Available online at: http://journal.iepa.ir

Iranian Journal of Learning and Memory 2019, 2 (7), 43-50

The Effect of Cathodal Transcranial Direct-Current Stimulation (c-tDCS) of Dorsolateral Prefrontal Cortex (DLPFC) on Learning Simple Serves in Beginner Volleyball Learners

Seyed Kazem Mousavi Sadati⁎, Ph.D.
Department of Sport Science & Physical Education, East Tehran Branch, Islamic Azad University, Tehran, Iran
Ali Sedghyan, M.Sc.
Department of Physical Education & Sport Sciences, East Tehran Branch, Islamic Azad University, Tehran, Iran

Abstract

This study aimed at determining the effect of cathodal Transcranial Direct-Current Stimulation (c-tDCS) of Dorsolateral Prefrontal Cortex (DLPFC) on learning simple volleyball serves. This semi-experimental study was performed as pre-test and post-test with a control group. Thirty male volleyball players with an average age of 14±0.50 years were selected through purposeful sampling based on inclusion and exclusion criteria. The participants were randomly assigned to experimental (n=15) and control (n=15) groups. During eight consecutive sessions, the left DLPFC of participants was stimulated for 10 min using sham and real c-tDCS of 1.5 mA before each session. The participants then performed 35 simple volleyball serves. Absolute error and total variability of participants' performance in pre-test, in the first, third and eighth sessions were recorded. Data analysis by repeated-measures showed that there was a significant difference between absolute error (F=14.597, P = 0.001) and total variability (F=17.523, P = 0.001) of experimental and control group performance. ANCOVA showed that absolute error and total variability of the experimental group performance was respectively (P = 0.013 and P = 0.018) in the first session, (P = 0.021 and P = 0.007) in the third session and (P = 0.001 and P = 0.001) in the eighth session, which were significantly higher than that in the control group. Thus, it seems that c-tDCS of DLPFC is associated with reduced declarative memory activity in the cognitive stage leading to a negative impact on serve learning in beginner volleyball learners.

Keywords: Dorsolateral prefrontal cortex, motor learning, tDCS, volleyball serve

Introduction

Recent motor learning theories argue that motor skills can be learned implicitly or explicitly (Asgari, Abdoli & Aslan Khani, 2013). According to Berry and Dienes (1991), in implicit learning, individuals become skilled without knowing what they are doing, whereas in explicit learning, they acquire information and declarative knowledge about skills and based on this knowledge, they learn skills and then practice them**.** Masters and Maxwell (2004) believed that information is processed at the subconscious level and cannot be verbalized in implicit learning. Some scholars consider explicit knowledge processing in working memory and predictive knowledge accumulation in early stages of learning as an important part of performance and motor learning (Shahabi Kaseb, Mokammeli Jahromi, & Estiri, 2016). According to Masters' theory of reinvestment (1992), one of the reasons for the decline in performance under psychological pressure is that explicit motor knowledge (knowledge) leads to consciously processing, which in turn results in impaired automatic control of motion. Implicit learning is slightly dependent on working memory causing a decrease in the accumulation of explicit skill-related knowledge while learning that skill. In implicit learning, performance is stable under stressful conditions, fatigue and simultaneous performance of multiple tasks (Asgari & Abdoli, 2013; Maxwell, Masters, & Eves, 2003; Zhu et al., 2015).

⁎ **Corresponding Author**
Email: drmousavisadati@gmail.com

Received: 11/30/2019
Accepted: 02/25/2020

Explicit motor learning is intentional and utilizes working memory to manage analytical aspects of verbal learning such as the use of verbal instructions, performance monitoring and control, formulating and testing hypotheses and error correction as well as collecting and retrieving descriptive knowledge. In contrast, implicit motor learning reduces analytic-verbal involvement in motor control through encouraging limited dependence on working memory (Liao & Masters, 2002; Zhu, Poolton, Wilson, Maxwell & Masters, 2011). Although no form of motor learning is purely implicit or explicit, efforts are made to design implicit motor learning patterns to reduce conscious control of motions during learning and performance of motor skills (Maxwell *et al.*, 2003; Poolton, Masters, & Maxwell, 2007).

DLPFC is one of the brain regions that regulate working memory (Arkan & Yaryari, 2014; Zaehle, Sandmann, Thorne, Jäncke & Herrmann, 2011). Imaging studies, which identify novel approaches to improve neurotoxicity of working memory processes in the brain, suggest the prefrontal cortex, especially DLPFC, as an important region of the prefrontal cortex. According to the literature, the left DLPFC is essential for manipulating verbal knowledge (Barbey, Koenigs & Grafman, 2013). Based on the concepts of explicit and explicit learning, the first hypothesis can be put forward in this way that: Any intervention reducing activation of the left DLPFC may prevent the use of verbal working memory and improve motor learning, especially those who are in association and Autonomous phase (McKinley, McIntire, Nelson & Goodyear, 2017).

On the other hand, based on Fitts and Posner's three-stage model, which is a standard model for describing motor skills learning, one of the learners' characteristics in the cognitive stage is "self-talk"; that is, the learners consciously focus on finding solutions for skill implementation. They may engage in “self-talk”, murmur the activities and attempt to “talk” about their own executive efforts (Edwards, 2011). Based on Fitts and Posner's model (1967), the second hypothesis can be put forward that: In beginners who are in the cognitive stage, any intervention inhibiting left DLPFC activation may prevent the use of working memory, reduce verbal analytical (declarative memory) processes involvement in motor control and decrease motor learning, especially in beginners.

Transcranial Direct Current Stimulation (tDCS) is a noninvasive, inexpensive and safe method. In this method, a weak direct current (1 to 4 mA) is applied from the scalp to specific areas of the cerebral or cerebellar cortex; and then, long-term changes occur in cortical polarity as a result of depolarization and hyperpolarization of neurons and neurotransmitters, and self-stimulated brain activity is facilitated or inhibited (Brunoni et al., 2012). For transcranial direct current stimulation, two electrodes, one as a positive pole and the other as a negative pole, are placed on the head through a sponge pad soaked in a conductive solution. After passing through various areas (scalp, skull, etc.), the electric current generated by these electrodes reaches the surface of the cortex, causing the neurons to be electrically charged and produces a positive and negative polarity. This in turn causes a change in the activity of that region (Arkan & Yaryari, 2014; Zamani & Doostan, 2018). According to Boggio et al. (2007), anodic and cathodal tDCS (c-tDCS) respectively increases and reduces cortical stimulation. Thus, one can conclude that the use of c-tDCS in the left DLPFC region during motor learning avoids working memory from being used and reduces apparent verbal analytic involvement in motor control (Zamani & Doostan, 2018; Zhu et al., 2015).

There are few studies on the effect of tDCS on DLPFC in motor skills. By examining the effect of c-tDCS of the right DLPFC on training of a procedural motor task, McKinley et al. (2017) concluded that this method could improve the performance and learning of motor skills in the retention test. They justified this finding as follows. C-tDCS probably inhibits right DLPFC activity and transfers cognitive resources from declarative memory to non-declarative memory processes leading to enhancement of procedural memory, motor performance and motor learning. Zhu et al. (2015) investigated the effect of left DLPFC stimulation on implicit learning of the pat golf, and found that the left DLPFC not only improved performance in the acquisition phase but also improved the performance of the pat golf skill in the retention phase. Therefore, transcranial stimulation in this region can be used to improve motor skill performance and learning. Fregni et al. (2005) also reported that anodic stimulation of DLPFC increased the number of correct responses and working memory. Moreover, the results of studies by Pixa and Pollok (2018), Buch et al. (2017), Ciechanski and Kirton (2017) as well as Apšvalka, Ramsey and Cross (2018) on the effect of TDCS on motor skills showed that this method could affect motor skill performance and learning. There is a little international and domestic research works on the impact of TDCS on DLPFC in motor skill learning and the finding new ways to facilitate motor skill learning is important. This study aimed at answering this question: Whether the application of c-tDCS on the left DLPFC of beginners prevents the use of working memory, reduces the verbal-analytic processes involvement in motor control and facilitates motor learning; or on the contrary, leads to negative interaction with the recognition phase processes and inhibits motor learning.

Method

Participants

This quasi-experimental study was performed as pre-test and post-test with control group. The statistical population of consisted of all male adolescents who went to Shahid Sakhaei Sports Hall to learn volleyball. Thirty male adolescent beginner [volleyball] learners aged 11 to 17 years were selected by purposeful sampling based on inclusion and exclusion criteria. The participants were randomly assigned to two experimental (real stimulation; n=15) and control (sham stimulation; n=15) groups using the randomized-blocks procedure. The average age of experimental group was (14±1.0) years and control group was (13.9±1.1) years. This procedure is the process of random assignment of participants according to their rank in the key dependent variable, to match the groups. To this end, the participants were ranked according to scores they received in performing a simple volleyball serve. Inclusion criteria included being in the age range of 11-17 years, gender (being male), being a beginner, lack of abnormalities in lower and upper extremities, lack of a medical record, and complete consent to participate in the study. The exclusion criteria included specific drug use, a history of receiving electric stimulation, having a specific motor-related illness, epilepsy, mental disorders, having a foreign object in the head, being out of the age range and being skilled in performing volleyball serves. Safety Screening Questionnaire for TMS & TDCS and the Persian version of the Mini Mental Status Evaluation (MMSE) Test were used to assess the exclusion criteria of the participants (Keel, Smith, & Wassermann, 2001).

Instruments

The Standard Safety Screening Questionnaire for TMS and tDCS was used for formulation of inclusion and exclusion criteria. This questionnaire, developed by Keel, Smith and Wassermann (2001), has been used in various studies to assess the safety and suitability of tCDCs for participants (Rabipour, Vidjen, Remaud, Davidson & Tremblay, 2018; Varoli et al., 2018). In this study, tDCS device (Active Dose, Activa Tek Co., Taiwan) was used; and based on the International 10-20 Electroencephalographic System, the cathode was placed at left DLPFC (F3) and the anode electrode at on the forehead above the right eye (FP2) (Zhu et al., 2015). In addition, the Persian version of the Mini Mental Status Evaluation (MMSE) Test was used to assess participants' cognitive impairments. Based on this test, the score of lower than the 23 was exclusion criteria of the participants. In a study done by Seyedian et al. (2007), internal reliability of this questionnaire with Cronbach's alpha coefficient was reported 0.81 for the whole test.

Procedure

To observe ethical considerations, after selecting the participants and prior to the start of interventions, the participants were informed of the safe method of intervention, the ability to exit the research at any stage if they do not wish to cooperate, and confidentiality of collected information. Then, a written consent was provided to all participants and their parents to be completed. After detail explanation of the intervention process and different stages and how to record scores, the volleyball training sessions started. Prior to the start of training, both sides of the volleyball court were divided into nine equal portions by colored lines, and participants were asked to serve in a way that the ball landed on both sides of the opposite median. When the ball landed outside the two zones, the error score was awarded to the performer. A camera was installed beside the volleyball court to accurately record volleyball performance of the participants; and the serve performances of each participant were recorded in pre-test, first, third and eighth intervention sessions. If, for any reason, it was not possible to record a performance score (point), the score of each serve was recorded after reviewing the recorded video of the performance.

During eight sessions in the same location and time in an indoor sports hall and a volleyball court striped with different colors, the participants in both experimental and control groups performed 35 volleyball serves per session. However, the scores were recorded only in pre-test, first, third and eighth intervention sessions. In all sessions, c-tDCS of the left DLPFC was used the experimental group, while the control group received a same but unrealistic stimulation (sham). Current stimulation was induced at 1.5 mA for 10 min before each training session. Absolute error (AE) and total variability (E) of participants' performance in each session were calculated with the help of Microsoft Excel; and the performance scores were recorded in each session. Finally, the absolute error and the total variability of the participants were inserted in SPSS.

Shapiro-Wilk and Levene's tests were respectively used to investigate the normality of data distribution and the equality of inter-group variance. Homogeneity of regression line slope was evaluated by calculating the F interaction between pre-test and independent variables through analysis of covariance. Data were analyzed using SPSS 23. A significance level of 0.05 was considered.

Findings

The mean and standard deviation of age, height and weight of participants in the experimental and control groups are shown in Table 1. As can be seen, there is no significant difference between the two groups in terms of input characteristics.

Table 1.

Descriptive Information of the Participants in the Experimental (N = 15) and Control (N = 15) Groups

Variable	Experimental group	Control group	t	P-value
	Mean±Standard Deviation	Mean±Standard Deviation		
Number of participants	15	15	-	-
Age (years)	14.07 ± 1.0	13.93±1.1	0.641	0.509
Height (cm)	161.2±2.8	160.1±2.9	0.098	0.922
Weight (kg)	50.87±4.3	49.4±4.7	0.374	0.725

Table 2 shows the descriptive statistics of mean and standard deviation of absolute error (AE) and total variability (E) of serving performance of the participants in the experimental and control groups in the first, third and eighth sessions.

Table 2.

Mean and Standard Deviation of Absolute Error and Total Variability in Different Measurement Stages

Stage	Experimental Group		Control Group	
	Absolute error	Total variability	Absolute error	Total variability
Pre-test	2.40±0.69	0.48±0.11	2.39±0.99	0.46±0.15
First session	2.92±0.94	0.56±0.15	2.26±0.65	0.45±0.09
Third session	2.58±0.71	0.52±0.10	1.97±0.74	0.40±0.11
Eighth session	2.86±0.92	0.56±0.13	1.82±0.38	0.38±0.05

As can be seen in the above Table, the total variability and absolute error of performance in the experimental group are greater than those in the control group at all measurement stages. According to the results, the distribution of pre-test and post-test data is normal in both control and experimental groups (Z = 0.135, P = 0.13) and the variance of pre-test and post-test data was the same in the control and experimental groups (F = 1.10, P = 0.45). On the other hand, the assumption of regression slope homogeneity is also established. Regarding the covariance test hypotheses, ANOVA and repeated-measures ANCOVA were used to evaluate the effect of training sessions (intra-group difference), groups (inter-group difference) and interaction of the number of sessions and groups on total variability and absolute error of serving performance, and the results are presented in Table 3.

Table 3.

Repeated-Measures Analysis of the Research Variables in the Experimental and Control Groups

Name of variable	Source of changes	Sum of squares	Degrees of freedom	Average of squares	F-value	P-value	Partial Eta squared
Performance absolute error	Group	13.314	1	13.314	14.597	0.001**	0.351
	Number of sessions	0.249	2	0.124	0.527	0.594	0.019
	Number of sessions * group	0.841	2	0.421	1.779	0.179	0.062
Performance total variability	Group	0.364	1	0.364	17.523	0.001**	0.394
	Number of sessions	0.002	2	0.001	0.229	0.796	0.008
	Number of sessions * group	0.026	2	0.013	2.533	0.089	0.086

** Significance level: P≤0.01

According to the results in Table 3, the number of sessions has no significant effect on absolute error and total variability of serving performance in both control and experimental groups; but the group (the use of real stimulation and sham) has a significant effect on absolute error and total variability of serving performance. The covariance analysis test was used to determine the exact difference between the experimental and control groups in the first, third and eighth sessions. The results of these tests are summarized in the combined and modified Table 4.

Table 4.
ANCOVA of the Research Variables in the Experimental and Control Groups

Variable	**Session**	**Group**	**Pre-test**	**Post-test**	**F-value**	**P-value**	**Partial Eta squared**
			Mean ± Standard Deviation	**Mean ± Standard Deviation**			
Absolute Error	First	Experimental	2.40 ±0.69	2.39 ±0.99	0.007	0.013*	0.20
		Control	2.39± 0.99	2.26±0.65			
Total Variability	First	Experimental	0.48±0.11	0.56±0.15	6.28	0.018*	0.18
		Control	0.46±0.15	0.45±0.09			
Absolute Error	Third	Experimental	2.40±0.69	2.58±0.71	6.04	0.021*	0.18
		Control	2.39±0.99	1.97±0.74			
Total Variability	Third	Experimental	0.48±0.11	0.52±0.10	8.59	**0.007	0.24
		Control	0.46±0.15	0.40+0.11			
Absolute Error	Eighth	Experimental	2.40 ±0.69	2.86 ±0.92	17.622	**0.001	0.39
		Control	2.39± 0.99	1.82±0.38			
Total Variability	Eighth	Experimental	0.48±0.11	0.56±0.13	24.456	** 0.001	0.47
		Control	0.46±0.15	0.38±0.05			

* Significance level: P≤0.05, ** Significance level: P≤0.01

As can be seen in Table 3, the absolute error and the total variability of the experimental group performance in the first session (P = 0.013 and P = 0.018), third session (P = 0.021 and P = 0.007), and the eighth session (P = 0.001 and P = 0.001) were significantly greater than those in the control group. The descriptive findings in Table 4 show the greater error and total variability of performance in the experimental group than the control group, indicating the destructive effects of electric stimulation on the performance of the beginner adolescent volleyball players in the experimental group. The effect size calculated in the first and third sessions showed that about 20% of the difference between the scores of experimental and control groups in the post-test is related to the intervention with tDCS in the experimental group. However, the effect size of intervention with tDCS in the eighth session justifies about 42% of differences between the scores of the experimental and control groups.

Discussion and Conclusion

The results of this study indicate the negative effect of c-tCDS of the DLPFC on the absolute error of volleyball serves performed by the beginners in the experimental group after one, three and eight sessions of intervention. To justify these results, one can refer to the Fitts & Posner's three-step motor skills learning standard model (Fitts & Posner, 1967). The first stage in this model is called the cognitive stage of learning, because conscious mental processes are dominant at the beginning of learning. At this point, learners are completely dependent on spatial memory; and information is consciously controlled and reviewed to regulate motion. Learners strive to "think" in the implementation of skills at this stage.

At this stage of learning, the main problem for learners is to understand the basic idea of a skill, which includes the goals of that skill and means to achieve them. Even when learners first learn the goals of a skill, they may not understand proper movement patterns to achieve them (Magill & Anderson, 2017; Spalva, 2016). In cognitive stage, participants mainly use cognitive processes to look for solutions to motor problems. Learners pay conscious attention on finding these solutions, and may engage in "self-talk" and murmuring, and try to "talk" about their executive efforts. At this stage, learners may feel that their movements have not led to the goals of those movements, but they do not know the corrective method (Schmidt & Lee, 2014). The Fitts and Posner's model illustrates a theoretical cognitive approach to classify learning stages with progression from predictive memory (explicit learning) to procedural memory (implicit learning) with the aim of describing the observable behavioral changes at each stage. Each stage represents a unique set of learning problems and the role of memory and cognition as a key element in learning motor skills (Edwards, 2011; Fitts & Posner, 1967). In this regard, literature indicated that suppressing verbal memory through c-tDCS of the DLPFC disrupts explicit learning strategy and analytical-verbal controls leading to implicit learning of motor skills (Nelson *et al.*, 2016), while beginner learners learn motor skills at the cognitive stage with the processes involved in the explicit motor learning.

For this reason, one, three and eight sessions of DLPFC electric stimulation in the beginner participants of this study during how-to-serve learning sessions resulted in impaired working memory learning, reduced explicit verbal analysis in motor control -which improves apparent learning in the cognitive phase - and decreased absolute and total error of the experimental group as compared to the control group. Based on Fitts and Posner's three-stage model, the second hypothesis can be put forward that: In beginners who are in the cognitive stage, any intervention inhibiting left DLPFC activation may prevent the use of working memory, reduce verbal analytical (declarative memory) processes involvement in motor control and decrease motor learning, especially in beginners.

Zhu et al. (2015) investigated the effect of c-tDCS of the DLPFC during PAT golf performance. Twenty-seven right-handed students were participated in this study and received a real c-tDCS stimulation on the left DLPFC (n = 14) or unrealistic stimulation/sham (n = 13) while learning the golf ball-kick task. The results showed that real c-tDCS on the left DLPFC improved PAT golf performance in the experimental (real stimulation) group while decreasing verbal working memory (Zhu *et al.*, 2015). The inconsistency in the results of the present study and those of Zhu *et al.* may be attributed to the differences in the level of participants.

According to Fitts and Posner's three-stage model, beginner participants have many actual cognitive needs, and those who are in the cognitive stage utilize murmuring to perform motor skills. Any intervention inhibiting left DLPFC activation can prevent the use of working memory and it can reduce explicit verbal-analytic involvement in motor control and inhibit motor learning. According to McKinley *et al.* (2017), verbal and nonverbal memory processes compete for the access to cognitive resources in the brain. The inhibitory c-tDCS probably inhibits activity in the DLPFC and transfers cognitive resources from verbal memory processes to nonverbal memory processes leading to impaired verbal cognitive memory, performance and learning in beginners and enhanced procedural memory, performance and motor skills learning in skilled people. The beginners participated in this study, with an average age of 14 years, were indeed in the cognitive stage that relies heavily on explicit learning, but the students participated in the study conducted by Zhu, with an average age of 21 years, were in the association or representation phase, which is mostly based on implicit learning. In the association (representation) phase, the need for self-talk or murmuring decreases at this stage, so that procedural memory overcomes the control of action. At this stage, self-talk or murmuring decreases as the procedural memory overcomes action control.

McKinley *et al.* (2017) found that application of c-tDCS on the DLPFC may improve verbal memory performance and learning of multiple motion tasks, i.e. Identification Friend-or-Foe (IFF) task, in 36 participants of Air Force through suppressing verbal memory. The inconsistency between the results of our study and those reported by McKinley *et al.* can also be attributed to the performance level of the participants, who were probably at the stage of association (representation) or semi-automatic rather than cognitive stage. Moreover, since the participants in this study were very young, they might have great deal of stress to tDCS, and this has affected their performance. Given the young age of the participants, which was associated with the low level of cognitive performance, it is impossible to conclusively determine the effect of DLPFC electric stimulation on implicit learning of volleyball serves.

Some of the limitations of the present study were to conduct study only on novice volleyball players, also changes in the central nervous system wasn’t investigated by nerve imaging. In future research, it is recommended to compare the effects of TDCs on beginner and skilled volleyball players and to use neural imaging in addition to behavioral criteria. It is also recommended to examine the effect of c-tDCS of the DLPFC of those volleyball players who are in the associative or semi-automatic phase to clarify some aspects of the impact of verbal memory suppression on implicit learning. Additional research that combines neurophysiology with behavioral outcomes should also be conducted to prove DLPFC inhibition by the tDCS paradigm.

According to the results, c-tDCS of the DLPFC seems to act as a suppressor of verbal and stressful memory in the cognitive stage in beginner players and consequently has a negative effect on motor function especially in cognitive stage of learning simple serves. Given the negative impact of c-tDCS of the left

DLPFC on explicit learning of the cognitive stage of simple volleyball serve motor learning, the results of this study provide some evidence for validation of the Fitts and Posner's three-stage model.

Acknowledgments

The authors wish to thank all students participated in this research as well as respected officials of the Shahid Sakhaei Sports Hall and East Tehran Branch of Islamic Azad University who helped us during various stages of this study.

References

Apšvalka, D., Ramsey, R., & Cross, E. S. (2018). Anodal tDCS over primary motor cortex provides no advantage to learning motor sequences via observation. *Neural Plasticity, 20*(18), 10-24.

Arkan, A., & Yaryari, F. (2014). Effect of transcranial direct current stimulation (TDCS) on working memory in healthy people. *Journal of Cognitive Psychology, 2*(2), 10-17.

Asgari, Z., & Abdoli, B. (2013). The Effect of analogy, explicit and discovery learning on performance breakdown under psychological pressure. *Journal of Motor Learning and Movement, 5*(12), 125-146. doi:10.22059/jmlm.2013.32151

Asgari, Z., Abdoli, B., & Aslan khani, M. A. (2013). Comparing the effect of explicit learning, analogy learning, and discovery learning in acquisition, retention, and transfer of topspin shot in table tennis. *Motor Behavior, 11*(9), 81-98.

Barbey, A. K., Koenigs, M., & Grafman, J. (2013). Dorsolateral prefrontal contributions to human working memory. *Cortex, 49*(5), 1195-1205.

Berry, D. C., & Dienes, Z. (1991). The relationship between implicit memory and implicit learning. *British Journal of Psychology, 82*(3), 359-373.

Boggio, P. S., Bermpohl, F., Vergara, A. O., Muniz, A. L., Nahas, F. H., Leme, P. B., & Fregni, F. (2007). Go-no-go task performance improvement after anodal transcranial DC stimulation of the left dorsolateral prefrontal cortex in major depression. *Journal of Affective Disorders, 101*(1-3), 91-98.

Brunoni, A. R., Nitsche, M. A., Bolognini, N., Bikson, M., Wagner, T., Merabet, L., & Pascual-Leone, A. (2012). Clinical research with transcranial direct current stimulation (tDCS): Challenges and future directions. *Brain Stimulation, 5*(3), 175-195.

Buch, E. R., Santarnecchi, E., Antal, A., Born, J., Celnik, P. A., Classen, J., & Nitsche, M. A. (2017). Effects of tDCS on motor learning and memory formation: A consensus and critical position paper. *Clinical Neurophysiology, 128*(4), 589-603.

Ciechanski, P., & Kirton, A. (2017). Transcranial direct-current stimulation can enhance motor learning in children. *Cerebral Cortex, 27*(5), 2758-2767.

Edwards, W. H. (2011). *Motor learning and control: from theory to practice* (pp. 250-260). United States: Cengage Learning.

Fitts, P. M., & Posner, M. I. (1967). Human performance. Brooks. *Cole, Belmont, CA, 5*, 7-16 .

Fregni, F., Boggio, P. S., Nitsche, M., Bermpohl, F., Antal, A., Feredoes, E., & Paulus, W. (2005). Anodal transcranial direct current stimulation of prefrontal cortex enhances working memory. *Experimental Brain Research, 166*(1), 23-30.

Keel, J. C., Smith, M. J., & Wassermann, E. M. (2001). A safety screening questionnaire for transcranial magnetic stimulation. *Clinical neurophysiology: official journal of the International Federation of Clinical Neurophysiology, 112*(4), 720-720.

Liao, C. M., & Masters, R. S. (2002). Self-focused attention and performance failure under psychological stress. *Journal of Sport and Exercise Psychology, 24*(3), 289-305.

Liebetanz, D., Nitsche, M. A., Tergau, F., & Paulus, W. (2002). Pharmacological approach to the mechanisms of transcranial DC-stimulation-induced after-effects of human motor cortex excitability. *Brain, 125*(10), 2238-2247.

Magill, R. A., & Anderson, D. I. (2017). *Motor learning: Concepts and applications (pp. 274-276)*. New York: McGraw-Hill Education.

Masters, R. S. (1992). Knowledge, knerves and knowhow: The role of explicit versus implicit knowledge in the breakdown of a complex motor skill under pressure. *British Journal of Psychology, 83*(3), 343-358.

Masters, R. S., & Maxwell, J. P. (2004). 10 Implicit motor learning, reinvestment and movement disruption. *Skill Acquisition in Sport: Research, Theory and Practice*, 207.

Maxwell, J., Masters, R., & Eves, F. (2003). The role of working memory in motor learning and performance. *Consciousness and Cognition*, *12*(3), 376-402.

McKinley, R. A., McIntire, L., Nelson, J., Nelson, J., & Goodyear, C. (2017). The effects of transcranial direct current stimulation (tDCS) on training during a complex procedural task *Advances in Neuroergonomics and Cognitive Engineering* (pp. 173-183): Springer.

Nelson, J., McKinley, R. A., Phillips, C., McIntire, L., Goodyear, C., Kreiner, A., & Monforton, L. (2016). The effects of transcranial direct current stimulation (tDCS) on multitasking throughput capacity. *Frontiers in Human Neuroscience, 10,* 589.

Pixa, N. H., & Pollok, B. (2018). Effects of tDCS on bimanual motor skills: A brief review. *Frontiers in Behavioral Neuroscience, 12,* 63-89.

Poolton, J. M., Masters, R. S., & Maxwell, J. P. (2007). The development of a culturally appropriate analogy for implicit motor learning in a Chinese population. *The Sport Psychologist, 21*(4), 375-382.

Rabipour, S., Vidjen, P. S., Remaud, A., Davidson, P. S., & Tremblay, F. (2018). Examining the Interactions between Expectations and tDCS Effects on Motor and

Cognitive Performance. *Frontiers in Neuroscience, 12*.

Schmidt, R. A., & Lee, T. D. (2014). *Motor learning and performance:From principles to application* (Fifth edition ed., pp. 405-410). United States: Human Kinetics.

Seyedian, M., Falah, M., Novrozyan, M., Najat, S., Dlavar, A., & Ghasemzadeh, H. (2007). Preparation and validation of the Persian version of Mini Mental Status Evaluation (MMSE). *Journal of Medical Council of Islamic Republic of Iran, 25*(4), 408-414 .

Shahabi Kaseb, M. R., Mokammeli Jahromi, M., & Estiri, Z. (2016). The effect of analogy, explicit, and combination learning on acquisition, retention, and transfer of complex motor skill. *Motor Behavior, 8*(26), 119-136. doi:10.22089/mbj.2016.866

Spalva, R. (2016). Improvement of dance composition skills during the study process in the perspective of the newest motor learning models. *Signum Temporis, 8*(1), 51-56.

Varoli, E., Pisoni, A., Mattavelli, G. C., Vergallito, A., Gallucci, A., Mauro, L. D., & Lauro, L. J. R. (2018). Tracking the effect of cathodal transcranial direct current stimulation on cortical excitability and connectivity by means of TMS-EEG. *Frontiers in Neuroscience, 12*.

Zaehle, T., Sandmann, P., Thorne, J. D., Jäncke, L., & Herrmann, C. S. (2011). Transcranial direct current stimulation of the prefrontal cortex modulates working memory performance: Combined behavioural and electrophysiological evidence. *BMC Neuroscience, 12*(1), 2. page???//

Zamani, G., & Doostan, M. R. (2018). The effect of transcranial direct current stimulation on working memory and reactiontime in athlete girls. *Neuropsychology, 3*(10), 51-62.

Zhu, F., Poolton, J., Wilson, M., Maxwell, J., & Masters, R. (2011). Neural co-activation as a yardstick of implicit motor learning and the propensity for conscious control of movement. *Biological Psychology, 87*(1), 66-73.

Zhu, F. F., Yeung, A. Y., Poolton, J. M., Lee, T. M., Leung, G. K., & Masters, R. S. (2015). Cathodal transcranial direct current stimulation over left dorsolateral prefrontal cortex area promotes implicit motor learning in a golf putting task. *Brain Stimulation, 8*(4), 784-786.