Research Paper

The Effect of Involuntary Tactile Stimulation on the Creativity and Rey Auditory-Verbal Memory of Young Adults

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Citation Estahbanati, F., Rezaeinasab, M., Akbari Chermahini, S., Mirzaeekia, H., Azin, M., and Shamsizadeh, A. (2022). The Effect of Involuntary Tactile Stimulation on the Creativity and Rey Auditory-Verbal Memory of Young Adults. *Basic and Clinical Neuroscience*, *13*(6), 755-764. http://dx.doi.org/10.32598/bcn.2022.147.4

http://dx.doi.org/10.32598/bcn.2022.147.4

Article info:

Received: 04 May 2021

First Revision: 08 Jun 2021

Accepted: 02 Aug 2021

Available Online: 01 Nov 2022

Keywords:

Tactile stimulation, Creativity, Remote association task, Alternative uses test, Memory

ABSTRACT

Introduction: Recent studies have revealed the possibility of learning skills through alternative methods and repetitive tactile stimulation without explicit training. This study aimed to examine the effect of involuntary tactile stimulation on the memory and creativity of healthy participants.

Methods: A group of 92 right-handed students participated in this study voluntarily. They were assigned to the experimental (n=45) and control (n=47) groups. The participants performed two creativity tests (divergent and convergent thinking) and a verbal memory task as the pretest. Then, the experimental group received 30-min involuntary tactile stimulation on the right index finger, and the control group did not. In the posttest, both groups were asked to perform the creativity and verbal memory tasks again.

Results: The learning score and speed of the Rey auditory-verbal learning test in the stimulation group significantly increased (P=0.02). Moreover, in the creativity-related tests, there was a significant effect of the intervention on convergent thinking, i.e., the remote association task (P=0.03), but not for the divergent thinking, i.e., the alternative uses test (P>0.05).

Conclusion: Using involuntary tactile stimulation on the index finger of the right hand of individuals could enhance their performance in verbal memory and creativity-convergent thinking.

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Highlights

- Involuntary tactile stimulation increase verbal learning skills in young adults
- Convergent thinking will increase following involuntary tactile stimuli
- However it seems that divergent thinking less affected by tactile stimuli

Plain Language Summary

There are two type of learning. Learning to drive a car is an implicit memory (no need for high consciousness). However memorizing a poem is an explicit ability (need to be highly conscious). Recent studies have revealed that some alternative implicit rehearsals can improve explicit cognitive skills in human. Here we studied whether involuntary tactile stimulation on fingers could improve some explicit cognitive abilities in human. Our results demonstrated that both verbal based memories and creativity get better following involuntary tactile stimulation.

1. Introduction

Traditionally, training is required to learn a skill. Nevertheless, recent studies have revealed that some alternative implicit rehearsals can improve explicit cognitive skills in humans. Beste and Dinse (2013) believed that involuntary tactile stimulation seems to be a good candidate as a rehearsal to improve cognition. The particular advantage of this stimulation which is a kind of sensory training-independent learning is its passive nature: individuals do not require active participation or attention. So, this technique is very easy to implement in individuals (Beste & Dinse, 2013). Nieuwenhuis et al. (2013) reported that intermittent sensory stimulations on hands could boost memory retrieval. Also, involuntary tactile stimulation with different frequencies can increase sensory and motor functions and treat inappropriate synaptic connections and non-adaptive formations (Nieuwenhuis et al., 2013). Kalisch et al. stated that repetitive electric stimulation on the fingers could cause a roughly stable improvement of the sensory and motor functions in humans (Kalisch T, 2010). This effect was also observed in stroke patients (Peurala S, 2002). Tactile stimulation can have a considerable effect on improving behavior as well as enhancing cognition and perception (Dow. 2021).

One of the higher-order human cognitive performances is creative problem-solving. Creativity is defined as new and imaginative ideas which result in novel solutions to problems. In other words, creativity consists of generating new ideas or rearranging the known elements in a new format that can provide a valid solution to a problem (Dow. 2021). Guilford et al. hypothesized that both convergent and divergent thinking could be distinguished from creative thinking. Convergent thinking finds one answer to a problem triggering much attention, while divergent thinking generates many answers for a given problem (Guilford, 1967).

The Rey auditory-verbal learning test (RAVLT) is a neuropsychological task based on a word list learning paradigm. RAVLT assesses some features of verbal memory, including immediate recall, verbal learning, susceptibility to both proactive and retroactive interference, recognition memory, and retention of the information after a certain time during which other activities are performed. The test was developed by Rey (Rey, 1958) and later modified based on the language and culture of different nations. The Persian version of RAVLT was developed by some authors considering different age groups (Jafari, et al., 2010; Zahra Jafari, et al., 2010; Sadeghi, et al., 2014).

Considering the effects of involuntary tactile stimulation on some aspects of cognitive functions (synaptic plasticity, neuronal activity, and memory), the present study aimed to examine the effect of involuntary tactile stimulation (applied on the right index finger) on the creativity and verbal explicit learning and memory, also known as important cognitive functions, in healthy volunteer students.

2. Materials and Methods

This cross-sectional study employed a randomized controlled pretest-posttest design with a control group.

Study participants

A total of 100 healthy right-handed students (aged 18-30 years) of Shiraz University of Medical Sciences were selected through public notification. All eligible participants signed an informed consent after the nature of the study was explained to them. The Ethics Committee of Rafsanjan University of Medical Sciences approved the study's protocol (IR.RUMS.REC.1396.59). The inclusion criteria were as follows: lacking any known neurodegenerative diseases and psychiatric disorders, and not using any drugs affecting memory. In this respect, the eligible individuals were randomly divided into two groups: the control and the tactile stimulation groups (n=50 in each group). Some participants that did not complete the procedure or submitted irrelevant data were excluded. Ultimately, the data of 45 students (11 men and 34 women) in the experimental (tactile stimulation) group and that of 47 students (15 men and 32 women) in the control (no stimulation) group were statistically analyzed.

Study procedure

The study's protocol was that a convergent thinking test, i.e., the remote association task (RAT), was firstly administered, which lasted for 10 min. Then, there was a 2-min break, and the participants could only drink water. Afterward, a divergent thinking test, i.e., the alternative uses test (AUT), was conducted for 3 min, with a 2-min interval. Finally, the RAVLT was taken. Subsequently, a 30-min tactile stimulation was applied to each volunteer of the experimental group to the right-hand index finger (for the control group, the device was connected for the same duration to the same finger but without any stimulation). Then around 5 min later, RAT, AUT, and RAVL were repeated, similar to the stage prior to the tactile stimulation (Figure 1). The Edinburgh Inventory was used to assess participants' handedness (Oldfield, 1971).

Tactile stimulation

The tactile stimulation device, manufactured in Iran (Mahan Sanat- Kavosh Pars Co), was used to create involuntary tactile stimulation (Figure 2). The device consisted of a control unit and the stimulation modules connected to the hand. The stimulation modules had protruding pins that could stimulate the tip of the right-hand index finger controlling by custom-designed software (control unit). The stimulation frequency was 16 Hz, and the height of the pins was 1.5 mm. The protocol lasted for 30 minutes.

Study measures

Remote association task (RAT)

This test was used to examine convergent thinking. RAT usually assesses creativity and consists of 20 items (three words/item). These words could be combined in different ways. For example, the participants could make a compound word, find a common feature in words, or even build a new meaning by connecting them (for example, the common feature of "call, cost, and line" on his phone). Creative thinking was required to find a valid solution because the first and the most obvious solution was not often correct. Therefore, there was a need to build more connections to associate the three words together. The response time for this test was 10 minutes (Colzato et al., 2013). The validity and reliability of the Persian version of this test have already been reviewed and approved by Akbari et al. (2019).

Alternative uses test (AUT)

In this test, the participants needed to write down all the possible uses of an everyday object (shoe and brick) in 3 minutes. In addition, scoring consisted of 4 components.

Originality: Each answer was compared with the total number of responses by the participants in the group. Answers provided by 5% of the given group were considered to be unusual and received 1 point, and answers given only by 1% of the group would be regarded as unique and received 2 points.

Fluency: The Sum of all responses was counted, and then they were scored. Each answer was also compared with the total number of responses provided by the participants in the group.

Flexibility: In this section, the answers were categorized based on their similarities. The higher the number of categories, the higher the scores received by a participant. Each answer was compared with the total number of responses given by the participants in the group.

Elaboration: The details of a response were evaluated and scored, i.e., "rubber doorstop" was scored 0, but "rubber doorstop used in order to avoid slamming of the door by the strong wind" was assigned 2 points (1 point for explaining slamming and 1 point for explaining wind). Each answer was then compared with the total number of responses by the participants in the group (Peters, et al., 2009). Scoring of the AUT test was accomplished by an expert who was blinded to the study groups.

Rey auditory-verbal learning test (RAVLT)

This neuropsychological test evaluates verbal memory in people aged 16 and older. This test includes 3 lists of words and 9 steps. First, the software reads 15 words with a frequency of one word per second from list A for the participant. After reading the list, the participant is immediately asked to recall every word and write them down in a form. If a word is no longer recalled by an individual, the same list is read out in similar conditions again, and the responses are inserted in the form. This step is repeated 5 times. After 5 repetitions, list B (known as the interference list, including 15 words that are different from the words in list A) is read out in conditions resembling step one, and then the responses are recorded.

Immediately after recalling list B, the participant is asked to bring to mind the words in list A. After 20 minutes, in which the participant is not allowed to have any verbal intervention, the participant is asked to recall words in list A, considered the delayed recall. Following these 8 steps, a list of 50 words is given to the participant in the recognition step to determine which words belong to list A. This list contains 30 words selected from both lists A and B, as well as 20 new words. The new words having the features of the words in lists A and B were selected in a way that was phonetically or semantically related to the words in these two lists (Jafari et al., 2010; Schoenberg, M. R., et al 2006). According to Ja'fari et al. (Jafari et al., 2010), the words used in the three lists were selected from the corpus of common words frequently used in the Persian Language. It should be noted that there was no semantic and phonetic relationship or even similarity among the words in this test. The variables derived from this test were as follows.

Learning score: the mean of the first 5 steps of the test (the mean of the correct words in the first 5 steps), Immediate recall: the number of the correct words in the seventh step of the test, Delayed recall: the number of correct words in the eighth step of the test, Recognition: the number of correct words in the ninth step of the test, and Learning speed: the number of correct words in the fifth step minus the number of correct words in the first step.

This test was also normalized in different populations, including Persian-speaking children aged 9-11 years old (Sadeghi et al., 2014), the elderly aged 60-80 years (Jafari et al., 2010), women aged 18-30 years, men aged 25-30 years, and children diagnosed with attention deficit hyperactivity disorder (ADHD) (Abraham, 2016).

Statistical analysis

The data were extracted from the custom-designed software (Mahan Sanat- Kavosh Pars Co.) and exported into Excel and SPSS software. One-way between-groups multivariate analysis of covariance (MANCOVA) was performed to investigate the impact of tactile stimulation in AUT, RAT, and RAVLT. The statistical test was used to analyze the estimated marginal means. A P value less than 0.05 was considered the significant difference between the variables.

3. Results

According to the results, the Mean±SD age of the participants was 21±2 years. The study participants comprised 26 men (28%) and 66 women (71%). The majority of participants (90%) were single. Regarding education, all participants in both groups had a bachelor's degree. There was no significant difference between the two groups in terms of age (P=0.7) and gender proportion (P=0.4) (Table 1). So, the two groups are comparable in terms of age and gender.

Remote association task (RAT)

A 1-way between-groups analysis of covariance (ANCOVA) was conducted to compare the effectiveness of involuntary tactile stimulation to improve participants' performance in RAT: a task to measure convergent thinking. The independent variable was the group (the control and the tactile stimulation groups), and the dependent variables consisted of the scores (the correct responses) on the RAT administered after the tactile stimulation was completed. The participants' scores on the pretest were used as a covariate in this analysis.

The preliminary checks were conducted to ensure no violation of the assumptions of normality, homogeneity of variances, homogeneity of regression slopes, and reliable covariate measurement. After adjusting the pre-intervention scores, there was a significant difference between the two groups in the posttest scores on RAT ($F_{1, 88}$=4.872, P=0.03, partial η^2=0.05, observed power= 0.6) (Figure 3).

Alternative uses test (AUT)

A 1-way between-groups multivariate analysis of covariance (MANCOVA) was performed to investigate the impact of involuntary tactile stimulation in divergent thinking as measured by AUT. Four components of AUT are fluency, flexibility, elaboration, and originality, which are considered 4 dependent variables. The independent variables were groups (control and tactile stimulation). The preliminary assumption testing was conducted to check for the normality, linearity, univariate and multivariate outliers (Mahalanobis distance was used to check the multivariate outliers), homogeneity of variance-covariance matrices, and multicollinearity, with no violations noted. There was no significant difference between the two groups on the combined dependent variables ($F_{4, 76}$=0.325, P>0.05, Wilks' Lambda= 0.98). So, considering the results of the dependent variables separately, there were no significant differences between the two groups (all P values >0.05). It means that there is no significant effect of involuntary tactile stimulation on the participants' performance in the divergent thinking task. Table 2 presents the descriptive information of the two groups in the pretest and posttest.

Rey auditory-verbal learning test (RAVLT)

A 1-way between-groups multivariate analysis of covariance (MANCOVA) was performed to investigate the impact of involuntary tactile stimulation in verbal memory as measured by RAVLT. The six scores of RAVLT, including immediate recall, delayed recall, recognition, learning score, learning speed, and the rate of forgetfulness, were considered 6 dependent variables. The independent variables were groups (control and tactile stimulation). The preliminary assumption testing was conducted to check for the normality, linearity, univariate and multivariate outliers (the Mahalanobis distance was used to check the multivariate outliers), the homogeneity of variance-covariance matrices, and the multicollinearity, with no violations noted. There was a significant difference between the two groups on the combined dependent variables ($F_{6, 65}$=2.63, P=0.024, Wilks' Lambda= 0.81, partial η^2=0.195, observed power=0.82). When the results for the dependent variables were considered separately, the only two differences to reach statistical significance were the learning score ($F_{1, 76}$=5.46, P=0.022, partial η^2=0.072, observed power=0.63) and the learning speed ($F_{1, 76}$=5.44, P=0.023, partial η^2=0.072, observed power=0.63). Figure 2 compares the control and tactile stimulation groups in the posttest after controlling for the pretest. Though there was a significantly better performance of the experimental group only in two measures of RAVLT (learning score and learning speed), this group performed better in all the RAVLT scores (Figure 4).

4. Discussion

Creative thinking is central to many aspects of human life, such as the arts and sciences. Guilford has considered convergent and divergent thinking as the main components of creative activities. Employing the involuntary tactile stimulation on the right-hand index finger could improve the learning scores and the learning speed associated with the RAVLT and RAT, while the other variables related to the RAVLT and AUT did not change after the involuntary tactile stimulation. In line with the present study, similar investigations have also been carried out, such as the one by Nieuwenhuis et al. (2013), reporting that the intermittent tactile stimulation from left to the right direction, with a frequency of two beats per second in the participants' hands, could boost memory, probably due to the increased links between the two hemispheres, although the use of intermittent auditory stimulation on the left and right ears did not produce the same results (Nieuwenhuis et al., 2013). The neural circuits that transform the relevant sensory information into cognitive behaviors are poorly understood. Itskov et al. demonstrated that the CA1 neurons are involved in the texture representation and touch-guided behaviors in rats (Itskov, et al., 2011). Interestingly, when rats explore the environment through their whiskers, there are some coherent activities in whisking rhythm, barrel cortex activities, and hippocampal electrical activities. This coherence may increase the efficacy of sensory information on memory and cognition (Grion, et al., 2016). It was also demonstrated that spatial memory strongly requires the processing of tactile information in the hippocampus (de Los Angeles, Del Carmen, Wendy, & Socorro, 2016; Gonzalez-Perez, et al., 2018). Both human and animal studies demonstrated that hippocampal medial prefrontal cortex electrical activities correlate with the retention of information over a brief period, a function crucial for a wide range of cognitive tasks (Stern, et al., 2001). Impaired working memory is observed in several clinical conditions, such as chronic pain (Luerding, et al., 2008). Comparing these results with the findings from the present study, one can conclude that involuntary tactile stimulation may be helpful for learning and creative functions of the brain.

This study also showed little effect of involuntary tactile stimulation on divergent thinking. Some other studies are reporting the difference between convergent and divergent thinking. Clozate et al. investigated conver-

Table 1. Comparing age and gender between the experimental and control groups

Group	Age (y)		Gender, No. (%)	
	n	Mean±SD	Male	Female
Experimental (tactile stimulation)	45	21.12±1.40	11(24.4)	34(75.5)
Control	47	21.22±2.05	15(31.9)	32(68.0)
P	-	0.746[a]	0.412[b]	-

[a] The Mann-Whitney U test. [b] The Chi-Square test.

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gent and divergent thinking (using RAT and AUT tests) during the 6-min moderate and vigorous exercise in two groups of athletes and non-athletes. They reported that convergent and divergent thinking in non-athlete participants was reduced because of exercise, while in athletes, vigorous physical activity could only improve convergent thinking (Colzato et al., 2013). In 2015, Zmigrod et al. tried to study whether the transcranial direct-current-stimulation could increase convergent and divergent thinking in individuals. To this end, they stimulated the dorsolateral prefrontal cortex and the posterior parietal cortex when taking the RAT and AUT in two separate experiments. The results revealed that the stimulation of the posterior parietal area led to better completion of RAT. The stimulation of the posterior parietal area also caused an increase in the insight solutions but reduced the analytic ones due to the role of this area in attention processes (Zmigrod, et al., 2015). In a study on patients with traumatic brain injury, the findings indicated that convergent thinking could be threatened because of medium to severe traumatic brain injury (Rigon, et al., 2018).

In 1967, Guilford defined divergent and convergent thinking as "divergent and convergent thinking are two types of human response to set a problem: divergent thinking is taken to represent a style of thinking that allows many new ideas being generated with more than one correct solution; in contrast, convergent thinking is considered a process of generating one possible solution to a particular problem" (Guilford, 1967). It has been assumed that there are different cognitive mechanisms behind convergent and divergent thinking (Chermahini & Hommel, 2010). Further support for this dissociation comes from a recent EEG study. In this study, the EEG pattern in convergent thinking was mainly in the θ1 band range and occurred more in the right hemisphere. In divergent thinking, the β2 band was more massive in inter-hemispheric connections of the cortex area. These results demonstrated topographical and frequency differences in EEG activities during convergent and divergent thinking (Razoumnikova, 2000). More support could be found in another EEG study by Molle et al. (1996), which examined the differences in the complexity of EEG activity during convergent analytical thinking compared with divergent creative thinking. EEG complexity over the frontal lobe was decreased during convergent thinking, while it increased during divergent thinking (Molle et al., 1996). As many

Table 2. Mean (SD) of participants' scores in pre-test and post-test in four components of alternative uses test

Alternative Uses Test	Mean±SD			
	Involuntary Tactile Stimulation Group (n=45)		Control Group (n=47)	
	Pre-test	Post-test	Pre-test	Post-test
Fluency	4.72±2.81	5.33±3.44	4.8±2.84	5.19±3.40
Flexibility	2.93±1.98	3.70±2.76	3.24±1.98	3.40±2.79
Elaboration	4.33±3.66	4.33±4.22	4.89±3.85	3.90±4
Originality	0.51±0.96	1.19±1.89	1.02±1.61	0.79±1.63

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There was no significant difference between the two groups on the combined dependent variables, $F_{4, 76}$=0.325, P>0.05

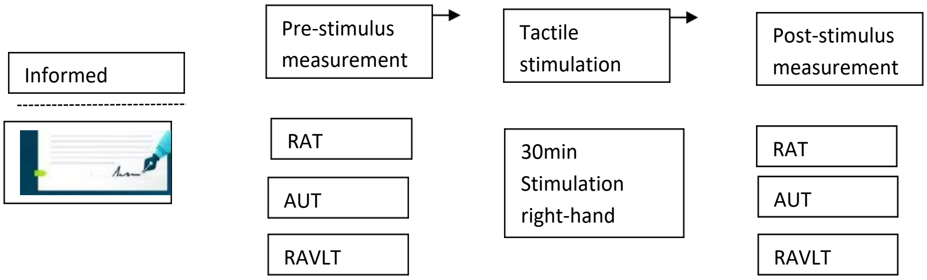

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Figure 1. Sequence of events for the participants performed the creativity tasks before and after tactile stimulation

studies demonstrate different mechanisms involved in RAT and AUT, learning one test does not interfere with learning other tests (Colzato et al., 2013).

It was reported that the efficacy of tactile stimulation depends on the duration and frequency of the stimulation. For example, Godde et al. reported an increase in the threshold of a two-point discrimination task following 2 to 6 hours of tactile stimulation, while reducing stimulation time to 0.5 hours could not improve the discrimination threshold (Godde, et al., 2000). The tactile stimulation of the left index finger at 30 and 300 Hz for 1000 ms positively affects proprioceptive localization (Mikula, et al., 2018). Also, it was reported that tactile stimulation at 20 Hz for 20 min could decrease two-point discrimination in humans. The stimulation protocols resemble those used in cellular long-term potentiation (LTP) and long-term depression (Ragert, et al., 2008). As we aimed to investigate the effect of tactile stimulation on creativity and memory, we chose 30 Hz stimulation for 30 min, which is more likely to induce LTP-like plasticity. However, further studies with different stimulation protocols need to clarify this issue.

The analysis of creativity and RAVLT between men and women revealed no significant differences (data not shown). Men and women with equal finger sizes can enjoy tactile acuity similarly (Peters et al., 2009). Also, it seems that creativity is not different among men and women, while the strategies used by each gender for creativity may be a little different (Abraham, 2016). However, due to the hormonal variations between men and women, more studies are needed to evaluate the effect of sex on tactile-induced creativity.

The Edinburgh Inventory was used to assess the participants' handedness (Oldfield, 1971). Reports indicate the effect of handedness on creativity (Shobe, et al., 2009). Thus, as we aimed to investigate the effect of tactile stimulation on creativity, we chose only right-handed

Figure 2. Stimulation device (see methods)

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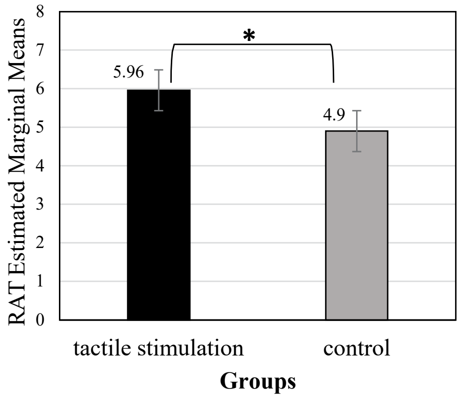

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Figure 3. Estimated marginal means of the correct responses on the remote association task (RAT)

(as a measure of creativity-convergent thinking) posttest (after controlling for the pretest scores using analyses of covariance) in the control (n=47) and involuntary tactile stimulation (n=45) groups, ($^*F_{1, 88}$=4.872, P=0.03).

persons who are more frequent among people. However, in future studies, it is suggested to investigate the effect of handedness and especially inter-hemispheric interactions on tactile stimulation-induced creativity. Also, as the type and density of the sensory receptors are different throughout the body, stimulating other body parts could affect creativity differently. Given that the duration of the involuntary tactile stimulation in this study was half an hour, it is suggested to use longer or more frequent tactile stimulation in future studies. Also, as it was reported that tactile stimulation could increase the primary motor cortex activity (Tanaka et al., 2015), we investigated the effect of tactile stimulation on motor imagery which is important for motor-related skills (Rezaeinasab et al., 2020).

5. Conclusion

Results of this study demonstrated that involuntary tactile stimulation could improve the learning scores and the learning speed associated with the RAVLT and RAT.

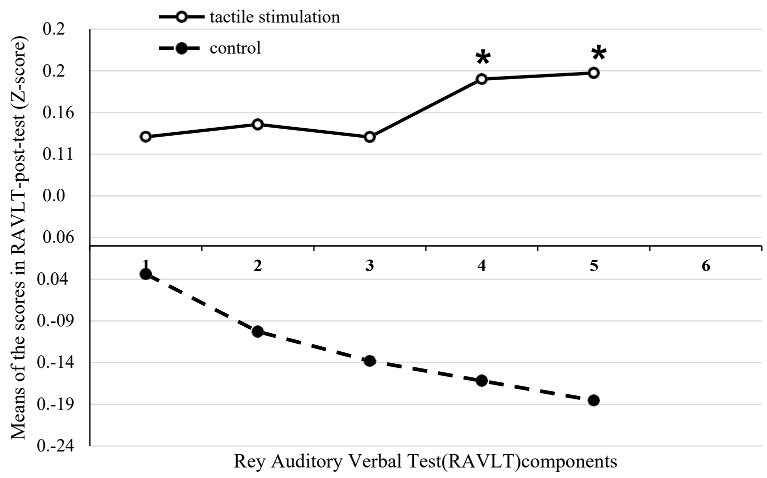

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Figure 4. Comparing the mean scores using MANCOVA

In z score of the control (n=47) and the involuntary tactile stimulation (n=45) groups in the posttest after controlling for the pretest in Rey auditory-verbal learning test (RAVLT)

The numbers in X-axes represent 6 RAVLT as a measure of memory scores: 1) immediate recall, 2) delayed recall, 3) recognition, 4) learning score, and 5) learning speed, with a significant difference in learning score and speed (*Learning score $F_{1, 76}$= 5.46, P=0.022 and the learning speed, $F_{1, 76}$=5.44, P=0.023).

Ethical Considerations

Compliance with ethical guidelines

All eligible participants signed an informed consent after the nature of the study was explained to them. The Ethics Committee of Rafsanjan University of Medical Sciences approved the study's protocol (IR.RUMS.REC.1396.59).

Funding

This study was funded by Kerman University of Medical Sciences and the Iran National Science Foundation (Grant No.: 96000575).

Authors' contributions

All authors equally contributed to preparing this article.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgments

We express our gratitude to all students of Shiraz University of Medical Sciences. We also like to thank Soghra Akbari Chermahini for her assistance with the English editing of the article.

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