Document Type: Original Article
doi: 10.22034/iepa.2021.247006.1206

Iranian Journal of Learning and Memory, 2020, 3 (11), 61-68

Comparing Cup Stacking and Transcranial Direct Current Stimulation on Working Memory and Processing Speed

Parvaneh Feiz
Ph.D. Candidate, Department of Psychology, Islamic Azad University, Central Tehran Branch, Tehran, Iran
Susan Emamipour*, Ph.D.
Department of Psychology, Islamic Azad University, Central Tehran Branch, Tehran, Iran
Peyman Hassani-Abharian, Ph.D.
Department of Cognitive Rehabilitation, Institute for Cognitive Science Studies, Brain and Cognition Clinic, Tehran, Iran
Shirin Kooshki, Ph.D.
Department of Psychology, Islamic Azad University, Central Tehran Branch, Tehran, Iran

Abstract

Students with attention disorders face many challenges in the educational process, which also affects their academic future. The goal of this study was to compare the effect of the Cup Stacking Method and Transcranial Direct Current Stimulation on the working memory and information processing rate on students with attention deficits. The research population included all fifth and sixth grade students in public schools in Tehran in 2019-2020. Forty-five students with attention deficit were purposefully selected and then randomly divided into three groups of 15: Transcranial Direct Current Stimulation; Cup Stacking; and Control groups. The Transcranial Direct Current Stimulation group was given a 10-session therapeutic trial; a 30-minute cup stacking game was played for 10 sessions by the second group. The Symbol Digit Modalities Test and the Digit Span subtest were used to assess the study variables. The results of mixed variance analysis showed that although both cup stacking and Transcranial Direct Current Stimulation improved the information processing rate and working memory of students with attention deficit, the two methods did not have a significant difference in their impact on these functions of the research subjects. It is recommended that school teachers use cup stacking in their daily interaction with the students, and that clinical professionals use Transcranial Direct Current Stimulation to address executive function issues.

Keywords: Attention deficit, cup stacking, information processing rate, Transcranial Direct Current Stimulation, working memory

Introduction

Attention-Deficit/Hyperactivity Disorder (ADHD) is the display of reduced consistent attention and hyperactivity, along with impulsive behaviors, that are more intense than children and adolescents with a similar developmental level (Wang, Wang, & Yan et al. 2020). ADHD is a complicated psychiatric disorder that impacts not only the individual, but on the integrated family unit (De Zeeuw, Hottenga, & Ouwens et al., 2019). The spread of this disorder has become critical in recent years. Attention deficit is also correlated with certain cognitive processes that may be measured via attention or memory tests, as well as with the impairment of executive functions (Diagnostic and Statistical Manual of Mental Disorders–5). The results of neuropsychological studies do not ascribe a single factor as the causative deficit for all mental disorders. However, it may be applicable to say that ADHD is an outcome of generally improper executive functioning, and more specifically, improper executive control, inhibition, or working memory (Al-Yagon, Forte, & Avrahami, 2017). The research shows that executive function disorders, which are associated with neuropsychological disorders, are some of the most

* **Corresponding Author**
Email: emamipursd@yahoo.com

Received: 09/14/2020
Accepted: 11/10/2020

common reasons behind ADHD in children (Schworer, Reinelt, &Petermann et al., 2020; Sibley, Graziano, Ortiz, et al., 2019; Wang et al., 2019). Executive functions include a series of cognitive processes that are associated with frontal lobe structure and function, including storing functions, intervention control, inhibition, planning, organized processing speed, working memory, and flexible attention control (Schworer et al., 2020)

Working memory comprises a system that enables storing mediating cognitive functions, along with their potential changes and dynamics (Sellers, Mellin, & Lustenberger, et al, 2015). Active memory is the ability to store information for a couple of seconds while performing cognitive functions associated with events (Arjmandnia & Shokouhi Yekta, 2012). Bush et al. (2008) showed that the ventrolateral prefrontal cortex controls spatial information in working memory, while the dorsolateral prefrontal cortex stores objective information. Another executive function element is the information processing rate, which points to the ability to develop a quick and effective roadmap to achieve a goal or to complete a task (Shiran & Breznitz, 2011). Information processing rate includes quick decision-making in terms of prioritization (Amir Asadi, 2013).

Executive functions develop throughout the child's growth and adolescence, helping the child to complete more complicated and difficult tasks (Colomer, Berenguer, & Roselló et al. 2017). Executive function impairment may result in considerable consequences in the social, educational, and emotional performance of children with ADHD. Therefore, the cup stacking game technique (Tretriluxana, Taptong, & Chaiyawat, 2015) and tDCS (Bandeira, Guimarães, & Jagersbacher et al., 2016) offer two effective therapeutic methods that can be used to address this impairment. Cup stacking game includes manually stacking and then collecting cups. This game provides a useful opportunity to enhance concentration, hand-eye coordination, movement speed, and simultaneous use of hemispheres and body parts through using both hands at the same time (Meyer, van der Wel & Hunnius, 2016). Research shows that cup stacking improves executive functions and certain other foundational capacities, including consistent visual movements (Meyer et al., 2016; Udermann, Mayer, Murray, & Sagendorf, 2004), information processing rate (Tretriluxana et al., 2015; Udermann et al., 2004), response control, self-control, and decision-making (Lessa & Chiviacowsky, 2015), observational learning (Granados & Wulf, 2007), and the ability to make predictions (Hart, Smith, & DeChant, 2005).

Additionally, research has shown that noninvasive techniques that directly focus and control dorsolateral prefrontal cortex functions, including tDCS, have the potential to improve working memory (Brandette et al., 2015). Direct electric stimulation of the brain is a noninvasive form of brain stimulation (Zaehle, Sandmann, &Thorne et al, 2011) that can cause temporary changes in cortex area excitability (Schlag et al., 2011). Direct electric stimulation of the brain causes alterations in brain cells through changing neuron excitability, as well as by moving neuron lesions towards depolarization or hyper-polarization (Bikson, 2016). This stimulation also causes enhanced or decreased brain function through using direct charge to in order to alter cortex excitability (Woods, 2016). Research shows that tDCS improves the comprehension of time, as well as reaction speed (Ptacek, Weissenberger, & Braaten et al., 2019), executive functions (Salehi Nejad, Wischnewski, & Nejati et al., 2019), behavioral inhibition (while reducing impulsivity) (Allenby, Falcone, & Bernardo et al., 2018), different types of attention and concentration (Jacoby & Lavidor, 2018), emotional understanding (Liu, Chen, & Sun et al., 2017), ADHD symptoms (Cachoeira, Leffa, & Mittelstadt et al., 2017; Soff, Sotnikova, & Christiansen et al., 2017), and working memory (Rubia, 2018) in individuals with ADHD.

Comparing the findings of differences between cup stacking and tDCS impact on working memory processing speed requires research studies like the present one. Therefore, the present study was conducted to see between tDCS and cup stacking, which method has a more effective impact on the working memory and processing speed of students with ADHD.

Method

The current study used a quasi-experimental design with pre-test, post-test, and follow-up, with one control group and two experimental groups.

Participants

The research population included all fifth and sixth grade students in public schools in Tehran in 2019-2020. 45 participants were selected based on the CSI-4 test cut-off point, with diagnosis based on the DSM-5 criteria for ADHD. The sample was purposefully selected, and then randomly divided into three groups of 15: tDCS, cups stacking, and control groups. Inclusion criteria were children older than 10 diagnosed with attention deficit; exclusion criteria were ADHD with complex symptoms, concussion, and the presence of other psychiatric issues. The subjects were screened via DSM-5 and the CSI-4 form that provide criteria to assess attention deficit/ADHD. Subjects were selected from those showing 6 or more indicators of A criteria (inattention) in DSM-5, and those scoring 6 or more in the CSI-4 questionnaire.

Instruments

Symbol Digit Modalities Test (SDMT)

SDMT was used to examine the subjects' processing speed. This test involves the numbers 1-9, each having a specific sign. The individual is instructed to associate each number with its specified sign. The test length is 90 seconds, with the maximum score of 93. Each task calculates the speed of substituting the signs, and needs follow-up and tracking. The validity coefficient of the test has been reported as 0.84 (Falman, Lundgren, & Wressle et al., 2019).

Wechsler's Direct and Reverse Digits' Span Subtest

One of most common methods to assess working memory is a digit's span tool using Wechsler Intelligence Test. In Wechsler's Direct and Reverse Digits' Span Subtest, the researcher reads aloud and softly three- to nine-digit numbers, then the subject should recall the list of the numbers in order. As one of the most common intelligence criteria, this test required subjects to recall the direct digits as stated, and the reverse digits in the reverse mode (Hesapcioglu & Ceilk, 2016). The brain's capacity for direct digit memory is assessed by the first set, and its capacity for reverse digit memory is assessed by the second set. This subtest assesses short-term hearing memory, concentration, attention, and working memory capacity (Ruchinskas, 2019). The subject's attention and concentration, as well as their distraction and anxiety, impact their score in the test. The Cronbach's alpha reliability coefficient for the digits' span subtest is 0.85 in Iran (Fadayi, Bigdeli, & Miladi, 2015).

Child Symptom Inventory Form-4

The CSI-4 form is used to diagnose a subject's attention deficit/ADHD. This form includes 18 questions, and shows the severity of children's attention deficit and ADHD, based on the judgments of parents and teachers. The test has a reliable diagnostic capacity, according to the third edition of the Diagnostic and Statistical Manual of Mental Disorders for children between 5 and 12. Spearman and Gado (1994) evaluated the reliability of this form as 0.83, and as 0.87 in the updated version. This form was normalized by Mohammad Esmaeil (2003), and is a reliable instrument to assess behavioral and emotional deficits in Iranian children. The cut-off point to diagnose attention deficit/ADHD is 6 and above (Mohammad Esmaiel, 2003).

Procedure

The tDCS experimental group was treated through 10 sessions of 13-10-13 tDCS (13 minutes of performing protocol, 10 minutes break, 13 minutes of treatment). The cup stacking experimental group was treated through 10 sessions of the cup stacking game, lasting 30 minutes each. The control group received no interventions. After completing the sessions, the assessment tools were again administered for all three groups. Furthermore, there was a follow-up test one month after the experiment to examine the persistence of the two interventions.

Findings

The average age of the tDCS group was 10.11, of the cup stacking was 10.02, and for the control group was 10.9. Table 1 shows the descriptive index of the study variables.

Table 1.
Descriptive Index of Processing Speed and Working Memory in the Three Groups

Variable	Phases	Pre-Test		Post-Test		Follow-up	
		Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation
Processing Speed	tDCS group	26.40	8.02	32.07	8.95	34.87	7.54
	Cup stacking group	29.79	4.58	35.14	6.83	37.43	4.89
	Control group	29.87	4.42	30.67	4.27	30.53	3.76
Working Memory	tDCS group	14.20	3.53	17.33	3.87	18.40	3.58
	Cup stacking group	13.79	2.78	15.93	3.34	16.79	3.51
	Control group	14.13	2.36	14.53	1.92	14.93	2.31

Table 1 shows that the average scores of processing speed and working memory increased at post-test and follow-up, compared to pre-test. The rate of increase in the cup stacking group was slightly higher than in the tDCS group, while the processing speed in pre- and post-tests, as well as in follow-up, did not show a significant difference.

Mixed variance analysis was also used to examine the significance of the scores. Shapiro Wilkes Test was used to examine the hypothesis of the normal distribution of the dependent variable scores. The results showed that the level of significance for "z" statistics in the Shapiro Wilkes Test was not significant for processing speed and working memory variables (p>0.05), so the hypothesis of dependent variable normality was shown to be true. Further, the hypothesis of variance homogeneity was examined and found to be true. The Chariot test was used for processing speed ($x^2(2)$=2.191, p>0.05) and for working memory ($x^2(2)$=0.882, p>0.05), and showed that in-group variance analysis was in line with Chariot values. Levin test showed that the assumption of variance homogeneity was valid, and parametric analysis can be performed on the data (processing speed F=2.58, P=0.86; working memory F=4.23, P=0.49).

Table 2.
Summary of Mixed Variance Analysis for Processing Speed

Groups	Factors	Change Resources	Sum of Square	Degree of Freedom	Square's Average	F	Significance	Effect Size
TDCS Control	Within-groups factor	Intervention phases	330.867	2	165.433	14.823	.000	.346
		Steps * phases	232.822	2	116.411	10.431	.000	.271
		Error	382.917	54	7.091			
	Between-groups factor	Group	12.844	1	12.844	.123	.728	.004
		Error	2920.089	28	104.289			
CUP Control	Within-groups factor	Intervention phases	269.358	2	134.679	18.993	.000	.413
		Steps * phases	181.726	2	90.863	12.814	.000	.322
		Error	948.740	82	11.570			
	Between-groups factor	Group	307.698	1	307.698	5.418	.028	.167
		Error	1533.383	27	56.792			
TDCS CUP	Within-groups factor	Intervention phases	982.186	2	491.093	29.811	.000	.525
		Steps * phases	2.508	2	1.254	.076	.927	.003
		Error	889.584	54	16.474			
	Between-groups factor	Group	196.553	1	196.553	1.702	.203	.059
		Error	**3118.183**	**27**	**115.488**			

The results of Table 2 show that in terms of the within-groups factor, there is a significant difference between the F score for the intervention stages between the tDCS experimental group and the control group, and also between the cup stacking experimental group and the control group. However, there was no significant difference between the two experimental groups (tDCS and CUP stacking). The effect size for cup stacking was (Eta^2 = 0.322) and for tDCS was (Eta^2 = 0.271). According to Cohen, the square of Eta is equal to 0.01 indicates a small effect size, 0.06 indicates a medium effect size, and 0.14 indicates a large effect size; thus, both cup stacking and tDCS were effective in improving processing speed. The effect on the cup stacking group was slightly greater than on the tDCS group, but this difference was not statistically significant.

In terms of between-groups factors, there was a significant difference between F scores for the cup stacking and control groups. The effect size for cup stacking was (Eta^2 = 0.167), but there was no significant difference between tDCS and control, nor between cup stacking and tDCS.

Table 3.
Summary of Mixed Variance Analysis for Working Memory

Groups	Factors	Change Resources	Sum of Square	Degree of Freedom	Square's Average	F	Significance	Effect Size
TDCS Control	Within groups factor	Intervention phases	99.089	2	49.544	30.981	.000	.525
		Steps * phases	48.689	2	24.344	15.223	.000	.352
		Error	89.556	56	1.599			
	Between groups factor	Group	100.278	1	100.278	4.140	.051	.129
		Error	678.178	28	24.221			

Groups	Factors	Change Resources	Sum of Square	Degree of Freedom	Square's Average	F	Significance	Effect Size
CUP Control	Within groups factor	Intervention phases	54.278	2	27.139	14.902	.000	.356
		Steps * phases	19.519	2	9.760	5.359	.008	.166
		Error	98.343	54	1.821			
	Between groups factor	Group	20.300	1	20.300	1.071	.310	.038
		Error	511.700	27	18.952			
TDCS CUP	Within groups factor	Intervention phases	201.260	2	100.630	68.932	.000	.719
		Steps * phases	5.950	2	2.975	2.038	.140	.070
		Error	78.832	54	1.460			
	Between groups factor	Group	28.453	1	28.453	.863	.361	.031
		Error	**890.144**	**27**	**32.968**			

The results of Table 3 show that in terms of within-groups factors, there was a significant difference between the F score for the intervention stages between the tDCS experimental group and the control group, as well as between the cup stacking experimental group and the control group. However, there was no significant difference between the two experimental groups (tDCS and cup stacking). The effect size for cup stacking was (Eta^2 = 0.166) and for tDCS was (Eta^2 = 0.352). Therefore, both tDCS and cup stacking methods affect working memory. While the effect of the tDCS group was slightly more than cup stacking group, this difference was not statistically significant. Also, in terms of between-groups factors, there was a significant difference between the F score for tDCS and control groups; the effect size for tDCS was (Eta^2 = 0.129). However, there was no significant difference between cup stacking and control, nor between cup stacking and tDCS.

Discussion and Conclusion

In this study, the tDCS experimental group received direct anodal electrical stimulation in the dorsal lateral region of the right hemisphere prefrontal cortex, and the cathode or reference electrode was placed on the frontal region of the left eyeball. They received 35 units of electrical stimulation for 10 sessions (10 consecutive days). With the cup stacking group, 10 sessions of the cup stacking game were performed. In these sessions, a specific plan was followed, in the form of a hierarchy of participant skills, including perceptual-motor skills, speed of action, accuracy, attention and focus, and ability to cooperate.

The results of this study showed that tDCS and cup stacking methods both have a positive effect on the processing speed and working memory of students with ADHD. However, there was no significant difference found in terms of their effectiveness in improving working memory and processing speed. Therefore, the results of this study are in accordance with those of Tretriluxana et al. (2015) and Udermann et al. (2004), who showed that the cup stacking game improves processing speed. The findings are also in line with those of Meyer et al. (2016) and Udermann et al. (2004) in showing that cup stacking impacts on executive functions and working memory. Additionally, the results of this study are in accordance with those of Ptaceck et al. (2019) as well as Salehi Nejad et al. (2019) who demonstrated that tDCS improves processing speed. This study results are also consistent with the results of Jacoby and Lavidor (2018) and Rubia (2018), showing that tDCS improves working memory in individuals with ADHD.

As a motor-perception sport, the cup stacking game is an applicable task which simultaneously engages both hemispheres, increasing information processing speed and motor-perceptual coordination, and improving reaction time (Udermann et al., 2004). Since working memory is a foundational task of cognitive processing, an improvement in information processing may also be manifested in its foundational capacities (Vilena et al., 2019). The more the individual can self-process simple tasks in a speedy and effective way, the more they can dedicate their attention and working memory to compete complicated tasks (Rowland, 2013).

Many research studies have shown that information processing speed and working memory can be improved, and that games and practical activities may increase processing speed (Ramani et al., 2019). The cup stacking game in this study, therefore, helped to reduce reaction time and to improve cognitive processing speed in subjects through practice and learning skills. Similarly, Udermann et al. (2004) showed that motor-perceptual activities like cup stacking improve student reaction times.

Motor-perceptual games help with hand-eye coordination, which would then improve basic abilities like perception, working memory, information processing, decision-making, and reaction speed (Pavan et al., 2019). Given the significance of this topic and regarding the present study's results, cup stacking may be considered as both an entertaining game and a therapeutic intervention to improve executive functions in students with ADHD. Since cup stacking helps to improve executive functions such as working memory and processing speed, it is recommended to be included in the curriculum in order to improve student motor-perceptual skills.

From a neurophysiological-anatomical perspective, working memory (along with other processes) is involved in the frontal lobe and neural networks, the evidence shows that working memory has a different performance foundation from other executive functions (Abellaneda et al., 2020). Working memory is one of the foundational functions essential to complete cognitive tasks, and it depends on prefrontal cortex function (Omary et al., 2019). As a core executive function, working memory directs many cognitive functions. Therefore, its improvement may help to improve many other cognitive abilities (van Abswoude et al., 2020). tDCS slightly and directly charges the cortex and facilitates or inhibits spontaneous neural activity. In this study, the prefrontal cortex of the tDCS experimental group was stimulated. tDCS may possibly increase Long-Term Potentiation (LTP) in the prefrontal lobe, which deals with executive functions like memory and processing speed (Nissim et al., 2019). Recognized as a foundation in learning and memory, LTP is a well-received model of neural plasticity. tDCS helps potentiate a long-term increase in neural transmitters, one that can last for several months and originates in pre- and post-synaptic activities. tDCS can increase pre-synaptic activities, along with post-synaptic depolarization, which would result in LTP, eventually leading to improved cognitive foundations (Wang et al., 2019). Additionally, tDCS increases dorsolateral prefrontal cortex excitability, which would then increase the level of glutamate amino acid, involved in working memory, memory recall, and timely response to stimulus (Abellaneda et al., 2020). By exciting regions F3 and F4, tDCS also results in improving working memory and processing speed, as well as increasing the brain's capacity to process incoming information (Nikolin et al., 2019). It is possible to conclude, then, that tDCS helps to improve working memory and cognitive processing speed by enhancing brain plasticity.

Considering the effectiveness of cup stacking games and tDCS to improve working memory and processing speed in students with ADHD, these therapeutic methods can be used to improve executive functions in students with attention deficit. Also, as there was no significant difference between these intervention methods in terms of improving working memory and cognitive processing speed, it is recommended that school teachers use cup stacking as an available tool at school, while child deficiency specialists use tDCS in appropriate controlled settings.

This study had some limitations, especially in terms of controlling variables such as individual subject differences, and psychological issues like anxiety and stress. Furthermore, as the study sample included students with ADHD of the attention deficit type, the results should only be generalized with caution.

References

Abellaneda-Pérez, K., Vaqué-Alcázar, L., Perellón-Alfonso, R., Bargalló, N., Kuo, M. F., Pascual-Leone, A., & Bartrés-Faz, D. (2020). Differential tDCS and tACS effects on working memory-related neural activity and resting-state connectivity. *Frontiers in Neuroscience*, *13*, 14-40.

Allenby, C., Falcone, M., Bernardo, L., Wileyto, E. P., Rostain, A., Ramsay, J. R., & Loughead, J. (2018). Transcranial direct current brain stimulation decreases impulsivity in ADHD. *Brain Stimulation*, *11*(5), 974-981.

Al-Yagon, M., Forte, D., & Avrahami, L. (2017). Executive functions and attachment relationships in children with ADHD: Links to externalizing/ internalizing problems, social skills, and negative mood regulation. *Journal of Attention Disorders*, 1087054717730608.

American Psychiatric Association (2013). *Diagnostic and Statistical Manual of Mental Disorders (DSM-5®)*. American Psychiatric Pub.

Amirasadi, A. (2013). *Comparison of executive function and creativity in students with high and low academic achievement*. Master Thesis in Psychology. University of Tehran.

Arjmand N., Ali, A., & Shokouhi Yekta, M. (2008). *Improving working memory*, Tehran: Tabib and Teymourzadeh Publishing.

Bandeira, I. D., Guimarães, R. S. Q., Jagersbacher, J. G., Barretto, T. L., de Jesus-Silva, J. R., Santos, S. N., & Lucena, R. (2016). Transcranial direct current stimulation in children and adolescents with attention-deficit/hyperactivity disorder (ADHD): A pilot study. *Journal of Child Neurology*, *31*(7), 918-924.

Bikson, M. (2016). Safety of transcranial direct current stimulation: Evidence based update 2016. *Journal of Brain Stimulation*, *9* (16), 641–661.

Bush, G., Spencer, T. J., Holmes, J., Shin, L. M., Valera, E. M., Seidman, L. J., & Biederman, J. (2008). Functional magnetic resonance imaging of methylphenidate and placebo in attention-deficit/hyperactivity disorder during the multi-source interference task. *Archives of General Psychiatry*, *65*(1), 102-114.

Cachoeira, C. T., Leffa, D. T., Mittelstadt, S. D., Mendes, L. S. T., Brunoni, A. R., Pinto, J. V., & Grevet, E. H. (2017). Positive effects of transcranial direct current stimulation in adult patients with attention-deficit/hyperactivity disorder: A pilot randomized controlled study. *Psychiatry Research*, *247*, 28-32.

Colomer, C., Berenguer, C., Roselló, B., Baixauli, I., & Miranda, A. (2017). The impact of inattention, hyperactivity/impulsivity symptoms, and executive functions on learning behaviors of children with ADHD. *Frontiers in Psychology*, *8*, 54-60.

De Zeeuw, E. L., Hottenga, J. J., Ouwens, K. G., Dolan, C. V., Ehli, E. A., Davies, G. E., & van Bergen, E. (2019). Intergenerational transmission of education and ADHD: Effects of parental genotypes. *BioRxiv*, *66*, 28-41.

Fadai, A., Bigdeli, I., & Miladi Gorji, H. (2015). Evaluation of working memory and prospective memory performance in methamphetamine and quit addicts. *Journal of North Khorasan University of Medical Sciences*, *6* (4), 861-873.

Fällman, K., Lundgren, L., Wressle, E., Marcusson, J., & Classon, E. (2019). Normative data for the oldest old: Trail Making Test A, Symbol Digit Modalities Test, Victoria Stroop Test and Parallel Serial Mental Operations. *Aging, Neuropsychology, and Cognition*, 1-14.

Granados, C., & Wulf, G. (2007). Enhancing motor learning through dyad practice: contributions of observation and dialogue. *Research Quarterly for Exercise and Sport*, *78*(3), 197-203.

Gillick, B., Feyma, T., Menk, J., Usset, M., Vaith, A., Wood, T.J., Worthington, R., & Krach, L.E. (2015). Safety and feasibility of transcranial direct current stimulation in pediatric hemiparesis. *Randomized Controlled Preliminary Study Physical Therapy*, *95*(3), 337-345.

Hart, M. A., Smith, L. A., & DeChant, A. (2005). Influence of participation in a cup-stacking unit on timing tasks. *Perceptual and Motor Skills*, *101*(3), 869-876.

Hesapçioglu, S. T., & Çelik, P. C. (2016). Analyzing the Wechsler Intelligence Scale for Children-Revised (WISC-R) in children with Attention Deficit Hyperactivity Disorder. *Predictive Value of Subtests, Kaufman, and Bannatyne Categories, Turkey.*

Jacoby, N., & Lavidor, M. (2018). Null tDCS effects in a sustained attention task: the modulating role of learning. *Frontiers in Psychology*, *9*, 476-485.

Jiang, X., Liu, L., Ji, H., & Zhu, Y. (2018). Association of affected neurocircuitry with deficit of response inhibition and delayed gratification in attention deficit hyperactivity disorder: a narrative review. *Frontiers in Human Neuroscience*, *12*, 506-512.

Lessa, H. T., & Chiviacowsky, S. (2015). Self-controlled practice benefits motor learning in older adults. *Human Movement Science*, *40*, 372-380.

Liu, L., Chen, W., Sun, L., Cheng, J., Su, Y., Rudaizky, D., & Wang, Y. F. (2017). The characteristics and age effects of emotional lability in ADHD children with and without oppositional defiant disorder. *Journal of Attention Disorders*, 1087054717745594.

Meyer, M., van der Wel, R. P., & Hunnius, S. (2016). Planning my actions to accommodate yours: joint action development during early childhood. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *371*(1693), 201-212.

Mohammad Esmail, E. (2003). *Evaluation of validity, validity and determination of cutting points of disorders of CSI-4 pediatric symptom questionnair*e. Tehran: Exceptional Children Research Institute.

Nikolin, S., Lauf, S., Loo, C. K., & Martin, D. (2019). Effects of high-definition transcranial direct current stimulation (HD-tDCS) of the intraparietal sulcus and dorsolateral prefrontal cortex on working memory and divided attention. *Frontiers in Integrative Neuroscience*, *12*, 64-75.

Nissim, N. R., O'Shea, A., Indahlastari, A., Kraft, J. N., Von Mering, O., Aksu, S., & Woods, A. J. (2019). Effects of transcranial direct current stimulation paired with cognitive training on functional connectivity of the working memory network in older adults. *Frontiers in Aging Neuroscience*, *11*, 340-349.

Omary, A., & Persky, A. M. (2019). Changes in working memory performance over an academic semester in student pharmacists. *American Journal of Pharmaceutical Education*, *83*(10).

Pavan, A., Hobaek, M., Blurton, S. P., Contillo, A., Ghin, F., & Greenlee, M. W. (2019). Visual short-term memory for coherent motion in video game players: Evidence from a memory-masking paradigm. *Scientific Reports*, *9*(1), 1-16.

Ptacek, R., Weissenberger, S., Braaten, E., Klicperova-Baker, M., Goetz, M., Raboch, J., & Stefano, G. B. (2019). Clinical implications of the perception of time in Attention Deficit Hyperactivity Disorder (ADHD): A Review. *Medical Science Monitor: International Medical Journal of Experimental and Clinical Research*, *25*, 18-39.

Ramani, G. B., Daubert, E. N., Lin, G. C., Kamarsu, S., Wodzinski, A., & Jaeggi, S. M. (2019). Racing dragons and remembering aliens: Benefits of playing number and working memory games on kindergartners' numerical knowledge. *Developmental Science*, e12908.

Rowland, J.E. (2013). *Discriminative ability of CHC factor scores from the WJ III tests of cognitive abilities in children with ADHD*. Doctoral Dissertation. Oklahoma State University.

Rubia, K. (2018). Cognitive neuroscience of attention deficit hyperactivity disorder (ADHD) and its clinical translation. *Frontiers in Human Neuroscience*, *12*, 100-112.

Ruchinskas, R. (2019). Wechsler adult intelligence scale-digit span performance in subjective cognitive complaints, amnestic mild cognitive impairment, and probable dementia of the Alzheimer type. *The Clinical Neuropsychologist*, *33*(8), 1436-1444.

Salehinejad, M. A., Wischnewski, M., Nejati, V., Vicario, C. M., & Nitsche, M. A. (2019). Transcranial direct current stimulation in attention-deficit hyperactivity disorder: A meta-analysis of neuropsychological deficits. *PloS one*, *14*(4).

Schlaug, G., Marchina, S., & Wan, C.Y. (2011). The use of non-invasive brain stimulation techniques to facilitate recovery from post-stroke aphasia. *Neuropsychol Rev*., *21*(3),288-301.

Schwörer, M. C., Reinelt, T., Petermann, F., & Petermann, U. (2020). Influence of executive functions on the self-reported health-related quality of life of children with ADHD. *Quality of Life Research*, 1-10.

Sellers, K. K., Mellin, J. M., Lustenberger, C. M., Boyle, M. R., Lee, W. H., Peterchev, A. V., & Fröhlich, F. (2015). Transcranial direct current stimulation (tDCS) of frontal cortex decreases performance on the WAIS-IV intelligence test. *Behavioral Brain Research*, *290*, 32-44.

Shiran, A., & Breznitz, Z. (2011). Cognitive training on recall range and speed of information processing in the working memory of dyslexic and skilled readers. *Journal of Neurolinguistics*, *24*, 524–537.

Sibley, M. H., Graziano, P. A., Ortiz, M., Rodriguez, L., & Coxe, S. (2019). Academic impairment among high school students with ADHD: The role of motivation and goal-directed executive functions. *Journal of School Psychology*, *77*, 67-76.

Soff, C., Sotnikova, A., Christiansen, H., Becker, K., & Siniatchkin, M. (2017). Transcranial direct current stimulation improves clinical symptoms in adolescents with attention deficit hyperactivity disorder. *Journal of Neural Transmission*, *124*(1), 133-144.

Tretriluxana, J., Taptong, J., & Chaiyawat, P. (2015). Dyad training protocol on learning of bimanual cup stacking in individuals with stroke: Effects of observation duration. *Journal of the Medical Association of Thailand:Chotmaihet thangphaet*, *98*, 106-112.

Udermann, B. E., Mayer, J. M., Murray, S. R., & Sagendorf, K. (2004). Influence of cup stacking on hand-eye coordination and reaction time of second-grade students. *Perceptual and Motor Skills*, *98*(2), 409-414.

van Abswoude, F., Buszard, T., van der Kamp, J., & Steenbergen, B. (2020). The role of working memory capacity in implicit and explicit sequence learning of children: Differentiating movement speed and accuracy. *Human Movement Science*, *69*, 102-116.

Villena-González, M., Rubio-Venegas, I., & López, V. (2020). Data from brain activity during visual working memory replicates the correlation between contralateral delay activity and memory capacity. *Data in Brief*, 28, 105-114.

Wang, N., Wang, Z., Yan, F., & Fu, W. (2019). Correlation between single nucleotide polymorphisms of neurotrophic factors and executive function characteristics in children with attention deficit hyperactivity disorder. *Wei sheng yan jiu Journal of Hygiene Research*, *48*(4), 577-582.

Wang, P., Yang, L., Liu, L., Sun, L., An, L., & Wang, Y. F. (2020). Altered brain white matter microstructural asymmetry in children with ADHD. *Psychiatry Research*, 112-117.

Woods, A. J., Antal, A., Bikson, M., Boggio, P. S., Brunoni, A. R., Celnik, P., & Knotkova, H. (2016). A technical guide to tDCS, and related non-invasive brain stimulation tools. *Clinical neurophysiology*, *127*(2), 1031-1048.

Zaehle, T., Sandmann, P., Thorne, J.D., Jancke, L., & Herrmann, C. S. (2011). Transcranial direct current stimulation of the prefrontal cortex modulates working memory performance: combined behavioral and electro physiological evidence. *BMC Neurosci.*,*12*(2),1-11.

How to Site: Feiz, P., Emamipour, S., Hassani-Abharian, P., & Kooshki, S. (2020). Comparing cup stacking and transcranial direct current stimulation on working memory and processing speed. *Iranian Journal of Learning and Memory*, *3*(11), 61-68. doi: 10.22034/iepa.2021.247006.1206