voltage are 4 mA and 80 (DC), respectively. The device consists of two anode and cathode electrodes that are located on certain points of the scalp (on the skull). The size of the electrodes used was 5 × 5 cm and anodic and cathodic stimulation sites were F3 (external posterior cortex of the forehead) and FP2 regions, respectively. Both control and experimental groups received stimulation, the only difference was that the experimental group experienced factual anodic stimulation for 10 sessions, each session 20 minutes with one mA every other day, but the control group was at the same time under the device, but did not receive stimulation, and the device was only on as sham. The specimens first accomplished the test without stimulation (bogus stimulation or sham), and the tests were performed again after stimulation. After two months, the tests were repeated for follow-up period. As such, the required data was collected and analyzed using repeated measurements.

Findings

Participants included 24 children with attention deficit and hyperactivity disorder (ADHD) aged 7-11 years old who were divided into two groups of girls and boys who were matched for age and gender.

Table 1.

Descriptive Indexes of Response's Inhibitory Control and Short-Term Memory Scores by Group

Groups	Steps	Mean	Standard deviation	k-s	Sig
Experiment	Response inhibitory control pre-test	74.55	17.98	1.044	0.225
	Response inhibitory control post-test	95.29	6.68	1.186	0.120
	Response inhibitory control follow-up	95.98	5.73	0.905	0.385
	Short-term memory pre-test	81.58	7.52	0.886	0.441
	Short-term memory post-test	95.83	8.66	1.181	0.123
	Short-term memory follow-up	93.16	7.06	1.029	0.241
Control	Response inhibitory control pre-test	74	18.28	0.788	0.546
	Response inhibitory control post-test	67.24	19.65	0.586	0.882
	Response inhibitory control follow-up	60.70	16.73	0.687	0.733
	Working memory pre-test	81.25	7.12	0.819	0.514
	Working memory post-test	84.25	6.70	0.545	0.928
	Working memory follow-up	82.50	6.12	0.531	0.941

According to information of Table above, the distribution of the pre and post-test scores of the participants in the experimental and control groups in response inhibitory control and short-term memory variables- shows various indicators of central tendency and dispersion. The results of Kolmogorov-Smirnov's Normalization test demonstrated that the distribution of participants' scores in measured variables at all three steps is close to normal distribution, so repeated measurements usage is permitted.

Table 2.

Summary of Repeated Measurement Test to Measure the Effect of Forehead Cortex Electric Current Stimulation on Inhibitory Control

Tests	Values	F	Df	df	Sig	λ^2
Piley effect	0.641	8.941**	2	10	0.006	0.641
Lambda Wilks	0.359	8.941**	2	10	0.006	0.641
Hotling effect	1.788	8.941**	2	10	0.006	0.641
Roy's Largest Root	1.788	8.941**	2	10	0.006	0.641

According to the multivariate test value of Lambda Wilks (0.349), with a degree of freedom of 2 and 10 the average of the participants' scores in response inhibitory control variable is different at the same time in three measurements. The size effect of the difference is high with respect to the IATA squared (0.641). In sum, the amount of IATA squared (0.641) indicates an acceptable relation between transcranial direct current stimulation and response inhibitory control. As a result, forehead cortical electric current stimulation on inhibitory control increase of children with hyperactivity and attention deficit has an acceptable significant effect.

Table 3.

Repeated Measurement Test Summary to Measure the Effect of Forehead Cortex Electric Current Stimulation on Working Memory

Tests	Values	F	df	Df	Sig	λ^2
Piley effect	0.778	17.488**	2	10	0.001	0.778
Lambda Wilks	0.222	17.488**	2	10	0.001	0.778
Hotling effect	3.498	17.488**	2	10	0.001	0.778
Roy's Largest Root	3.498	17.488**	2	10	0.001	0.778

Considering the multivariate test value of Lambda Wilks (0.222) with 2 and 10 degrees of freedom, the average of participants' scores in short-term memory variable is different at the same time at three measurements. The size effect of the difference is high with respect to the IATA squared (0.641). Totally, the IATA squared (0.778) indicates an acceptable relation between transcranial direct current stimulation and short-term memory. As a result, stimulating the forehead cortex electric current stimulation has a sustainable significant effect on increasing the working memory of children with hyperactive and attention deficit disorder.

Discussion and Conclusion

This study aimed to determine the effect of forehead cortex electric current stimulation on inhibitory control and working memory in children with attention deficit hyperactivity disorder (ADHD). The first result of the study exhibited that there is a significant difference between the control and experimental groups in terms of post-test inhibitory control with pre-test control. Comparing the means showed that the mean of response's inhibitory control in post-test of the experimental group was higher than that of the control group. Also, the mean of participants' scores in response's control variable was different at three measurements, simultaneously. Overall, the amount of squared IATA (effect size) indicates an acceptable link between transcranial direct current stimulation and response's inhibitory control. Comparing the mean of the three steps suggested that the mean of inhibitory control score of experimental group response in the pre-test step was lower than that of post-test and follow-up ($p < 0.01$). Meanwhile, the mean of response's inhibitory control of post-test and follow-up was the same. This conclusion suggests that the effect of transcranial direct current stimulation on response inhibitory control in the follow-up phase is still maintained. Finally, according to the collected evidence, it can be concluded that transcranial direct current stimulation can increase response's inhibitory control. The findings are consistent with those of Gladwin et al. (2012), Pecchinenda et al. (2015), as well as Pong, Kongjing, Bailey and Sha (2012).

Pong, Kongjing, Bailey and Sha (2012), in their study found that children with dyscalculia disorder have a significant inhibitory defect compared with healthy children. The results of this analysis showed a significant difference in response's inhibitory control to the non-impaired group. In explaining these findings, it can be stated that inhibitory control is the response to the ability to think before acting. Children suffering from this function may be distracting and impulsive. They may add additional words to a statement (Nathan, 2009). This finding may be corroborating Barclay's (1997) attention control theory, which indicates a lack of behavioral inhibition and providing hesitation in automatic response allowing inhibitory control to guide behavior towards the target (Antshel, Hier & Barclay, 2014). Some other related studies, like the current study, have dealt with the effect of assaying inhibition using go/no go of cognitive rehabilitation on of inhibitory control in children with attention deficit hyperactivity disorder. Among the investigations, Najian and Nejati (2017) applied go/no go test to measure inhibition. Which their goals of their study was to investigate the effect of motion-based cognitive rehabilitation on improving the ability to inhibitory control of subjects. The results of the analysis showed that cognitive rehabilitation was effective in improving three indicators of the go/no go test, which is consistent with those being used in this study. Thus, it can be seen that the result of this study conforms to the findings of most similar and new studies on the effect of cognitive rehabilitation on impulsivity improvement in children with attention deficit hyperactivity disorder.

Concerning the study's second result, findings suggest that transcranial direct current stimulation of forehead external posterior cortex impacts working memory. Furthermore, the mean scores of participants in the short-term memory variable were coincidently different at three measurements. In sum, the IATA squared value represents an acceptable relation between transcranial direct current stimulation and short-term memory. Comparing three-step means indicated that the mean for experimental group's short-term memory in the pre-test was lower than that for post-test and follow-up scores ($p < 0.01$). Yet, average post-test and follow-up short-term memory was the same. This result shows that the effect of transcranial direct current stimulation on short-term memory in follow-up phase is still maintained. Considering the evidence gathered in this study, it can be concluded that transcranial direct current stimulation can increase short-term memory. Comparison of means unveils that the mean of short-term memory in post-test in the experimental group was higher than the control one. These findings comply with those of Anderberg et al. (2013) and Sakai et al. (2014). Saakai et al. (2014) have shown that DLPFC stimulation can increase continuous attention in vehicle control.

Roe et al. (2016) also claimed the same result and showed that stimulation of DLPFC due to cognitive load can increase visual attention. Najarzadegan et al. (2015), in a research on children with attention deficit hyperactivity disorder, replaced 30 children in two experimental and control groups and tried to improve their impulsivity using cognitive rehabilitation of working memory on the experimental group. The results of the study by covariance analysis revealed that the scores of the experimental group as a result of cognitive rehabilitation in the impulsivity decreased significantly. Of characteristics of this research, matching the experimental and control groups in terms of interventional variables such as age and rhetoric and practical intelligence was highlighted .

Reviewing the current research results clearly showed that they are consistent with the findings of the studies in the field of impulsivity. Working memory improvement induced by anodic DLPFC stimulation was observed in patients with Parkinson and depression diseases (Boggio et al., 2006). Qrouchi and Mameli (2008) stated that stimulating temporal region increased the memory performance of words recognition of Alzheimer's patients, but cathodic stimulation in this area caused a decrease in yield. Arkan et al. (2014) also showed that DLPFC stimulation promotes the memory of individuals. Researchers conducted are different from the area of stimulation and the type of memory being measured. The only nonconformist research with this study (amongst researches used anodic left DLPFC stimulation to examine working memory) is related to the work of Harvas et al. They benefited one-session stimulation and compared the difference between the stimulus and the sham groups. According to what discussed in the second chapter, ten 20-minute sessions will have a long-term impact. However, one-session stimulation may only be effective at due stimulation time or shortly thereafter. In explaining this finding, it can be said that active memory is one of the important cognitive processes that underlies thinking and learning. On the other hand, children with attention deficit hyperactivity disorder are easily distracted and their attention is transmitted to another stimulus in the environment. Since the attention bases the memory, the distraction, consequently, causes no attention to be maintained and memory classes are not formed (Pennington, 2008). The present point can be explained from a neurological point of view. According to this view, the functions of attention and working memory involve the common areas in the brain (Perfetti et al., 2009). Due to such close relationship, the difference in working memory performance was not unavoidable. In fact, the ability to focus, preservation and work with information in mind, filtering distracting agents, and policy change resemble managing an air traffic control system at a crowded airport with the arrival and departure of dozens of airplanes on multiple runways. In the brain, this air traffic control mechanism is called an executive function, which is actually a set of skills assisting individuals concentrate on the multiple streams of information receiving simultaneously and, if necessary, revising their program (Center Harvard University's Child Evolution, 2015) .

Ultimately, by summarizing the findings of this study and also considering similar studies in the field of the effectiveness of various rehabilitation on children with attention deficit hyperactivity disorder, we can conclude that the efficacy of transcranial direct current stimulation of forehead external posterior cortex, alongside other rehabilitation programs, including working memory, can have a positive effect on the inhibitory control in children with attention deficit hyperactivity disorder and improve these skills. Consequently, relying on extensive research conducted by psychologists and other researchers active in child-dependent fields on the effectiveness of transcranial direct current stimulation of forehead external posterior cortex, the results suggest current method as an effective, efficient and Low-cost treatment for the problems of children with hyperactivity (Odendal, 2010). The above-mentioned treatment has been successfully effective in most cases up to 80%. Further analysis suggests that if parents intervened with their treatment and education, much better results would be acquired (Brautin et al., 2005).

The limitations of this research were a small sample size enforced to use non-random sampling. It limits the ability to generalize research results, as well as the inability to control psychological and family variables. According to the findings and limitations of the research, it is recommended that a similar study be conducted within the framework of group methods to better extrapolate the results and to investigate the effect of possible interactions in multiple evaluations that can be more accurate and truer than the results of the test. It is also suggested that in future researches, in addition to abiding by matching individuals in terms of age, gender, family status (cultural and economic) and the type of drug consumed, to eschew the non-random selective constraints, the conditions and facilities for random sampling be provided.

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