Asian J Sports Med. 2016 September; 7(3):e38633. doi: 10.5812/asjsm.38633.

Published online 2016 August 30. **Research Article**

The Effect of 20 Minutes Scuba Diving on Cognitive Function of Professional Scuba Divers

Seyedeh Faezeh Pourhashemi,[1] Hedayat Sahraei,[2] Gholam Hossein Meftahi,[2,*] Boshra Hatef,[2] and Bahareh Gholipour[3]

[1]Faculty of Sport Science, University of Allameh Tabataba'i, Tehran, IR Iran
[2]Neuroscience Research Center, Baqiyatallah University of Medical Sciences, Tehran, IR Iran
[3]Faculty of Sports and Physical Education, University of Ferdowsi, Mashhad, IR Iran

[*]*Corresponding author*: Gholam Hossein Meftahi, Neuroscience Research Center, Baqiyatallah University of Medical Sciences, Tehran, IR Iran. Tel/Fax: +98-2126127286, E-mail: hossein.meftahi@bmsu.ac.ir; meftahi208@yahoo.com

Received 2016 April 24; **Revised** 2016 July 05; **Accepted** 2016 July 20.

Abstract

Background: Physical activity increases the performance of the nervous system by stimulating the body's metabolism and improving the efficiency of the ATP production system.
Objectives: In the present study, the effect of twenty minutes scuba diving in high depth (10m) on cognitive function and stress system activity was investigated.
Methods: Twelve professional scuba divers with a mean age of 23 ± 1 year, weight of 80 ± 2.5 kg and height of 1.79 ± 3.5 cm resident in the city of Mashhad participated in the test. Their cognitive functions were measured 60 min before and 20 min after diving and the data were evaluated using the PASAT software. In the present study, parameters such as general mental health, sustained attention, average response speed, and mental fatigue were measured. Moreover, in order to determine the activity of the stress system, their salivary cortisol was collected before and after diving.
Results: Results revealed that, the general mental health of these scuba divers was normal and it did not undergo a remarkable change after diving. Their average response speed and sustained attention had a significant decrease after scuba diving. Mental fatigue after diving increased. Also, salivary cortisol level significantly increased after diving.
Conclusions: According to our data, it seems that scuba diving as stress stimulant increases cortisol level and therefore reduces cognitive performance after diving.

Keywords: Cognitive Function, Mental Fatigue, Processing Speed, Salivary Cortisol, Sustained Attention, PASAT

1. Background

As the main factor distinguishing human-beings from other creatures, cognitive activities are particularly important in regulating people's relationships together and with the environment. It seems that these activities can be influenced by the environmental changes. For instance, it has been shown that stress may be able to reduce cognitive activities such as the memory function (1). Stress is a state of threatened homeostasis that is counteracted by adaptive processes involving biochemical, physiological, affective, and cognitive behavioral responses in an attempt to recover homeostasis (2). It has been shown that stress may damage the hippocampus, which is involved in cognitive function, caused by neurochemicals or metabolic challenges (3-5). Moreover, cognitive ability such as judgment can be affected by environmental factors (6). Also, drug abuse as a stress factor could damage the central nervous system (7, 8). Various environmental factors can stimulate the synthesis and secretion of cortisol due to the activity of the hypothalamus-pituitary-adrenal (HPA) axis. Increase in cortisol level is considered as a main factor in reducing cognitive activity (9). These disturbances may affect the cognitive function temporarily or permanently (10). The prefrontal, temporal, parietal and occipital lobes and subcortical regions such as the hippocampus are the main area of the brain which is involved in cognitive functions (10). Stress affects in memory and cognitive functions in many ways (11). Moderate stress during learning can facilitate information storage, but excessive or severe stress chronically can be highly harmful to memory function (12). Stress can enhance a person's susceptibility to false memories which is mediated through the impact of stress on the hippocampus and prefrontal cortex (12).

Diving with an independent breathing apparatus

(SCUBA) has become a global sport. Effects of diving on cognitive functions have been previously demonstrated (13). Some of these studies have shown the neurologic effects of diving. Di Piero et al. (2002) (14) reported that cerebral perfusion abnormalities occurred under high pressure oxygen breathing in professional divers. Furthermore, Tetzlaff et al. (15) showed that elderly former professional divers were at risk of detrimental long-term effects on the central nervous system and decreased related neuropsychological performances.

The paced auditory serial addition test (PASAT), is one of the tests which is used for the evaluation of awareness processing tests by neuropsychologists. In this test the role of attention and short-term memory in which the stimulant is provided through vision or hearing is evaluated. This test also allows calculation of a temporal threshold measure that showed the speed of digital presentation that a person was capable of processing and providing the proper answer to. This test was first designed by Gronwall and Sampson (1974) (16) to measure cognitive efficacy in individuals with brain damage. Previous studies also show the full applicability of this test in patients with stress (17).

2. Objectives

The aim of the present study was to assess possible changes in cognitive function after a 20-minute diving session. To do so, a group of scuba divers with no history of decompression sickness was investigated using PASAT test. Since, in this study scuba diving may act as a stressor, which in long term can damage the intellectual capacity, through the application of PASAT test, changes in cognitive function such as general health, mental tiredness and attention are investigated in volunteers before and after diving. Moreover, the cortisol salivary concentration was considered in these volunteers as the most important stress hormone.

3. Methods

Twelve professional divers with a mean age of 23 $\pm$ 1, weight of 80 $\pm$ 2.5 kg and height of 1.79 $\pm$ 3.5 m resident in the city of Mashhad were recruited to participate in the test. Divers were non-smokers and volunteers taking any medications such as benzodiazepine or psychoactive drugs were excluded.

Their cognitive functions were measured 60 minutes before and 15 minutes after diving using the PASAT software. To determine their stress system's activity, the subjects' saliva samples were taken before and after diving for cortisol change evaluation. The PASAT software used in this study measures some cognitive functions, including general mental health, response speed, sustained attention and mental fatigue (17, 18). The PASAT software was used in the past to measure the degree of the effect of traumatic brain injuries on cognitive functions, but has recently also been used in the athletic community (17). In the present study, we have used the PASAT software to measure general health, mental fatigue, sustained attention and response speed in professional divers. The PASAT used in this study has been described in the previous studies (18). Briefly, in this test, 61 numbers between one and nine are randomly pronounced to the subject with 3-second intervals and the subject should add up each last two consecutive numbers and call out his answer before the next number is pronounced. For example, if numbers two and six are provided in this order, the correct answer to examine to announce would be eight. Each subject provides a number of correct answers in each test (response accuracy) and the test results are, therefore, compared before and after the intervention. The study also assessed the mean response time (response speed), the longest chain of correct answers (sustained attention) and the longest chain of incorrect answers (mental fatigue). Saliva samples were collected and conserved in 10 mm falcon tubes and were kept frozen at a temperature of -20°C. Measuring salivary cortisol was done by an ELISA kit (Cortisol ELISA kit, Diagnostics Biochem Canada Inc, dbc). On the day of the experiment, the samples were melted in the room temperature then, centrifuged for five minutes with a rotation of 3000 per minute, 20 micro liters of each sample was separated for the test (19, 20).

Data are expressed as Mean $\pm$ SEM. The Paired t-test was used to determine the significance of differences in the group. $P < 0.05$ were considered significant.

4. Results

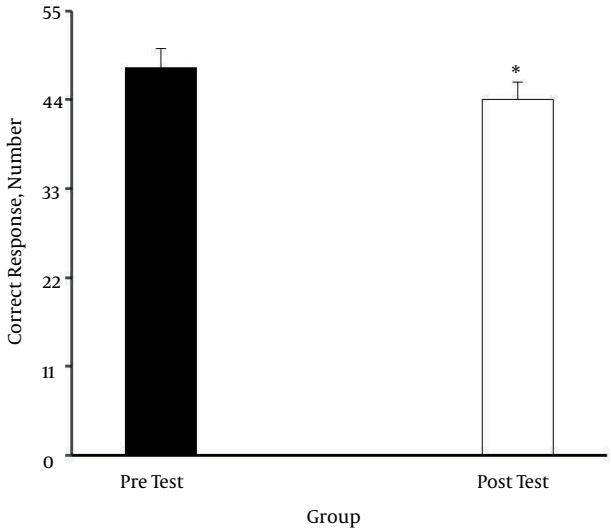
4.1. The effect of 20 Minutes of Diving on General Mental Health (the Number of Correct Answers) as Assessed by the PASAT

The results showed that the number of correct answers significantly reduced after diving. This reduction was statistically significant ($P < 0.05$ and $t_9 = 2.493$); (Figure 1).

4.2. The Effect of 20 Minutes of Diving on Response Time According to the PASAT

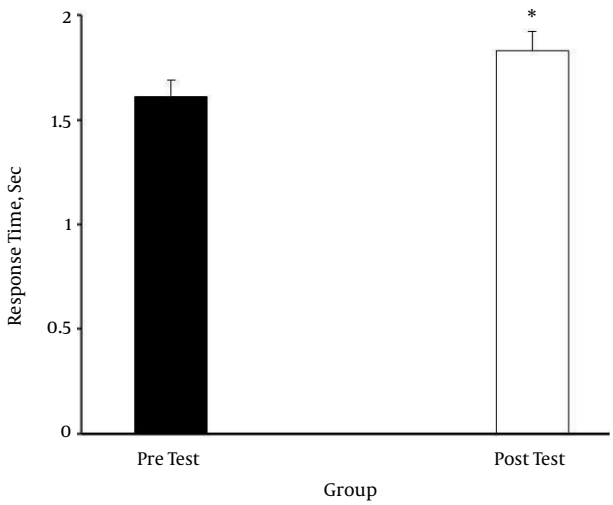
The results obtained from PASAT showed a significant increase in the response time after diving compared to before diving ($P < 0.05$ and $t_9 = 3.91$); (Figure 2).

Figure 1. General Mental Health in Scuba Divers Before and After Diving



Global mental health in subjects before diving was significantly higher than that after diving. Data are shown as mean ± SEM of the number of correct responses, *P < 0.05 different between the groups.

Figure 2. Changes in Reaction Time Before and After Diving in the Volunteers

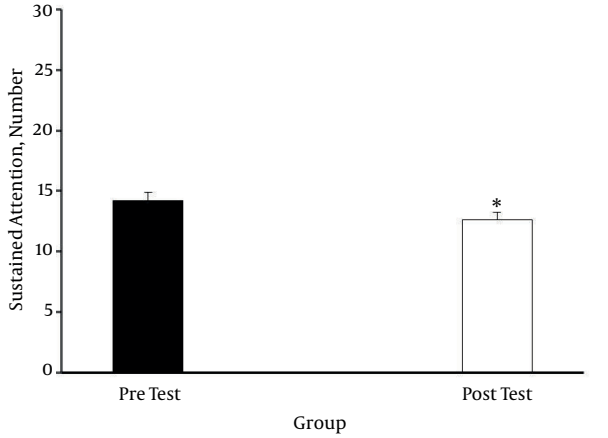


Time needed for the reaction was statistically significant after the diving than that of before diving. Data are shown as mean ± SEM of reaction time; *P< 0.05 different between the groups.

4.3. The Effect of 20 Minutes of Diving on Sustained Attention

As already discussed, the longest chain of correct answers is regarded as an indicator of sustained attention. The results showed a reduction in sustained attention after diving, which was statistically significant (P< 0.05 and t_9 = 1.554); (Figure 3).

Figure 3. Sustained Attention Changes Before and After Diving

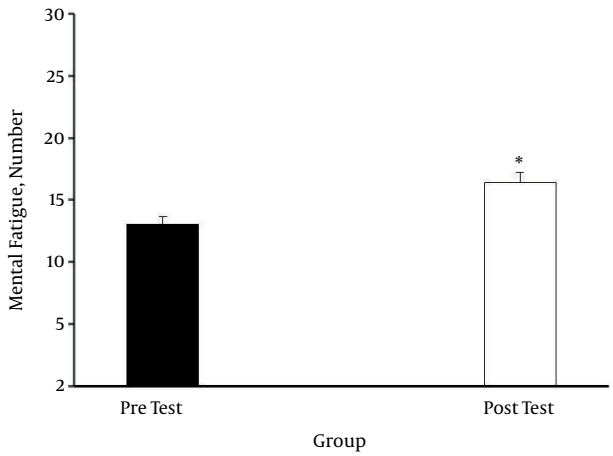


Sustained attention was significantly higher before than after the diving. Data are shown as mean ± SEM of the number of longest chain of corrected response, *P < 0.05 different between the groups.

4.4. The Effect of 20 Minutes of Diving on Mental Fatigue

In the PASAT, the longest chain of incorrect answers is regarded as an indicator of mental fatigue. According to the results, a greater mental fatigue was observed in the subjects after diving, the increase was statistically significant (P> 0.05 and t_9 = 2.493); (Figure 4).

Figure 4. Comparison of Mental Fatigue Before and After Diving in the Volunteers

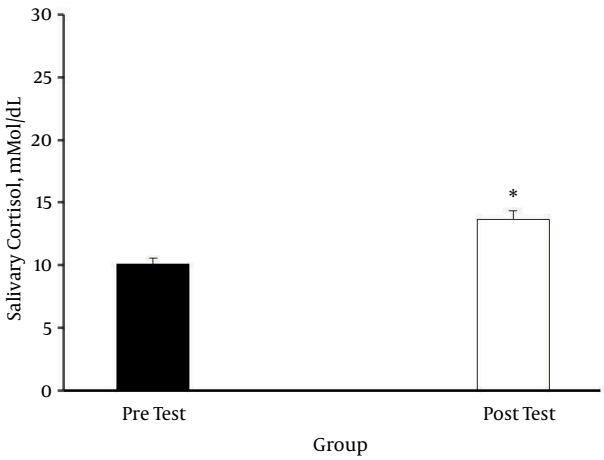


The mental fatigue was significantly lower before diving as compared to after diving. Data are shown as mean ± SEM of mental fatigue. *P < 0.05 different between the groups.

4.5. The Effect of 20 Minutes of Diving on Salivary Cortisol Concentration

The cortisol concentration in the saliva samples collected was analyzed using the ELISA method. The results revealed a significant difference between salivary cortisol before and after diving. Diving has increased cortisol salivary concentration ($P < 0.05$ and $t_9 = 2.15$); (Figure 5).

Figure 5. Salivary Cortisol Concentration Before and After Diving



Diving has increased cortisol salivary concentration. Data are shown as mean ± SEM of salivary cortisol, *P < 0.05 different between the groups.

5. Discussion

The present study was conducted to assess cognitive changes occurring after 20 minutes of diving in professional divers. The changes in mental health, response time, sustained attention and mental fatigue were investigated to evaluate cognitive function. These factors were measured using the PASAT. Previous studies have used this test for patients with diseases such as multiple sclerosis, depression and injured nervous systems (21). The present study used this software to assess the effects of scuba diving as a stressor in cognitive function in a group of scuba diver volunteers. Also, a cortisol level change was investigated.

Analysis of the data showed a significant increase in response time after 20 minutes of diving ($P < 0.05$). Also, salivary cortisol level (the main stress system hormone secreted in the body) was increased after diving ($P < 0.05$). It has been shown that scuba can lead to reduced processing speed (22). On the contrary, running increased cognitive function in the male athletes (23). In this study, although response time is longer in divers, this parameter may be associated with a transient increase at the end of the diving and we suggest that changes in response time may be due to increased plasma cortisol levels. It seems that diving acts as a stress stimulant and increases cortisol levels, thereby reducing the cognitive function after diving. Increased cortisol levels can lead to a reduced cognitive function. Also, several studies showed that the administration of cortisol to healthy people can reduce their memory function (24-26). Moreover; the administration of corticosteroids such as hydrocortisone may also reduce the memory function (27). The reduction in memory function occurs in both humans and animals and is a major factor contributing to impaired judgment in individuals exposed to constant stress (28-31).

As already discussed, the number of correct answers was taken to indicate the individual's mental health in the present study, which fell in the normal range in the divers. General mental health is an important indicator of proper mental performance and of the existence of a proper relationship between the various parts of the nervous system and cognitive functions, including memory, learning and fluent speech. Our data showed a brief descending trend in the divers' mental health following diving. These changes can be regarded as indicators of rising cortisol levels due to diving. Also, it can be said that the learning capacity of individuals and preserving their mental health were not totally without an effect, and since all participants were professional divers, they were able to maintain a good level of mental ability. Other aspects assessed by the PASAT include mental fatigue and sustained attention. The analysis of the data showed that the mental fatigue increased and sustained attention decreased after dividing. Previous studies have shown that diving reduces sustained attention (22). The "autonomous phase" may be responsible for these slight changes; according to Fitts and Posner's theory (1967) (32), the autonomous phase takes over at higher levels of learning. Individuals ascend to this phase after having undergone excessive training and then learn to increase their skill under different circumstances.

In conclusion, since the cognitive function is changed with variable factors, in this study the effects of diving were evaluated. It seems that a scuba dive may decrease brain cognitive function for a short time after diving. Based on our data, it can be concluded that after the diving response rate is low and it's better that divers immediately refrain from doing something with high attention after diving.

Acknowledgments

This study was conducted as part of a PhD student thesis project, which was supported by a grant from the neuroscience research center, Baqiyatallah University of Medical Sciences, Tehran, Iran.

Footnote

Authors' Contribution: Gholam Hossein Meftahi and Hedayat Sahraei designed and monitored the study, contributed in conducting the study, laboratory analyses, data acquisition, data interpretation and drafting of the manuscript. Seyedeh Faezeh Pourhashemi acquisition of data, analysis and interpretation of data. Bahareh Gholipour was involved in conducting the study. Boshra Hatef performed the statistical analysis.

References

1. Steinberg SI, Sammel MD, Harel BT, Schembri A, Policastro C, Bogner HR, et al. Exercise, sedentary pastimes, and cognitive performance in healthy older adults. *Am J Alzheimers Dis Other Demen.* 2015;**30**(3):290–8. doi: 10.1177/1533317514545615. [PubMed: 25100746].
2. Stults-Kolehmainen MA, Sinha R. The effects of stress on physical activity and exercise. *Sports Med.* 2014;**44**(1):81–121. doi: 10.1007/s40279-013-0090-5. [PubMed: 24030837].
3. Conrad CD. Chronic stress-induced hippocampal vulnerability: the glucocorticoid vulnerability hypothesis. *Rev Neurosci.* 2008;**19**(6):395–411. [PubMed: 19317179].
4. Meftahi G, Ghotbedin Z, Eslamizade MJ, Hosseinmardi N, Janahmadi M. Suppressive effects of resveratrol treatment on the intrinsic evoked excitability of ca1 pyramidal neurons. *Cell J.* 2015;**17**(3):532–9. [PubMed: 26464825].
5. Meftahi G, Janahmadi M, Eslamizade MJ. Effects of resveratrol on intrinsic neuronal properties of CA1 pyramidal neurons in rat hippocampal slices. *Physiol Pharmacol.* 2014;**18**(2):144–55.
6. Roozendaal B. Stress and memory: opposing effects of glucocorticoids on memory consolidation and memory retrieval. *Neurobiol Learn Mem.* 2002;**78**(3):578–95. [PubMed: 12559837].
7. Chalabi-Yani D, Sahraei H, Meftahi GH, Hosseini SB, Sadeghi-Gharajehdaghi S, Ali Beig H, et al. Effect of transient inactivation of ventral tegmental area on the expression and acquisition of nicotine-induced conditioned place preference in rats. *Iran Biomed J.* 2015;**19**(4):214–9. [PubMed: 26210948].
8. Hosseini SB, Sahraei H, Mohammadi A, Hatef B, Meftahi GH, Chalabi-Yani D, et al. Inactivation of the nucl. accumbens core exerts no effect on nicotine-induced conditioned place preference. *Neurophysiol.* 2015;**47**(4):295–301.
9. Lau WK, Leung MK, Chan CC, Wong SS, Lee TM. Can the neural-cortisol association be moderated by experience-induced changes in awareness?. *Sci Rep.* 2015;**5**:16620. doi: 10.1038/srep16620. [PubMed: 26577539].
10. Arnsten AF. Stress weakens prefrontal networks: molecular insults to higher cognition. *Nat Neurosci.* 2015;**18**(10):1376–85. doi: 10.1038/nn.4087. [PubMed: 26404712].
11. Kim JJ, Diamond DM. The stressed hippocampus, synaptic plasticity and lost memories. *Nat Rev Neurosci.* 2002;**3**(6):453–62. doi: 10.1038/nrn849. [PubMed: 12042880].
12. Payne JD, Nadel L, Allen JJ, Thomas KG, Jacobs WJ. The effects of experimentally induced stress on false recognition. *Memory.* 2002;**10**(1):1–6. doi: 10.1080/09658210143000119. [PubMed: 11747571].
13. Slosman DO, De Ribaupierre S, Chicherio C, Ludwig C, Montandon ML, Allaoua M, et al. Negative neurofunctional effects of frequency, depth and environment in recreational scuba diving: the Geneva "memory dive" study. *Br J Sports Med.* 2004;**38**(2):108–14. [PubMed: 15039241].
14. Di Piero V, Cappagli M, Pastena L, Faralli F, Mainardi G, Di Stani F, et al. Cerebral effects of hyperbaric oxygen breathing: a CBF SPECT study on professional divers. *Eur J Neurol.* 2002;**9**(4):419–21. [PubMed: 12099928].
15. Tetzlaff K, Friege L, Hutzelmann A, Reuter M, Holl D, Leplow B. Magnetic resonance signal abnormalities and neuropsychological deficits in elderly compressed-air divers. *Eur Neurol.* 1999;**42**(4):194–9. [PubMed: 10567814].
16. Gronwall DM, Sampson H. The psychological effects of concussion. Auckland; 1974.
17. Tombaugh TN. A comprehensive review of the Paced Auditory Serial Addition Test (PASAT). *Arch Clin Neuropsychol.* 2006;**21**(1):53–76. doi: 10.1016/j.acn.2005.07.006. [PubMed: 16290063].
18. Erfani M, Sahraei H, Bahari Z, Meftahi G, Hatef B, Mohammadi A, et al. Evaluation of the effect of time change in cognitive function in volunteers in tehran. *Glob J Health Sci.* 2016;**9**(2):119.
19. Paris JJ, Franco C, Sodano R, Freidenberg B, Gordis E, Anderson DA, et al. Sex differences in salivary cortisol in response to acute stressors among healthy participants, in recreational or pathological gamblers, and in those with posttraumatic stress disorder. *Horm Behav.* 2010;**57**(1):35–45. doi: 10.1016/j.yhbeh.2009.06.003. [PubMed: 19538960].
20. Vining RF, McGinley RA. The measurement of hormones in saliva: possibilities and pitfalls. *J Steroid Biochem.* 1987;**27**(1-3):81–94. [PubMed: 3320544].
21. Vollmer T, Huynh L, Kelley C, Galebach P, Signorovitch J, DiBernardo A, et al. Relationship between brain volume loss and cognitive outcomes among patients with multiple sclerosis: A systematic literature review. *Neurological Sci.* 2016;**37**(2):165–79.
22. Hemelryck W, Germonpre P, Papadopoulou V, Rozloznik M, Balestra C. Long term effects of recreational SCUBA diving on higher cognitive function. *Scand J Med Sci Sports.* 2014;**24**(6):928–34. doi: 10.1111/sms.12100. [PubMed: 23902533].
23. Sepahvand H, Zareian E, Aghaei H, Sahraei H. Cognitive function in male track and field iranian national team athletes. *hippocampus.* 2015;**4**:5.
24. Lupien SJ, Nair NP, Briere S, Maheu F, Tu MT, Lemay M, et al. Increased cortisol levels and impaired cognition in human aging: implication for depression and dementia in later life. *Rev Neurosci.* 1999;**10**(2):117–39. [PubMed: 10658955].
25. Wolkowitz OM, Lupien SJ, Bigler E, Levin RB, Canick J. The "steroid dementia syndrome": an unrecognized complication of glucocorticoid treatment. *Ann N Y Acad Sci.* 2004;**1032**:191–4. doi: 10.1196/annals.1314.018. [PubMed: 15677408].
26. Bahari Z, Manaheji H, Hosseinmardi N, Meftahi GH, Sadeghi M, Danialy S, et al. Induction of spinal long-term synaptic potentiation is sensitive to inhibition of neuronal NOS in L5 spinal nerve-transected rats. *EXCLI J.* 2014;**13**:751–60. [PubMed: 26417298].
27. Lupien SJ, Gillin CJ, Hauger RL. Working memory is more sensitive than declarative memory to the acute effects of corticosteroids: a dose-response study in humans. *Behav Neurosci.* 1999;**113**(3):420–30. [PubMed: 10443770].
28. Lupien SJ, Lepage M. Stress, memory, and the hippocampus: can't live with it, can't live without it. *Behav Brain Res.* 2001;**127**(1-2):137–58. [PubMed: 11718889].
29. Asalgoo S, Jahromi GP, Meftahi GH, Sahraei H. Posttraumatic stress disorder (ptsd): Mechanisms and possible treatments. *Neurophysiol.* 2015;**47**(6):482–9.
30. Ghodrat M, Sahraei H, Razjouyan J, Meftahi GH. Effects of a saffron alcoholic extract on visual short-term memory in humans: a psychophysical study. *Neurophysiology.* 2014;**46**(3):247–53.
31. Bahari Z, Manaheji H, Dargahi L, Daniali S, Norozian M, Meftahi GH, et al. Time profile of nNOS expression in the spinal dorsal horn after L5 spinal root transection in rats. *Neurophysiol.* 2015;**47**(4):287–94.
32. Fitts P, Posner MI. Human factors psychology. 1967 :159–77.