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Research Article

Dietary supplementation with *Salvia officinalis* L. and aerobic training attenuates memory deficits via the CREB-BDNF pathway in amyloid beta- injected rats

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ABSTRACT

Background: AD is a neurodegenerative disorder in which there is a gathering of beta-amyloid plaques, primarily in the hippocampus, that lead to neuronal death. Exercise training and botanical medications can play a role in the prevention and treatment of neurodegenerative disorders. **Objective:** The aim of this study was to determine the effects of aerobic training and *Salvia officinalis* extract on the improvement of learning and memory deficits in amyloid beta - injected rats. **Methods:** Rats were injected with an A β solution into the CA1 hippocampal region. Rats were then exposed to treadmill exercise and *S. officinalis* extract for 4 weeks, at which point they performed the MWM. Additionally, we studied the molecular factors involved in neuronal plasticity, such as CREB and BDNF. The animals were also evaluated histologically to determine the deposition of A β in the brain tissue. **Results:** The results showed that aerobic training and *S. officinalis* improved learning and memory in the behavioral test. The results of the molecular analysis showed that CREB and BDNF levels were attenuated in the A β -injected rats in comparison with the control group. The density of surviving neurons was considerably higher in the training-extract-A β group ($P < 0.01$) and extract-A β group ($P < 0.05$) than the negative control groups. **Conclusion:** In the present study, behavioral testing and biochemical analysis demonstrated that aerobic training and *S. officinalis* extract treatment for 4 weeks protects against memory deficits in A β -injected rats.

1. Introduction

Alzheimer's disease is the most common neurodegenerative disease and is characterized by the deposition of Amyloid beta plaques in the brain [1], gathering of intracellular

neurofibrillary tangles, synaptic loss, and neuronal cell death. Studies have shown that soluble oligomers of A β have neurotoxic effects [2] and lead to neuronal apoptosis well as learning and memory deficits. CREB is a

Abbreviations: AD, Alzheimer's disease; A β , Beta-amyloid; MWM, Morris water maze test; CREB, Ca²⁺/cAMP-response element binding protein; BDNF, Brain-derived neurotrophic factor

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transcription factor that has long been considered a critical factor in the molecular basis of learning and memory [3, 4, 5]. A β inhibits CREB phosphorylation and cell proliferation in the hippocampus of transgenic mice [6].

Previous studies have shown that exercise training leads to an increase in CREB and BDNF gene expression [7, 8, 9]. The intensity and duration of exercise is important in the regulation of these genes [10, 11, 12]. As well, strength and aerobic training can produce similar or different effects on CREB or BDNF gene expression [13, 14, 15]. One of the most important signaling pathways in the brain is the binding of BDNF to its specific receptor in various regions of the hippocampus [16]. The binding of BDNF to its receptor leads to activation of several signaling pathways, including PKC, MAPK, and CREB [17, 18, 19]. Studies have shown that changes in BDNF signaling are necessary to produce the effects of exercise training on the formation of the hippocampus. Further, BDNF signaling can attenuate neuronal plasticity; blockade of this signaling pathway inhibits the memory and learning improvements caused by exercise training in rodents [20]. Even a single training session can lead to an increase in BDNF levels [21].

Salvia officinalis L. has antioxidant properties due to its polyphenolic compounds, and studies have shown that phenolic components increase neuronal development and protection [22, 23]. Previous studies have suggested that salvia extract increases CREB phosphorylation and improves spatial memory in rats [24]. Chlorogenic acid and fluorogenic acid are important components of salvia extract that decrease cholinesterase activity [25, 26]. Previous studies have suggested that 1mg of salvia extract improves learning and memory in A β -injected rats [24]. Exercise training and dietary salvia

extract are thought to activate neurogenesis via different pathways. Thus, the aim of this study was to determine the effects of exercise training and *S. officinalis* extract on learning and memory deficits and CREB and BDNF gene expression in A β -injected rats.

2. Materials and Methods

2.1. Animals

Male Wistar rats weighing 220-240 g were obtained from the Pasteur Institute (Tehran, Iran). Rats were housed for over one week at $23 \pm 1^\circ\text{C}$ on a controlled 12-h light-dark cycle. Animals were housed in groups of six. Food and water were provided freely except during the brief test periods. All experiments were conducted in accordance with the Guide for the Care and Use of Laboratory Animals (National Institutes of Health Publication No. 80-23, revised 1996) and were approved by the Research and Ethics Committee of Tehran University of Medical Sciences.

2.2. Preparation of A β 1-42 and fiber formation

To prepare the A β , we dissolved A β ₁₋₄₂ stock (Sigma-Aldrich, St. Louis, MO, USA) powder in phosphate-buffered saline (PBS), then made aliquots and stored them at -20°C . A 200 ng/ μl concentration of A β was prepared in PBS (0.1 M). The solution of A β was incubated for 5 days at 37°C . On the test day, PBS was added to the solution to reach a final concentration of 10 ng/ μl .

2.3. Surgery and microinjection

Rats were anesthetized by intraperitoneal injection of ketamine hydrochloride (Alfasan, Netherlands) (50 mg/kg) and xylezine (Alfasan, Netherlands) (4 mg/kg) and secured in a stereotaxic frame. The coordinates used for injection into the dorsal hippocampus were: anteroposterior: -3.2mm from bregma; lateral: ± 1.8

from bregma; and vertical: 7.2 mm from dura according to the atlas by Paxinos and Watson (1986). A β was injected by means of polyethylene tubing with a 25- μ g Hamilton syringe. The left and right hippocampi were microinjected with 3 μ l of A β per side (10 ng/ μ l) into the CA1 bilaterally (1 μ g/rat) over one min.

2.4. Experimental design

Thirty-two adult male rats were assigned to one of the following groups:

Group 1 (control): microinjection of A β into the CA1 bilaterally (1 μ g/rat).

Group 2: microinjection of A β into the CA1 bilaterally (1 μ g/rat) and treadmill running (30, 45 or 60 min/day) for 28 days.

Groups 3: microinjection of A β into the CA1 bilaterally (1 μ g/rat) and treatment with *S. officinalis* (100 mg/kg/day by gavage, once daily) for 28 days.

Group 4: microinjection of A β into the CA1 bilaterally (1 μ g/rat), treadmill running (30, 45, or 60 min/ day) and treatment with *S. officinalis* (100 mg/kg/day by gavage, once daily) for 28 days.

Due to the importance of the CREB-BDNF signaling pathway in neuroprotection, the involvement of this pathway in exercise and the neuroprotective effects caused by *S. officinalis* against A β -induced disturbances were studied. Real-time reverse transcriptase polymerase chain reaction (RT-PCR) was performed to study the changes in BDNF and CREB gene expression induced by exercise and *S. officinalis* treatment. In addition, Haematoxylin and Eosin (H&E) staining was performed to study cell density and neurodegeneration.

2.5. Plant material

S. officinalis was acquired from Institute of Medicinal Plants, Karaj, Iran (June 2001;

voucher herbarium specimen: NPIH-2988). The plant's aerial parts were air-dried darkness. The dried plants were then powdered. The powder was stored in a dark pot at room temperature (25°C). The powder was extracted by methanol four times overnight. The methanolic extract was concentrated under reduced pressure on a rotary, evaporator, then filtered and lyophilized.

2.6. Exercise protocol

Rats ran on a leveled motorized treadmill (Pishro Andishe sanat Co, Tehran, Iran) on week days between 9:00 am and 4:00 pm for 4 weeks. The rats were familiarized with the treadmill while it was idle. During the first two weeks, rats assigned to exercise ran on the treadmill for two 15-min sessions at a speed of 10m/min. During the 3rd and 4th weeks, rats ran for 3 and 4 sessions, respectively, at a speed of 15m/min. A 5-min rest period was given between sessions to prevent muscle fatigue. A mild electric tingling (intensity = 0.5 mA) was constantly delivered from stainless bars located at the start of each running lane to encourage reluctant rats to continue running [27].

2.7. Behavioral test: Morris water maze (MWM)

The maze consisted of a painted black circular pool 136 cm in diameter filled with water (temperature: ~ 23 °C, depth: 25 cm). The pool was situated in a room with different colored visual cues on the walls. A black platform 10 cm in diameter was submerged in the water (2 cm below the surface). The pool was conceptually divided into four quadrants with four points designed as starting positions (N, S, W, and E). Motivation of the rat in the direction of a visible platform was evaluated by a visible platform task. The animal's position was monitored by a camera placed above the center of the pool. Animal movement was recorded by a 3CCD

camera (Panasonic Inc., Japan) placed 2 m above the MWM apparatus. Locomotion tracking was evaluated using Ethovision software (version XT7) and a video tracking system for the automation of behavioral experiments (Noldus Information Technology, the Netherlands). Escape latency, distance traveled, and swimming speed were recorded during a 90 s window in both the probe and training trials.

2.7.1. Habituation

Twenty-four hours before commencing training, the rats were habituated to the pool by allowing them to perform 90 s of swimming in the absence of the platform.

2.7.2. Procedure

The behavioral tests started 28 days after the end of the protocol. The behavioral tests included a single training session consisting of four trials over four days. Each trial was started in a different quadrant of the maze. Each of the four starting positions was used twice during the four training sessions in a random order. During each trial, the rat was given 90 s to find the hidden platform. After finding the platform, the animals were allowed to remain on the platform for 30 s, and then were placed in a holding cage for 30 s until the start of next trial. When training was complete, the animals were returned to their home cages until the probe trial, which started 24 h later (on the test day). In the probe trial, the hidden platform was removed and the animals were released from a fixed location (N) and allowed to swim freely for 90 s. All experiments were conducted between 9:00 AM and 1:00 PM.

2.8. Real-time reverse transcriptase polymerase chain reaction (RT-PCR)

Total RNA was extracted from 200 µg of hippocampus tissue using ONE STEP-RNA

reagent (Bio Basic, Markham, Ontario, Canada Inc.) according to the manufacturer's instructions. Extracted RNA was assessed for quantity and quality using a nanodrop (ND-1000, Thermo Scientific Fisher, USA) and gel electrophoresis, respectively. To eliminate genomic contamination, RNA was treated with DNase I (Qiagen, Hilden, Germany) per the manufacturer's instructions. Next, complementary DNA (cDNA) was synthesized using 1 µg of total RNA. The integrity and quality of the cDNA was examined using a glyceraldehyde 3-phosphate dehydrogenase (GAPDH) primer as the housekeeping gene. RT-PCR was carried out to evaluate the differences in expression patterns of the BDNF and CREB genes among the experimental groups. The primers were designed using Primer 3 software version 0.4 (frodo.wi.mit.edu) (Table 1).

Real-time RT-PCR was performed in 20-µl reactions containing 1 µl of cDNA target, 100 nM of each the forward and reverse primers, and 1 X SYBR1® Premix Ex Taq™ II (Takara, Tokyo, Japan). Experiments were carried out in triplicate using a CFX96™ Real-Time System (C1000™ Thermal Cycler; Bio-Rad, Hercules, CA, USA). The amplification conditions were as follows: initial denaturation at 95 °C for 10 min followed by 40 cycles (denaturation at 95 °C for 15 s, annealing and extension at 60 °C for 1 min). The relative values of the mRNA expression of the CREB and BDNF genes were calculated by comparing the cycle thresholds (CTs) of the target genes with that of the housekeeping gene (GAPDH) using the $2^{-\Delta\Delta C_T}$ method and REST 2009 software [28]. Serial dilutions of the cDNAs were used for calculation of the primer set efficiencies in real-time PCR.

Table 1. RT-PCR primers

Genes	Primer sequences
BDNF	Forward: 5'-GGAGGCTAAGTGGAGCTGAC-3' Reverse: 5'-GCTTCCGAGCCTTCCTTTAG-3'
CREB1	Forward: 5'-CAGACAACCAGCAGAGTGGA-3' Reverse: 5'-CTGGACTGTCTGCCCATTG-3'
GAPDH	Forward : 5'-AGACAGCCGCATCTTCTTGT-3' Reverse: 5'-CCGTTACACCGACCTTCA-3'

2.9. Histopathology

The animals were euthanized after 28 days of treatment and 5 days of behavioral testing. The harvested brain tissues were fixed in 10% neutral buffered formalin (NBF, pH 7.26) for 48 h, then processed and embedded in paraffin. Five μm-thick sections were prepared and stained with Haematoxylin and Eosin (H&E) staining. An independent reviewer evaluated the slides using light microscopy (Olympus BX51; Olympus, Tokyo, Japan). The slides were assessed for histological changes, including inflammatory responses, neuronal degeneration, hemorrhage, and hyperemia.

2.10. Data analysis

Data are expressed as the mean ± SEM (standard error of the mean). Data analysis, was performed using SPSS software (version 17). For the behavioral testing and molecular studies, two-way analysis of variance (ANOVA) and two-way repeated measures ANOVA followed by post hoc Bonferroni analysis were used. A P-value less than 0.05 ($P < 0.05$) was considered statistically significant (* $P < 0.05$, ** $P < 0.01$, and *** $P < 0.001$).

3. Results

3.1. Behavioral results

3.1.1. Aerobic training and *Salvia officinalis* treatment improved spatial learning in MWM in $A\beta$ -injected rats

We used the MWM test to test spatial learning and memory because it is more useful than other test apparatuses. The data obtained in the training session showed a significant difference between the first and fourth day in escape latency and distance traveled in all experimental groups ($P < 0.01$; Fig. 1A and 1B). The swimming speed did not show any significant change between the first and fourth day training trials, indicating that there was no motor disturbance in the treated animals ($P > 0.05$; Fig. 1C).

3.1.2. Aerobic training and *Salvia officinalis* affected the $A\beta$ -induced spatial memory impairment in MWM

After training the rats, we tested spatial memory impairment on the fifth day using the MWM. The statistical analysis revealed that in the probe test, the latency to the platform zone significantly increased in the training group $F(1, 20) = 6.815$; $P < 0.05$), in the extract (100 mg/kg/day) group $F(1, 20) = 6.369$; $P < 0.05$, and there was no significant changes in the training-extract group compared with the control group $F(1, 20) = 3.909$; $P > 0.05$ (Fig. 1D).

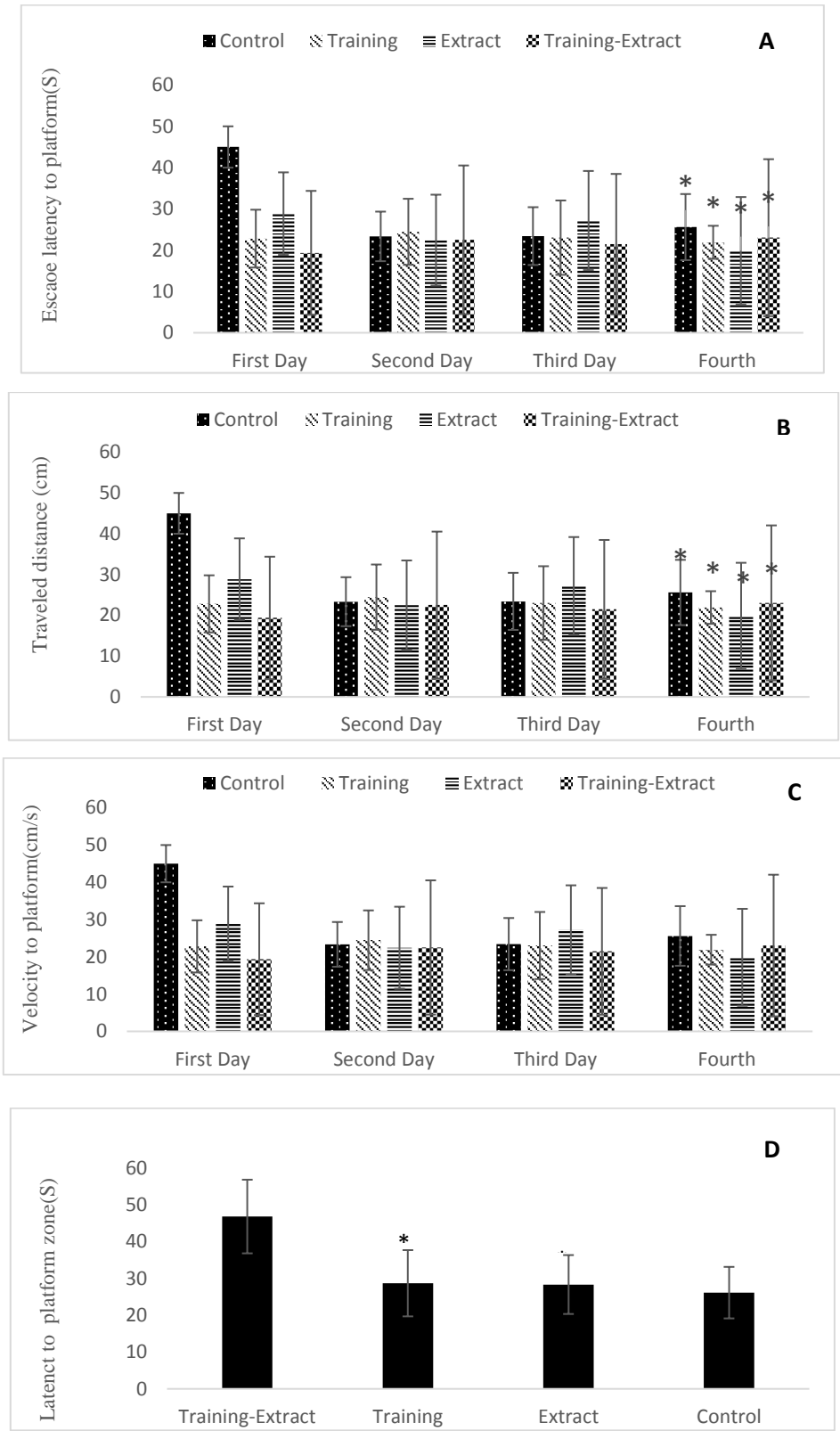


Fig. 1. Morris water maze test Results. A) Escape latency to the platform (s) over 4 days. B) Distance traveled to the platform (cm) over 4 days. C) Velocity to platform (cm/s) over 4 days. D) Latency to platform zone (s) in the probe test.

3.2. Molecular results

3.2.1. Aerobic training and *Salvia officinalis* increased CREB gene expression in A β -injected rats

The training, extract (100mg/kg/day), and training-extract groups had higher CREB gene expression in the CA1 region of the hippocampus than the control group ($P < 0.001$) (Table 2).

3.2.1. Aerobic training and *Salvia officinalis* increased BDNF gene expression in A β -injected rats

The training, extract (100 mg/kg/day), and training-extract groups had higher BDNF gene expression in the CA1 region of the hippocampus than the control group ($P < 0.001$) (Table 2).

3.3. Histopathological Results

3.3.1. Aerobic training and *Salvia officinalis* increased the density of the surviving neurons in A β -injected rats

The Hematoxylin and Eosin (H&E) sections from the different experimental groups were evaluated histologically to determine the deposition of A β in the brain. The control (C) group showed morphological signs of necrosis,

including cytoplasmic swelling of neurons, various degrees of vacuolization, numerous indistinct and dark cells and necrotic cells (Fig. 2C). In addition, the organization of the hippocampus CA1 neuronal layer was generally disrupted.

The histopathologic findings of the training (T) group showed lesions similar to the negative control (C) group, with dark-stained or a lack of a visible cell boundary in the *hippocampal* CA1 areas (Fig. 2T). Micrographs of extract (E) - treated animals showed that the treatment markedly attenuated the A β -induced neuronal damage, as evidenced by the fact that fewer necrotic neuronal cells were observed in the extract (E) group (Fig. 2E).

Histopathological evaluation of the training-extract (T+E) showed a considerable reduction of A β injury in the CA1 neurons in comparison with the control (C) group (Fig. 2T+E). However, some degree of neuronal loss was still evident in this group. Treatment with training and extract appeared to have the best results in comparison with the control and other experimental groups.

Table 2. Real- time PCR results of CREB and BDNF gene expression (relative expression compared with control)

Genes	Groups	Mean	Standard Error of the Mean (SEM)	F	df	sig	Partial Eta Squared
CREB	Control	0.99769750	0.003988050	-	-	-	-
	Training	1.51222663	0.006044753	24809.271	1,8	0.001	1
	Extract	1.26583768	0.0175547815	16981.026	1,8	0.001	1
	Training-extract	3.60505959	0.024988219	10142.881	1,8	0.001	0.999
BDNF	Control	0.00483177	0.000069932	-	-	-	-
	Training	1.10830044	0.280381134	26.846	1,8	0.01	0.770
	Extract	1.25727593	0.031569487	49.076	1,8	0.01	0.860
	Training-extract	1.00014414	0.020796289	69.384	1,8	0.01	0.897

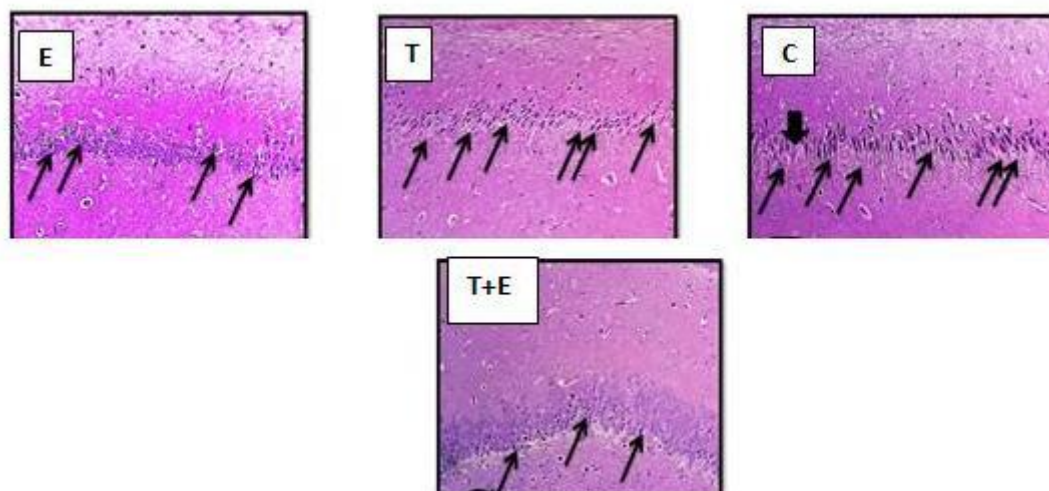


Fig. 2. Histopathologic sections of the brain in different experimental groups. C (control), T (training), E (extract), T+E (training-extract), thin arrows: CA1 pyramidal neurons necrosis. Magnification: x400.

4. Discussion

AD is a neurodegenerative disorder that constitutes up to 75% of all dementia and cognitive impairment is one of its early symptom [29]. Using phytochemicals, such as plant extracts, in remedy of dementia was useful on different communications from ancient times. It is evaluated that more than 25% of the currently used molecules as prescribed drugs derived, directly or indirectly from plants that show the important role of plants in the development of new drugs [30]. It has been well-known that salvia species are effective on improving learning in AD in humans and animals [31, 32]. Extract or leaves of some edible membrane of the salvia, such as *S. officinalis* and *S. lavandulifolia* are used for more than two millennia by humans to decrease and suppress cognitive decline [33].

Additionally, studies have shown that exercise decrease Alzheimer's symptoms by increasing neuronal vitality and neurogenesis [34, 35, 36]. The study of exercise in rats has shown that exercise increase spatial learning and neurodensity in the dendate gyrus of

hippocampus, which leads to improvement in short-term memory [36, 37].

Additionally, studies have demonstrated that light and moderate treadmill training increases cell infiltration in juvenile rats in comparison with control animals; these studies also demonstrated that treadmill exercise increases cellular infiltration and synapses in the brain [36, 37, 38].

We assessed the effect of *S. officinalis* and aerobic training in A β -injected rats. As it has been shown that neurodegeneration cannot be found in transgenic models of amyloidosis [39].

We used the injection model. It has been previously demonstrated that injection of A β (1-42) leads to brain dysfunction, which was manifested as learning and memory deficits in MWM [40].

Previous studies established that behavioral alterations emerge in 20 days after injection [41, 42].

So, the treatment protocols started 20 days after injection. Based on the obtained results, treated rats displayed lower impaired spatial learning and memories (as assessed in MWM

task), which is regarded as a good indicator of hippocampal function [42].

The amelioration of cognitive deficits has been shown for other membrane of sage family, such as *S. lavandulaefolia*, *S. sahendica* and other exercise training as well [32, 43, 36, 37].

As mentioned, one of the major symptoms of AD is cognitive disorder and memory loss.

Several cascades involved in memory formation are impaired in AD. CREB is a transcription factor that has been long considered as a critical molecular basis of learning and memory. This molecule plays its pivotal role in early process of long term memory and neuronal plasticity through c-fos, whose up-regulation associates with spatial and behavioral learning and memory in rats [3, 4, 5].

We found that dietary supplementation of, *S. officinalis* and aerobic training increased CREB expression in A β -injected rats. Beside, based on our results *S. officinalis* and aerobic training increased Brain-derived neurotrophic factor (BDNF) expression in A β -injected rats.

BDNF, an important nerve growth factor, plays a vital role in synaptic plasticity, neurogenesis and neuronal survival [44].

BDNF and its receptor, tropomyosin related kinase B, are regulated by cAMP and CREB. Furthermore, CREB-BDNF signaling has been implicated in regulating several neural functions like learning, memory, mood balance and reward mechanisms [45].

Regular modest level of physical activity improves mitochondrial function through several mechanisms such as increasing mitochondrial biogenesis and glucose transport (BDNF), elimination of damaged mitochondria (autophagy) and consequently inhibition of sterile inflammation by controlling mitochondrial ROS and DAMPs production [46].

the ethanolic extract of sage improves memory via the muscarinic and nicotinic systems

[31]. Sage extract significantly decreased escape latency in the learning period and increased the A β -injected rats' presence in the platform zone in comparison with the control group. In molecular studies, sage has been shown to increase CREB expression in treatment groups, leading to increased memory and learning [24].

Other studies have demonstrated that BDNF increases synapsin 1 mRNA, CREB and TrkB receptors in the hippocampus. Therefore, exercise appears to have a feedback effect on BDNF expression and synaptic plasticity [47, 18]. Most studies have demonstrated that exercise has a positive effect on memory and learning. 2 weeks of training with 7,8-Dihydroxy flavone increased cellular- metabolism, hippocampal activity, and synaptic plasticity in the brain of injured rats [48]. Voluntary and involuntary training attenuated vascular dementia of the hippocampus and increased BDNF, PCREB, PERK1/2 in the C1 and C2/3 dentate gyrus in rats with vascular dementia [49]. Female ovariectomized Alzheimer's model rats following 3-months of training and found that training improved memory and learning [50]. Training significantly increased BDNF, activating CREB and APE 1 in the cerebral cortex and hippocampus of rats [51].

Training attenuated the vitality of cells in the dentate gyrus by increasing CREB phosphorylation in ischemic rats, thereby improving memory [7].

In our histopathologic study, we showed that the density of survival neurons increased in the training and extract groups in comparison with the control groups. Similar to our findings, in one study, demonstrated that drugs that contain sage risibiom attenuate the memory impairment caused by beta-amyloid plaques, similar to the effect of donepezil [52].

Although the present study did not address other main molecules involved in this pathway.

The molecular mechanisms underlying A β -mediated neurotoxicity still remain to be elucidated, but a great deal of investigation confirms the contribution of caspase pathway in the disease process of AD. Studies have shown the caspase-3 activation in A β -injected rats [41, 42] as well.

Many neurodegenerative disease trigger by revelation to diet or exercise [34-36, 53, 54].

So, it is imaginable that a diet and exercise training strategy maybe proper prophylactic strategy. It should be mentioned that *S. officinalis* supplemented diet and aerobic training were well tolerated by rats, because no significant weight loss was observed over 4 weeks of feeding and training.

5. Conclusion

The present results from behavioral testing and biochemical analysis demonstrated that, the combined use of aerobic training and sage extract

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have synergistic effects on neurogenic factors. Considering the inherited of *S. officinalis* and aerobic training, such as efficiency, fewer side effects and abundant resources make this strategy a valuable candidate for AD [55].

Future studies should focus on the other mechanisms possibly involved in this phenomenon.

Author contributions

Iman Mohseni, carried out the experiments; Maghsoud Peeri, Supervisor of the project; Mohamad Ali Azarbayjani, Consulting supervisor of the project.

Conflict of interest

The authors declare that they have no conflict of interest.

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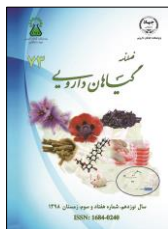
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مقاله تحقیقاتی

اثر تمرین هوازی وعصاره هیدرومتانلی مریم گلی (*Salvia officinalis*) بر حافظه، بیان CREB و BDNF در آلزایمر القا شده با بتا آمیلوئید

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چکیده

اطلاعات مقاله

مقدمه: بیماری آلزایمر اختلال زوال نورونی وابسته به سن بوده و تجمع آمیلوئید بتا، خصوصاً در ناحیه هیپوکامپ مهم‌ترین علت مرگ نوروها در این بیماری است. فعالیت بدنی و داروهای گیاهی می‌تواند در پیشگیری و درمان اختلالات زوال نورونی مؤثر باشد. **هدف:** این مطالعه با هدف تعیین تأثیر تمرین هوازی و عصاره خوراکی مریم گلی بر حافظه، بیان (CREB) و فاکتور مشتق از نوروتروفیک مغز (BDNF) در موش‌های صحرایی مدل آلزایمری تیمار شده با بتا آمیلوئید، اجرا شد. **روش بررسی:** در یک کارآزمایی تجربی ۳۲ سر رت نر تحت تزریق بتا آمیلوئید (۱۰ ng/μl) قرار گرفتند و به صورت تصادفی در گروه‌های کنترل، تمرین هوازی، عصاره و تمرین هوازی - عصاره قرار گرفتند. پس از ۲۱ روز، گروه عصاره ۱۰۰ mg/kg تمرین هوازی را به صورت گاوآژ دریافت کردند. گروه‌های تمرینی نیز چهار هفته روی تردمیل دویدند. بعد از اتمام دوره مداخله، از ماز آبی موریس جهت ارزیابی حافظه فضایی استفاده شد. BDNF و CREB با روش Realtime PCR اندازه‌گیری شد و همچنین ارزیابی بافت‌شناسی جهت بررسی میزان تجمع پلاک‌های بتا آمیلوئید در بافت مغز صورت گرفت. **نتایج:** نشان داد عصاره مریم گلی و دویدن روی تردمیل، سبب بهبود یادگیری و حافظه شد، سطوح (CREB $P=0/001$) (BDNF $P=0/001$) در آزمودنی‌های آلزایمر القاء شده در مقایسه با گروه کنترل افزایش معنی‌دار یافت، چگالی سلول‌های عصبی، به طور قابل ملاحظه‌ای در گروه‌های دوند و روی تردمیل و دریافت‌کننده عصاره نسبت به گروه کنترل افزایش معنی‌داری داشت ($P=0/001$). **نتیجه‌گیری:** نتایج مطالعه حاضر نشان داد تمرین هوازی و عصاره مریم گلی اثر هم‌افزایی بر بهبود حافظه، نقص عصبی و چگالی سلول‌های عصبی در شرایط آلزایمر القا شده با بتا آمیلوئید دارد. لذا استفاده همزمان این دو مداخله پیشنهاد می‌شود.

گل‌واژگان:

بیماری آلزایمر

تردمیل

مریم گلی

هیپوکامپ

موش صحرایی

مخفف‌ها: Brain-derived neurotrophic factor (BDNF)؛ Ca²⁺/cAMP-response element binding protein (CREB)* نویسنده مسؤول: m.peeri@iauctb.ac.ir

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