The Effect of Transcranial Direct Current Stimulation on Working Memory and Depression in Mothers with Deaf Children

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Abstract

Introduction: Hearing loss is a common disorder in children. Out of every thousand children born, 2 to 3 of them are born with moderate to severe hearing loss for various reasons. This problem, regardless of culture and communities, increases the challenge and hardship in families. Over time, hearing loss leads to anxiety, depression, isolation and loneliness in these individuals and their families. If left untreated, hearing loss can become a psychological complication in in these individuals and their families. The aim of this study was to investigate the effect of Trans cranial Direct Current Stimulation on working memory and depression in mothers of Children with deafness. **Materials and Methods:** In this quasi-experimental study with pre-test and post-test, 40 mothers of Children with deafness in Yazd city were selected randomly. 20 mothers were in experimental and 20 mothers were in the control group. Beck Depression Inventory (1988) and working memory scores were compared by n-back test before and after treatment. In the control group, each patient received 10 sessions of dummy electrical stimulation (20 minutes) and in the experimental group received 10 sessions of simultaneous anodic and cathode stimulation (2 mA-20 minutes) in the left and right dorsal peripheral cortex, respectively. Data analysis was performed using analysis of covariance. **Results:** Data analysis showed that the scores of depression and working memory tests in mothers of children with deafness showed significantly improvement (P=0.01) compared with the control group with dummy electrical stimulation, respectively. **Conclusion:** According to the results of this study, it seems that direct electrical stimulation in the Dorsal Lateral Prefrontal Cortex increases the ability of working memory and improves depression in mothers of children with deafness and can be used in the rehabilitation program of these patients.

Keywords: Depressive Disorder; Hearing Loss; Transcranial Direct Current Stimulation (tDCS)

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Introduction

Hearing loss is a common disorder and out of every thousand children born, 2 to 3 of them are born with moderate to severe hearing impairment due to various reasons (1). This problem, regardless of culture and society, increases the challenge and difficulty in families (2), so that the diagnosis of hearing disorders during infancy is a challenge and a critical event with stress for the parents of these children (3, 4). In deaf people, the possibility of psychological disorders increases due to the inability to establish proper communication with others (5). Deafness leads to a decrease in the quality of life, isolation, reduction in activities of daily living and feelings of rejection, and due to these emotions, the possibility of marital discord and aggression in the parents of children with deafness increases (6). In addition to stress, the depression of parents of children with deafness can increase due to the presence of a disorder in their child. According to psychiatrists, a mother's depression during her child's childhood affects her social activities in the future and leads to depression disorders and a decrease in hope for her life in adulthood (7).

Working memory is a cognitive system with a limited capacity that is responsible for temporary storage of available information for processing. Working memory is often considered synonymous with short-term memory, but some theorists distinguish these two types of memory and believe

that working memory allows the manipulation of stored information, while short-term memory only it refers to the short-term storage of information (8). The estimate of working memory capacity is lower in adults than in young people (9). Parents of children with deafness have cognitive deficits in several areas, including working memory (10). Direct electrical stimulation from the skull for the treatment of major depressive disorder has been investigated in recent years. Current tDCS protocols generally use two flat electrodes, one called the anode and the other the cathode. A direct current of 1 or 2 mA is passed between two 35 cm2 (5 x 7 cm) electrodes placed on the head for about 20 minutes. The current flows from the anode to the cathode, some of it is transferred to the scalp and some of it passes through the brain, and depending on the direction and intensity of the current, it leads to an increase or decrease in cortical excitability. Anodic tDCS generally has an excitatory effect on the cerebral cortex by depolarizing nerves, while cathodic tDCS plays a role in the hyperpolarization process and has the opposite effect. In general, tDCS has very few side effects. A general statement on the efficacy of tDCS as a therapeutic tool in major depression appears premature. tDCS is considered a safe treatment option and is associated with only minor side effects. The effectiveness of tDCS decreases with treatment resistance. Psychoactive drugs may reduce or enhance its effects. Using a current of 2 mA for more than 20 minutes per day in a short period of time can be considered safe (11).

Today, the use of direct electrical stimulation of the brain in clinical research has increased from basic neuroscience research to the treatment of various neurological and psychiatric disorders, and all these studies have shown the positive effects of this treatment method in the treatment of psychiatric disorders. tDCS research suggests that doing more of this treatment and its repeatability can improve the level of effectiveness(12).

The studies showed that anodic tDCS in the motor cortex and frontal lobe of the brain of patients with major depression, which was performed for 20 minutes and at the rate of 1 to 2 milliamps, reported a significant improvement in the patients (11). Baumert *et al.* (12) a study showed in that working memory improved following electrical stimulation of the brain in healthy students.

One study evaluated the effect of direct electrical stimulation on the level of anxiety caused by negative thoughts after an accident. The results showed the possibility that anodic stimulation in the left hemisphere can reduce anxiety to some extent (13).

Considering the relatively high prevalence of hearing problems in children and the fact that there are many families with hearing problems and since all these families suffer from psychological problems, conducting studies that can reduce the problems of parents of Children with deafness can be valuable. On the other hand, since no study has investigated the effect of direct tDCS on working memory and depression of parents of Children with deafness, in this research we aim to investigate the effect of tDCS on working memory and depression in mothers of children with deafness.

Materials and methods

This study is a quasi-experimental study with pre-test and post-test. The statistical population included mothers of children with deafness referred to the rehabilitation clinics of Yazd city, which were about 230 people. Among the mothers of children with deafness, 40 mothers who were depressed according to the depression test were selected as available, then 20 of them entered in the experimental group and 20 entered in the control group.

The inclusion criteria included a mother with a child with hearing problems, the presence of mild to severe depressive disorder, the age range of 30 to 50 years, and the passing of at least one year since the birth of the child, and the exclusion criteria were the presence of a disability other than hearing, such as blindness, and the use of psychiatric drugs.

In addition, based on the individual report of the patient's companion and the patient himself and his medical record, it was ensured that they do not have convulsive and psychiatric diseases. Each person completed the consent form to participate in the research.

The samples were randomly divided into two groups based on the type of intervention (experiment or control in which the device was turned off).

Assessment tools

The following tests and tools were used in this research:

Beck Depression Inventory (BDI) (1988):

Includes 21 groups of questions, was first developed in 1961 by Aaron T. Beck. This questionnaire is a self-test that takes 5 to 10 minutes to complete, and to fully understand the meaning of the articles, reading at the fifth to sixth grade level is required.

This test is one of the most common psychometric tests to measure the severity of depression. In this test, some symptoms of depression such as hopelessness, irritability, guilt, and feeling of being punished and physical symptoms such as fatigue and weight loss are examined.

The validity and reliability of BDI was investigated by Hamidi *et al.* (14) in Iran. Intra class correlation coefficient was

calculated as 0.81. The internal consistency of the test was obtained using Cronbach's alpha method of 0.93. The sum of test scores can fluctuate from 0 to 62, and according to the score each person gets, he is placed in one of the following groups:

1. Normal average (1-15) or (1-18): People who do not have depression and are at a normal level.
2. Mild depression (16-31) or (18-28): People suffering from mild depression.
3. Moderate depression (32-47) or (29-35): People suffering from moderate level of depression.
4. Deep depression (48-62) or (36-63): People suffering from severe depression.

Test 2–back

This test is used to evaluate working memory ability. It contains 100 numbers (1 to 9) that are repeated randomly. After presenting the numbers audibly, the patient must decide whether it is similar or dissimilar to the two previous numbers and mark it in the answer sheet. In this research, the number of correct answers about the numbers that are similar to the previous number is considered as the test score. The obtained number is the variable score of the working memory of the patient.

Direct electrical stimulation device from the skull

The device used is the iOMED device, made in America (2011), which has two electrodes, anode and cathode. The anode electrode, which has a stimulating aspect, and the end of the device's cable, which is red in color, represents the anode electrode. The cathode electrode is the inhibitor, and the end of the device's cable, which is black, represents the anode electrode. The device has the ability to stimulate up to 4 amps, and in this study, 2 amps stimulation was used.

Research implementation method

First, 40 mothers of children with deafness were selected. The initial assessment of the patient took place on the first day and lasts 1.5 hours. Also, information such as the time that has passed since the birth of the child with hearing loss, the cause and the treatments that have been done so far are completed. The treatment protocol used in this study for each patient was 10 20-minute treatment sessions of 2 mA in the DLPFC area (15). The desired area for stimulation is obtained by measuring the head. For this purpose, the 20/10 EEG system is usually used.

After selecting the participant, the evaluation and intervention sessions done as follows:

In this study, participants received two different types of direct electrical stimulation from the skull in the DLPFC area, which are:

1. tDCS with a current whose anode electrode is placed on the left side and cathode electrode is placed on the right hemisphere (Experimental group).
2. Sham tDCS (sham) as control (control group)

In the first session, the patient questionnaire completed and the consent form signed too. Then, mother tested for the diagnosis of Beck and 2-back depression. At the same time, she experiences tDCS to relieve the stress regarding the treatment protocol. We record the results in the patient questionnaire.

In the next session, the patient received brain stimulation with direct electrical current from the anodic skull in the left DLPFC area and cathode brain stimulation with direct electrical current from the skull in the right DLPFC area. It is worth noting that the electric current is of direct type, with an intensity of 2 milliamps and a duration of 20 minutes, and for the control group, the device remains off in the fake mode (the device is on for 30 seconds and then it is turned off). Also, because the electrodes were wet with 0.9% saline solution, we put a towel around the patient's neck.

At the end of the treatment, depression was evaluated using the BDI and working memory using the 2-back test again by the technician who was unaware of the intervention protocol or sample control, and the results were recorded in the patient questionnaire.

Data analysis was done by SPSS 21 software. Data analysis was done using statistical analysis of covariance.

Results

In this research, 40 mothers of children with deafness were selected. Also, the mean ± SD age of the mothers was 38.37 (±4.36). The mean, standard deviation, highest and lowest scores related to the pre-test and post-test of depression in two experimental and control groups are presented in Table 1.

The Kolmogorov Smirov test showed the normality of the distribution of scores. The significance level for the depression variable in the control and experimental groups was greater than 0.05, so the distribution of scores was normal.

Also, according to Levine's test, the null hypothesis for the equality of the variances of the scores of the two groups was confirmed in the depression pre-test, but the depression variable was not confirmed in the post-test (significance lower than 0.05). It should be noted that due to the distance of the measurement scale and the random assignment of the subjects to two groups, the defect of this covariance analysis condition can be ignored and the obtained results can be trusted.

The results of covariance analysis to investigate the effect of tDCS on depression in mothers of children with deafness are shown in Table 3. The F value between the two experimental

Table 1. Mean (SD) of depression variable

Test	Group	Mean (SD)
Control	Pretest	38.45 (11.08)
	Post test	37.5 (12.14)
study	Pre test	39.30 (11.49)
	Post test	27.80 (14.15)

Table 2. Mean (SD of working memory variable

Test	Group	Mean (SD)
Control	Pretest	18.10 (5.12)
	Post test	19.55 (5.61)
study	Pre test	20.60 (5.87)
	Post test	26.15 (4.17)

Table 3. The results of univariate covariance analysis of depression post-test scores in experimental and control groups

Sources of changes	sum of squares	Degrees of freedom	mean square	F	*P*-value	Eta coefficients	power
Depression pretest	1304/11	1	1304/11	10/76	0/002	0/22	0/89
group (independent)	1213/86	1	1213/86	10/02	0/003	0/21	0/86
error variance	4481/38	37	121/11				
Total	84872	40					

Table 4. The results of univariate covariance analysis of working memory post-test scores in experimental and control groups

Sources of changes	sum of squares	Degrees of freedom	mean square	F	*P*-value	Eta coefficients	power
Depression pretest	1191/11	1	1104/11	10/76	0/002	0/24	0/89
group (independent)	1324/86	1	1334/86	10/02	0/005	0/22	0/86
error variance	4341/38	37					121/11
Total	64852	40					

and control groups, keeping the pre-test effect constant, is equal to 10.02 and its significance level is 0.003, so the statistical hypothesis was accepted and it can be concluded that tDCS has good effect transcranial brain stimulation on depression in mothers of children with deafness. It affects the listener. Therefore, the research hypothesis is also confirmed. And the effectiveness of the treatment according to the coefficients obtained is 21%. The power of the test is 0.86 which indicates relatively high statistical accuracy.

Regarding working memory, the Kolmogorov-Smirov test showed the normality of the distribution of scores. The significance level for the working memory variable in the control and experimental groups was greater than 0.05, so the distribution of scores was normal.

Also, according to Levine's test, the null hypothesis for the equality of the variances of the scores of the two groups was confirmed in the pre-test of working memory, but it is not confirmed in the post-test of the working memory (significance lower than 0.05). It should be noted that due to the distance of the measurement scale and the random assignment of the subjects to two groups, the defect of this covariance analysis condition can be ignored and the obtained results can be trusted.

The results of covariance analysis to investigate the effect of transcranial brain stimulation on working memory in mothers of children with deafness shown in Table 4. The F value between the two experimental and control groups, keeping the pre-test effect constant, is equal to 10.02 and its significance level is 0.005, so the statistical hypothesis is accepted and it can be concluded that tDCS can have good effect on working memory in mothers of children with deafness. It affects hearing loss. Therefore, the research hypothesis was also confirmed. And the effectiveness of the treatment according to the coefficients obtained is 22%. The power of the test was 0.86 which indicates relatively high statistical accuracy.

Discussion

The findings of the present study showed that tDCS has an effect on depression and working memory of mothers of children with deafness and leads to improvement of depression and working memory in these mothers. The use of tDCS is rapidly increasing due to its non-invasive nature (16) and low side effects (17) and low economic burden (18). This therapy has been extensively tested for the treatment of major depressive disorder (19, 20).

Previous studies have consistently shown that tDCS had good safety and tolerability profiles and was associated with only mild side effects in most trials, including pruritus, skin redness, and tingling. Early reports of tDCS experiments included descriptions of skin burns under the scalp electrodes, but no such effects have been reported since

researchers began using saline instead of water to soak the electrodes before use. (21). both clinical trials and systematic reviews with meta-analysis have shown that tDCS not only has the potential to improve mood symptoms in depressed patients (22) but also is able to enhance cognitive functions of them (17-19). tDCS in patients with bipolar disorder in a period of major depression (23, 24) and postpartum depression (25), as well as in adults (26, 27) and the elderly population (28) Recent systematic reviews on the effectiveness of tDCS have shown that tDCS can lead to partial to moderate improvement in depression, which the results of the present study also confirmed. Depressive disorders are common and persistent mental disorders. A significant proportion of patients with depression do not benefit from conventional treatments such as antidepressants and Cognitive Behavioral Therapy (CBT). In accordance with previous systematic reviews and expert recommendations on the clinical effectiveness of tDCS in depression, our findings confirmed that frontal lobe tDCS is effective in the treatment of depressive episodes (29). In previous clinical trials, the anode was mainly placed over the left dorsolateral prefrontal cortex (DLPFC) while the cathode was applied over the right upper DLPFC or right front temporal region (29) .However, the neural mechanism underlying tDCS treatment and how its relationship with behavioral changes in depressed patients can still be investigated. It can be said that since the left prefrontal region of the brain is responsible for producing positive thoughts and the right prefrontal region is involved in the production of negative thoughts (30), anodic stimulation of the left DLPFC region leads to an increase in positive thoughts and emotions in depressed patients. On the other hand, the cathode stimulation of the DLPFC area leads to the inhibition of this area and thus leads to the reduction of negative thoughts and emotions. As a result, these effects may be involved in the improvement of depression in the sample. Future studies could perform network analyzes to characterize the neural networks in which tDCS targets. In addition, there is preliminary evidence that DLPFC activation can improve working memory compared to before tDCS treatment (31).

In the past decades, there has been increasing research interest in using non-invasive brain stimulation techniques, including direct current stimulation over the skull, to modulate cortical plasticity and enhance human brain function (11). tDCS involves the delivery of a weak electrical current through electrodes through the scalp, resulting in a sub-threshold modulation of resting membrane potentials that alter cortical excitability and activity: depolarization increases excitability and spontaneous neural activity, while hyperpolarization has opposite effects. At the macroscopic level, with classical stimulation protocols, anodal tDCS (stimulation with the anode in the target area) increases, while cathode tDCS decreases the excitability of damaged neurons (13). Several studies have shown that anodal tDCS over the left DLPFC can increase performance in working memory tests. Past research using the n-back test has shown the involvement of the left DLPFC in working memory. In these tasks, participants are presented with consecutive numbers or letters and instructed to respond when the current number or letter matches one of n previously presented steps. The accuracy and delay in executing the correct answers show the ability to keep information active for a short period of time and update them flexibly (12). A recent meta-analysis of such studies suggests that the effects of anodal tDCS on working memory may be more reliably observed after the end of stimulation than during the period of active stimulation. (32) Understanding the timing of anodal tDCS effects on working memory for theoretical reasons and it is functionally relevant. If effects persist after stimulation, applied therapies involving tDCS delivery may be able to capitalize on cognitive enhancement that extends beyond the limited time span of active stimulation. However, it is unclear whether such side effects occur only indirectly, through the enhancement of tDCS training on a working memory task during active stimulation, or whether the effects persist beyond stimulation without specific training of working memory under stimulation. Distinguishing the validity of these alternative possibilities is important if we want to understand how anodic tDCS affects cognitive function. Both para-clinical and clinical studies have shown therapeutic effects of tDCS. Indeed, in human studies, anodal tDCS applied intermittently to the prefrontal cortex during slow-wave sleep improved the recall of expressive memories (word pairs) (33). Also, anodic tDCS over the DLPFC improved working memory in patients with major depression by increasing cortical excitability (32). Our study also showed that anodic stimulation in the left DLPFC area can lead to improvement of working memory in the 2-back task and this area can improve people's performance in cognitive tasks due to its role in working memory. Considering the role of the prefrontal region in mood and working memory (34), direct electrical stimulation from the skull of simultaneous anode/cathode 2 mA 20 minutes in the left and right DLPFC region at the same time, reduced depression and working memory in mothers of children with deafness improved.

Conclusion

The findings of this research showed that electrical stimulation of the brain from the skull can increase the scores related to working memory in mothers of children with deafness, and in the case of depression score, it can decrease their scores. Therefore, simultaneous 20-minute anodic/cathode tDCS in the left/right DLPFC region can improve depression and working memory in mothers of children with deafness. Therefore, it can be recommended that by using more studies and more samples, this treatment protocol can be used as a complementary treatment in the rehabilitation of patients with depression and working memory problems. Other brain stimulation techniques such as brain magnetic stimulation can also be used and these new approaches should be investigated and compared in different patients in order to use the best treatment protocol for patients by comparing the results. In addition, with more studies with different amperes and different locations of brain stimulation, better treatment protocols can be provided for treatment. **Acknowledgments**

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Ethical considerations

Ethical considerations have been considered in accordance with the instructions of the Jihad Ethics Committee of Mashhad University, and the code of ethics has been received under the number IR.ACECR.JDM.REC.1401.007.

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Conflict of interest

None.

Authors' contributions

All authors contributed equally to the preparation of this manuscript.

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