Contents lists available at Islamic World Science Citation Center (ISC)

International Journal of Motor Control and Learning (IJMCL)

Journal Home page: http://www.ijmcl .com

Does Swimming Moderate the Negative Effects of Maternal Deprivation on Hippocampal BDNF Levels, Spatial Learning and Motor Function?

Mozhgan Abdollahzadehnobejari [a], Shahzad Tahmasebi Boroujeni [b*], Elahe Arabameri [c]

[a] MSc at Motor control and Learning, Department of Behavioral and Cognitive Sciences in Sport, Faculty of Sport Sciences and Health, University of Tehran, Tehran, Iran.Email: m.abdollahzadeh13@gmail.com
[b] Associate Professor, Department of Behavioral and Cognitive Sciences in Sport, Faculty of Sport Sciences and Health, University of Tehran, Tehran, Iran. Email: shahzadtahmaseb@ut.ac.ir
[c] Associate Professor, Department of Behavioral and Cognitive Sciences in Sport, Faculty of Sport Sciences and Health, University of Tehran, Tehran, Iran. Email: eameri@tu.ac.ir

A R T I C L E I N F O

Article history:

Received: 2023/02/06
Accepted: 2023/05/13
Available online: 2023/05/16

Keywords:

Neonates
BDNF Protein
Open Field
Morris Water Maze
Stress
Motor Activity

A B S T R A C T

Background: Previous research has emphasized the negative impact of early maternal deprivation on learning and memory. On the other hand, the role of training on cognition has been examined. However, whether neonates are given exercise at the same time as being deprived of their mothers is a novelty of this research. We also considered the study of underlying mechanisms, such as the study of changes in BDNF levels. So, the purpose of this study was to examine the effect of swimming training on spatial learning, memory and motor function in male rats under early deprivation. **Methods:** Twenty-eight rats divided into four groups: Early maternal deprivation (EMD), Swimming Training (ST), EMD+ST group, and Control (CON) groups. The rats were exposed to deprivation for 10 days, three days a week for 30 minutes. The rats were at 33 postnatal days and their spatial learning and memory were assessed using the Morris Water Maze (MWM) test. Rats' motor function was assessed by the Open-Field (OF) test. Finally, after the extraction of the hippocampus, BDNF protein was measured by ELISA. **Results:** The results of this study revealed that male rats exposed to EMD had learning and spatial memory impairments, lower hippocampal BDNF protein levels. In addition, swimming alone has a positive impact on the BDNF protein level and motor function. **Conclusions:** Despite these findings, due to the high intensity of stress, swimming could not modify the irreparable effects of deprivation.

1. Introduction

Childhood is the most sensitive period of human life and its determinants of neurodevelopmental, motor ability, and psychological development. Infancy events can affect a wide range of physical, behavioral, motor, mental, and neurological components. Some of these issues are extremely stressful and have a more profound impact on child performance (Cooke, 2007; Wiersma et al., 2009). One of them is early maternal deprivation (EMD), it can have adverse effects on growth hormones (Braun, Lange, Metzger, & Poeggel, 1999). Significant changes in brain cells and the hypothalamic-pituitary-adrenal (HPA) axis (Fries, Shirtcliff, & Pollak, 2008) have damaging effects on diverse types of learning and spatial memory (Lévy, Melo, Galef, Madden, & Fleming, 2003) and one's cognitive and emotional development (Ahun & Côté, 2019; Kiernan & Huerta, 2008). Due to previous studies, early life experiences have selective effects on the optional maturation of memory capabilities. It is undeniable that episodic memories exactly after birth are faded away, however, special events can recall them (Bessières, Travaglia, Mowery, Zhang, & Alberini, 2020). In other investigations, the influence of EMD has assessed on structure and function of the hippocampus. They have concluded that females were more resilient to early deprivation stress (Loi et al., 2017). Scientists have claimed that EMD could affect genes expression and the probability of facing Schizophrenia will grow remarkably after puberty (Janetsian-Fritz et al., 2018). Spatial learning and memory are essential cognitive components that have an intense impact on human performance at altered stages of life.

Neuron structural and functional growth in rats is an intricate procedure and any type of stimuli during pregnancy can extremely affect the neuron's functional maturation in life span. According to human and animal investigations, the environmental stimulus such as swimming training (ST) significantly increases the spatial learning and memory ability in the fetus (Akhavan et al., 2008; e Silva-Gondim, de Souza, Rodrigues, & Guedes, 2019; Kim, Lee, Kim, Yoo, & Kim, 2007; Robinson & Bucci, 2014; Song, Kim, Kim, Park, & Lee, 2019). This amelioration happens as an outcome of various styles of exercise during pregnancy, for instance, swimming (e Silva-Gondim et al., 2019), voluntary wheel running (Robinson & Bucci, 2014), or intense running on a treadmill (Akhavan et al., 2008).

Corresponding author: Shahzad Tahmasebi Boroujeni, [b] Associate Professor, Department of Behavioral and Cognitive Sciences in Sport, Faculty of Sport Sciences and Health, University of Tehran, Tehran, Iran. E-mail addresses: shahzadtahmaseb@ut.ac.ir

[DOI: 10.61186/ijmcl.5.2.21]

International Journal of Motor Control and Learning 2023; 5 (2) 21-28

As previous research has shown, early stress in addition to decrease BDNF levels, which regulates brain function and behavior (Xianqiang Zhang et al., 2020), destroys long-lasting changes at the level of (HPA) axis, which are accompanied by age-related memory (Roceri, Hendriks, Racagni, Ellenbroek, & Riva, 2002) and decrease learning and spatial memory (Lévy et al., 2003). So, we examine whether swimming can moderate the damaging impact of EMD on cognitive and motor function. To evaluate this hypothesis two behavioral measurements; MWM for assessing spatial learning and memory ability and OF test for measuring their mobility has been used. Moreover, to figure out the underlying mechanism, BDNF protein was evaluated as well.

Swimming can moderate the negative effects of maternal deprivation on hippocampal BDNF levels. Maternal deprivation has been shown to increase immobility time and decrease climbing time in adult rats, along with reduced BDNF protein levels in the amygdala and hippocampus. It is found that maternal exercise promotes changes in the rat offspring's cerebellum that are still evident in young adult life that may contribute to a protective phenotype against Aβ-induced neurotoxicity in young adult male rat offspring[46]. However, swimming can reverse these effects, leading to decreased hippocampal neuronal apoptosis and increased BDNF expression[55]. Maternal deprivation also leads to increased levels of stress-related hormones, such as corticosterone, and alterations in DNA methylation levels of BDNF and its receptor in the hippocampus of offspring. These molecular changes induced by maternal stress can persist across generations and negatively influence offspring phenotypes. Overall, swimming appears to have a beneficial effect on hippocampal BDNF levels and may help mitigate the negative consequences of maternal deprivation. Swimming has been shown to have positive effects on spatial learning and motor function. Multiple studies have demonstrated that swimming exercise can improve cognitive function, including spatial memory formation and non-spatial memory performance. In particular, swimming exercise has been found to enhance learning, short-term and long-term memory formation, and increase brain-derived neurotrophic factor (BDNF) levels in the hippocampus. Additionally, swimming exercise has been shown to improve visuomotor performance and cognitive functioning acutely. These findings suggest that swimming can moderate the negative effects of spatial learning and motor function, potentially providing benefits for cognitive health and performance. a multilevel meta-analytic approach was used to quantify the intergenerational transmission of exercise effects on brain and cognition, showing that parental exercise showed a tendency for increasing their offspring's brain structure by 12.7% (albeit statistically non-significant) probably via significantly facilitating neurogenesis. In another study It is pointed out that swimming during gestation in rats could prevent prematurity related brain damage in progeny with high translational potential and possibly interesting cost-benefits[50]. swimming exercise has been shown to protect against cognitive and non-cognitive deficits induced by amyloid-beta (Aβ) neurotoxicity in mice, possibly through the inhibition of inflammation and up-regulation of neurotrophic factors in the brain[48,49]. it seems that SD and treadmill exercise interact with each other, and moderate long-term exercise can reverse the negative effects of long-term SD on memory and oxidative status; although, it disrupted memory function and increased oxidative stress by itself[48] . Maternal physical activity should be considered as a therapeutic means of countering the effects of maternal undernutrition, by providing a useful strategy for enhancing the neuronal activity of children born to mothers who experience a restricted diet during pregnancy.

2. Materials and Methods

2.1. Subjects

40 female rats have mated and those that became pregnant, by the presence of vaginal plug, have been placed in routine Plexiglas cages, they were free to use water and food as much as they demand. The 12:12 light/dark cycle was applied during the test and the room temperature was adjusted to be 23±2 ◦C until delivery day (S. DastAmooz, Tahmasebi Boroujeni, Shahbazi, & Vali, 2018). The sample size was calculated by using G * Power version 3.1.9. For the statistical method of univariate one-way analysis of variance with α= 0.05 and power 0.76 with the effect size of 0.70 total number, 28 samples were used.

After delivery, 28 male albino Wistar rats were selected randomly and were divided into four groups and 7 subjects in each group; Early maternal deprivation (EMD), Swimming Training (ST), EMD+ST group, and Control (CON) groups. This investigation has been done through Helsinki's ethical code about animal studies. Also, ethical Committee in University of Tehran approved it (IR.UT.SPORT.REC.1398.052).

2.2. Apparatus and Task

2.2.1. Intervention

Maternal Deprivation

In the second postnatal day, for ten consequence days, neonates were deprived from their mothers for 3 hours a day. All neonates were placed in one cage then the mothers were taken out from the cage. The cage temperature varied from 32◦c at 1 to 5 deprived days to 30◦c from 6 to 10 deprived days (S. DastAmooz et al., 2018)[19]¹⁸.

Swimming Training

Two days after delivery, neonates were forced to swim for 30 min, three times for three weeks (Iñiguez et al., 2019). The swimming apparatus was a calendric shape pool with 140 cm in diameter. The water temperature was 25◦c that is an optimal condition for rat swimming (Venkataramaiah, Swathi, & Rajendra, 2018).

Swimming Training + Maternal Deprivation

Two diverse interventions were applied for the EMD+ST group; firstly, the neonates were separated from their mothers for three hours, and secondly, they were forced to swim for 30 minutes three times a week for three consequence weeks. The control group did not do anything during the experimental days.

2.2.2. Apparatus

Morris Water Maze Test

The MWM contains a roundish pool, escape platform, and a tracer video came that was located at over the box. The Cylindrical pool (140 cm diameter, 60 cm depth) was supplied with water (20 °C), the escape platform was hidden about 1 cm under the surface of the water. The apparatus surface was divided into four quadrants regarding the tracking software: North East, North West, South East and South West (SW). The invisible platform was adjusted in the middle of the SW quadrant. Some signs were stocked to the walls; these were to be surrounding signs for the rats. The video recorder was put exactly over the center of the water maze and connected to software that mapped and assessed escape latency and distance each neonate travels to reach the platform. Each subject accomplished eight trials each day for four consequence days (two blocks of four trials with the timeout between blocks for a couple of minutes) as acquisition sessions(Sima DastAmooz, Tahmasebi Boroujeni, Shahbazi, & Vali, 2018). The neonate was situated in the water; hence, it faced the wall of the pool at modification initiate position and then was sat free to swim to find the hidden platform. Accusation sessions in each block launched in a random system with two blocks of four trials. Pending per trial, the neonates had a chance (60 s) to discover the invisible platform and then were admitted to rest on it for 30 s. If the neonate was not able to discover the

[DOI: 10.61186/ijmcl.5.2.21]

platform, it was addressed to the platform by the operator. The moment that the last trial was accomplished, the neonates were dried out and translocate in their cage. On the fifth day, to investigate memory retention in various groups of neonates, the platform was extracted from the pool (probe test). The neonate swam 60 s exploring the maze. An alternative test conducted on the fifth day was the "visible test" during which the platform was covered with aluminum foil, was the changeover to the southeast (SE)fourth, and appeared the water surface. This test was executed 60 min after the probe test had been displayed. Based on the outcomes of this test, it was investigated that motivation, visual capability, and excellent motor coordination was in all groups and that former test outcomes were not affected by these elements(Naghdi, Majlessi, & Bozorgmehr, 2005). Whole experiments were recorded and kept on a computer using a video tracker system linked to the operator laptop (Etho-Vision XT software), that carries row data to excel software to evaluate navigation elements like; escape latency, and traveled distance.

Open-field Test

To specify the motor function in the rats, the Open-field test was accomplished by applying the common procedure (Sherif & Oreland, 1995). This apparatus has a black Plexiglas box (a cube is equal-sided by definition) 60 cm × 60 cm × 60 cm. Video capture was adjusted over the Open field box and linked to the computer with analysis software. The software discrete the Open-field into equal 20 cm × 20 cm squares. Afterward, the total traveled distance, and the peripheral total traveled distance of each rat was tracked and recorded. The Open-field box was placed in a divided room from the animal colony. For familiarizing the neonates with the Open-field box setting and diminish stress in the main test, they were situated in the test environment one day before the exam for five minutes individually. For the main test, neonates were made to complete one tryout (five minutes) in the Open-field box.

BDNF Test

Hippocampal BDNF levels are assessed using an ELISA kit manufactured in Wuhan, Fine Biotech, China. The results were evaluated by using an ELISA reader (Ststfax, USA). Gene expression was measured by real-time PCR (ABI Stepone machine, USA). Hippocampus samples were centrifuged, (Hectic centrifuge made in Germany), for 5 min at 16,000. round The accuracy of the ELISA Kit was, and the sensitivity was 46.875pg/ml.

2.3. Procedure

The male neonates were tested at 33 postnatal days (PND) firstly, in Morris Water Maze (MWM) for five days; the first four days were acquisition sessions, on the fifth-day probe, and visible tests were manipulated. Secondly, the neonate's mobility was assessed using a motor function task in the Open-field for five minutes. Finally, the hippocampus was isolated and prepared for BDNF levels. All tests were performed at 11 A.M. at the animal laboratory at the at the Pasargad Tissue and Gene institute (Histogenotech Co, Iran).

2.4. Statistical analysis

Mean and the standard deviation was used for the descriptive statistic. In inferential part; Shapiro-Wilk test was used to check the normal distribution of data, homogeneity of variances was assessed through Leven statistics, repeated measure ANOVA was used to measure changes from the first to the fourth day of acquisition. For specifying differences among groups, one-way ANOVA followed by Tukey's post hoc test was applied ($P \leq 0.05$)

3. Results

3.1. MWM

Intragroup acquisition days

The escape latency and traveled distance through the first day to the fifth day of acquisition sessions in the MWM test in each group; EMD, ST, MD+ST, and CON are presented in the summary of findings table (**Table 1**). The statistical assessment revealed a significantly reduction in escape latency during the days of training in the EMD+ST group ($F_{(4, 24)} = 9.192$, $P = 0.004$), EMD group ($F_{(4, 24)} = 4.156$, $P = 0.011$), ST group ($F_{(4, 24)} = 6.325$, $P = 0.019$), and CON group ($F_{(4, 24)} = 3.891$, $P = 0.034$). However, no significant differences observed in EMD+ST, EMD, and ST group's traveled distance (respectively, $P = 0.053$; $P = 0.305$; $P = 0.227$).

As it is illustrated in the Tukey post hoc tests in the ST group depicted the training showed more reduction in escape latency from the first day of training to the last day of acquisition sessions (47.72 ± 5.68 s, 35.18 ± 11.79 s, 28.93± 10.22 s, 29.60± 10.03 s), also in the EMD+ST (51.10 ± 4.51 s, 42.59 ± 5.38 s, 39.06 ± 4.58s, 35.46 ± 12.75 s), and EMD (49.45 ± 5.88 s, 46.84 ± 5.75 s, 42.32 ± 9.79 s, 40.95 ± 11.59) groups.

However, traveled distance from first to last training days' decrease remarkably in the CON group (1090.48 ± 100.049 cm, 911.77 ± 283.60 cm, 715.95 ± 164.56cm, 669.68 ± 74.41cm).

Table 1:
The mean of escape latency (A) and traveled distance (B) within groups during the acquisition period (1-4 day) and probe test (day 5).

Traveled Distance	EMD+ST	EMD	ST	CON
Day 1	51.1	49.46	47.72	44.15
Day 2	42.6	46.85	35.18	34.86
Day 3	39.06	42.32	28.39	31.4
Day 4	35.46	40.95	29.6	30.28
Probe	29.32	33.2	25.67	32.67
Escape Latency	**EMD+ST**	**EMD**	**ST**	**CON**
Day 1	51.1	49.46	47.72	44.15
Day 2	42.6	46.85	35.18	34.86
Day 3	39.06	42.32	28.93	31.04
Day 4	35.46	40.95	29.6	30.28
Probe	29.32	33.2	25.68	32.67

[DOI: 10.61186/ijmcl.5.2.21]

Intergroup acquisition days

Figure 1A, shows the mean of total time to attain the hidden platform during acquisition sessions in the MWM test among the EMD, ST, EMD+ST, and CON groups. A significant difference has been distinguished between groups ($F_{(3, 24)}$ = 6.71, *P* = 0.002). The following Tukey post hoc test demonstrated that escape latency in the EMD group (44.89 ± 4.36) was significantly higher than in the ST (35.35 ± 5.33 s, P = 0.008), and CON groups (35.16 ± 4.97 s, *P* = 0.007).

Figure 1B compares the average total traveled distance in the acquisition sessions during the MWM test between groups. The one-way ANOVA analysis reveals that there was a significant difference among groups ($F_{(3,24)}$ = 9.15, *P* = 0.0001).

The Tukey post hoc test represented that the EMD group (1157.50 ± 122.82) passed a notably more distance than the ST (906.35 ± 148.57cm, *P* = 0.006), CON (846.97 ± 123.89 cm, *P* = 0.001) performed. Moreover, EMD+ST (1078.94 ± 122.82) was weaken than CON groups (846.97 ± 123.89 cm, *P* = 0.011). Hence, this propounded that Deprivation at an early age destroys spatial learning of neonates, however, regular ST like swimming would diminish its harmful effects.

Probe test

One-way ANOVA and Tukey post hoc test analysis demonstrates that there is no remarkable difference in spending time in the SW quadrant among groups ($F_{(3,24)}$ = 1.970, *P* = 0.145). According to the traveled distance results, one-way ANOVA showed a significant difference between the groups ($F_{(3,24)}$ = 3.340, *P* = 0.036). The Tukey post hoc has found the difference between EMD (1080.72 ± 267.46 cm) and CON groups (651.11 ± 221.53 cm, *P* = 0.024).

3.2. Visible Test

Statistical analysis of the visible test displays that there were no significant differences in escape latency ($F_{(3, 27)}$ =1.48, *P*= 0.167) and traveled distance ($F_{(3, 27)}$ =2.8, *P* =0.061) between groups. According to the results of this test, it can be concluded that motivation, visual ability, and motor coordination ability were present in all groups of the study and the outcomes did not rely on these factors.

Open field test

The average traveled distance in central parts of Open field

The total distance passed in the Open field between the Deprivation, ST, EMD+ST, and CON groups were compared in **Figure 2**. The ANOVA one-way result showed that there is a significant difference between the groups ($F_{(3, 24)}$ =4.54, *P* =0.012). The Tukey Post hoc revealed that the ST group (914.29 ± 324.081 cm) outperformed in comparison to the EMD group (528.57 ± 169.64 cm, *P* = 0.008).

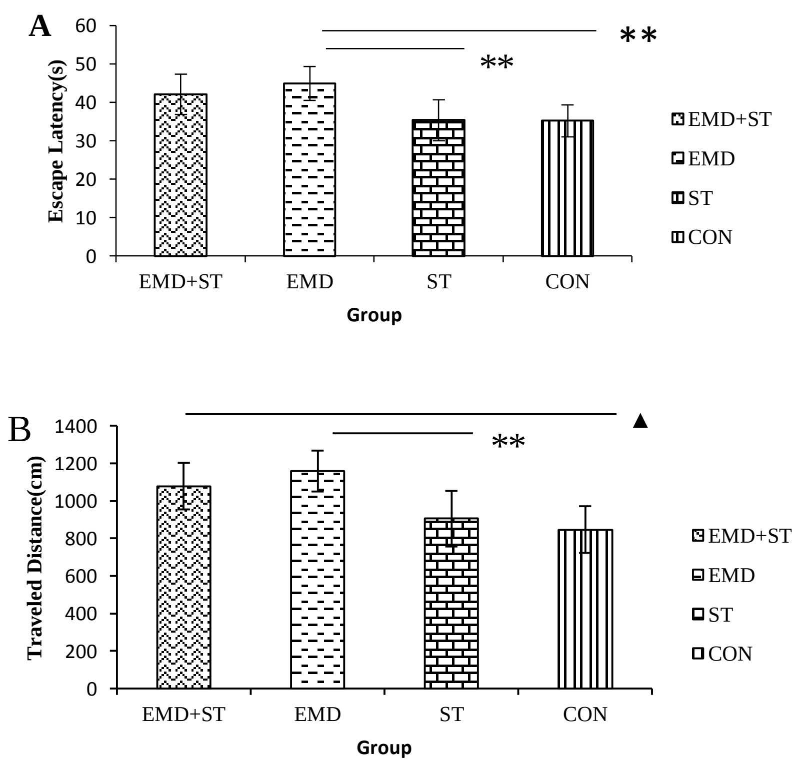

Figure 1. Evaluating the mean of escape latency (1A) and traveled distance (1B) among groups; each value displays the mean ± SEM for seven rats at ST, EMD, EMD+ST and CON groups. Significant differences from the EMD group with P ≤ 0.05 showed with *; ** reveals P ≤ 0.01. Significant differences from the EMD+ST group with P ≤ 0.05 showed with ▲; ▲reveals P ≤ 0.05.

[DOI: 10.61186/ijmcl.5.2.21]

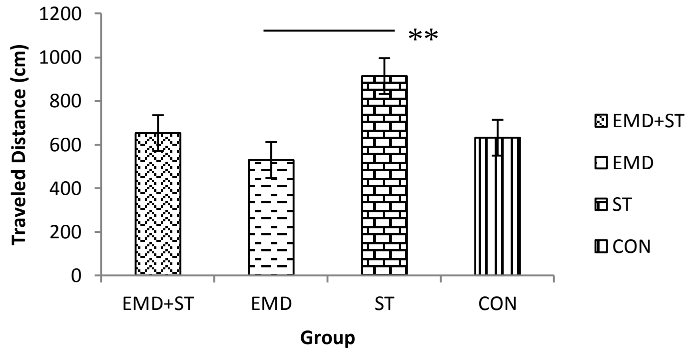

Figure 2. Evaluating the total distance passed in the Open field between groups; each value displays the mean ± SEM for seven rats at ST, EMD, EMD+ST and CON groups. Significant differences from the EMF group with $P \leq 0.05$; ** reveals $P \leq 0.01$.

BDNF Concentration

The comparisons of the BDNF protein concentration among groups have been assessed by one-way ANOVA and the results were shown in Figure 3 significant difference between groups was found out by the one-way ANOVA statistical test ($F_{(3, 24)}$ = 8.88, P = 0.0003). A Tukey post hoc test depicts that the BDNF concentration in the EMD group (1.12 ± 0.30) was remarkably lower than in the ST (2.22 ± 0.52, P = 0.005) and CON groups (1.96 ± 0.50, P = 0.0001).

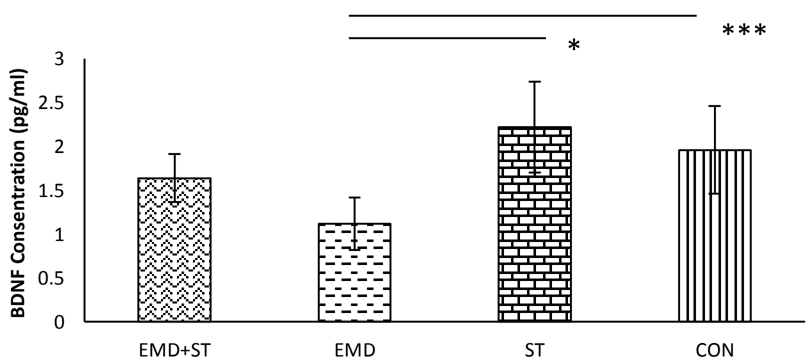

Figure 3. Evaluating BDNF Concentration between groups; each value displays the mean ± SEM for seven rats at ST, EMD, EMD+ST & CON groups. Significant different from the EMF group with $P \leq 0.05$; ** reveals $P \leq 0.01$, *** reveals $P \leq 0.001$.

4. Discussion and Conclusion

MWM Test

The present study aimed to assess the effect of early deprivation on spatial learning in neonates. The prime outcomes were: 1) early deprivation results in spatial learning and memory deficit in the neonates; 2) ST affects the spatial memory positively 3) Due to having the severity of the stress, regular exercise was not effective, and could not diminish the adverse effects of early maternal stress. 4) unlike ST improves the concentration of BDNF protein, deprivation remarkably reduces this protein.

According to the previous study, the cognitive behavior of neonates at the age of puberty would be affected by maternal physical activity during pregnancy (Gomes da Silva et al., 2016). In another study, swimming from day one of pregnancy to delivery improved neonate's short term memory (Lee et al., 2006). Moreover, Dastamooz et. al, 2018 have acclaimed that ST could diminish the adverse impact of environmental conditions on embryo's cognitive and motor function (Sima DastAmooz et al., 2018). these investigations are in line with the present study. The reason for this cognitive improvement due to exercise activity can be found in the production of neurotrophin in the hippocampus which leads to spatial memory enhancement (Gomes da Silva et al., 2016).

Our outcomes demonstrated the early deprivation devastated spatial learning and memory in neonates. The result coincided with previous researches in this area (Daniels, Marais, Stein, & Russell, 2012; Faure, Uys, Marais, Stein, & Daniels, 2007; Rees, Akbari, Steiner, & Fleming, 2008; Tanapat, Hastings, Rydel, Galea, & Gould, 2001; Wang, Li, Wu, & Li, 2019). In an investigation, scientists have revealed that early age stress had a huge adverse impact on learning and spatial memory in comparison to the control group. Moreover, the hippocampal volume of rats exposed to chronic stress was lower than the hippocampal volume of the control group(Wang et al., 2019). Exposure to stressful conditions and early deprivation in rats causes the neonates to be overly sensitive to the unknown position and to reduce hippocampal volume. Moreover, in adulthood, these rats suffer from impaired memory and lifelong learning. The fear memory of rats under initial deprivation was also high. Deprivation of the mother as a stressful pattern of early life disrupts mother-neonate interaction. Early deprivation alters mother behavior (Czarnabay et al., 2019). Some studies have also shown

[DOI: 10.61186/ijmcl.5.2.21]

that chronic stress does not affect spatial learning and memory (Conrad, 2010), others indicate that this exposure enhances spatial memory in male rats (Xuliang Zhang et al., 2014) and enhancement of spatial memory in Y-maze testing (McLaughlin, Baran, Wright, & Conrad, 2005). The discrepancy between the findings is quite clear. the effect of chronic stress on the spatial ability is associated with; task, measured dependent variable, task performance, type and duration of stress, animal living conditions including access to food and other rats, duration from the end of stress to onset of behavioral assessment (Conrad, 2010). However, chronic stress seems to cause the least defect or may even facilitate spatial learning (Conrad, 2010).

Experiencing stress early in life can cause long-term impacts on the central nervous system and these effects can cause abnormal behaviors as well as long-term biochemical changes in the brain. Besides, problems with learning memory and mental disorders are one of the consequences of early maternal deprivation(Faure et al., 2007).

Open Field Test

The results of data analysis showed that early deprivation and maternal separation had a significant effect on the motor function of male rats (Figure 2). In other words, early deprivation could have a significant effect on the motor function of neonates. Considering previous research and literature on the impact of early age traumatic events, it is clear that many studies have emphasized that traumatic events can have adverse and devastating effects on the mental and motor development of children in later stages and motor function(Braun et al., 1999; Cooke, 2007; Wiersma et al., 2009). Swimming training did not have a significant effect on the motor function of the group that was exposed to early deprivation and then did the swimming exercise. The effect of swimming exercise on motor function shows a positive effect on improving motor function in male rats. These results are in line with the previous research (Irandoost, Taheri, Dev, & 2014, 2014). In a study aimed at investigating the effect of swimming programs on motor performance reported that standardization swim exercises can increase motor performance in general(Dimitrijević et al., 2012). Swimming exercise, as a sensory-motor activity, can increase the motor function in children who are growing. These studies have emphasized that capillary growth in motor areas of the brain is a specific mechanism for explaining the effect of continuous ST and exercise on motor function. The vascular system also enhances the motor cortex of the animals during exercise(Pollock, Peacock, Ryan, Spitznagel, & Ridgel, 2019; Swain et al., 2003).

BDNF Test

Numerous studies have confirmed the beneficial effects of regular ST on brain functions such as increased hippocampus BDNF levels (Antunes, Rossi, Teixeira, & Lira, 2020). Assessing the BDNF protein outcomes reveals that swimming increased the BDNF protein levels significantly. This improvement has compensated the adverse effect of early deprivation in neonates. This consequence is in line with the former studies (Huang, Larsen, Ried-Larsen, Møller, & Andersen, 2014; Yarrow, White, McCoy, & Borst, 2010). moderate forced exercise lessens anxiety, BDNF, and Cognitive deterioration in male(Shahroodi et al., 2020). 19 adults were asked to do 35 min of physical exercise, mindfulness, and cognitive training. The outcomes have demonstrated that ST has a significantly larger effect on the BDNF level in comparison to the mindfulness and cognitive training groups (Håkansson et al., 2017). In an early investigation, researchers have found that low BDNF levels and depression have a significant correlation, and doing regular stretch exercise could increase the BDNF level in depressed participants (Szuhany & Otto, 2020). One of the important mechanisms in improving hippocampal plasticity following high-intensity resistance training is positive changes in BDNF scientists concluded that ST improves cognitive abilities, learning, expression of neurotrophic factors, stem cell proliferation in dynamic brain centers, structural changes in the brain, and ultimately the growth and remodeling of brain areas. Brain-derived neurotrophic factor (BDNF) plays an essential role in brain plasticity by interceding modifications in synaptic density and cortical thickness in reply to environmental enrichment and ST (Håkansson et al., 2017). Maybe that is the main reason for various results in the present investigation within groups.

The paper investigates the effect of swimming training on spatial learning, memory, and motor function in male rats under early maternal deprivation. The study found that swimming alone has a positive impact on the BDNF protein level and motor function, but it could not modify the irreparable effects of deprivation due to the high intensity of stress.

Author’s contribution

Conception and design of study: M.A, SH.T.B; data collection: M.A; Data analysis and/or interpretation: M.A, SH.T.B; Drafting of manuscript and/or critical revision: M.A, SH.T.B, E.A; Approval of final version of manuscript: M.A, SH.T.B.

Conflict of interest

The authors declare that there is no conflict of interest.

Funding

This research received no external funding.

Acknowledgments

The authors thank the staff of animal laboratory at the Gens and tissue Institute of Pasargad.

References

Ahun, M. N., & Côté, S. M. (2019, February). Maternal depressive symptoms and early childhood cognitive development: a review of putative environmental mediators. *Archives of Women’s Mental Health*. Springer-Verlag Wien. https://doi.org/10.1007/s00737-018-0870-x

Akhavan, M. M., Emami-Abarghoie, M., Safari, M., Sadighi-Moghaddam, B., Vafaei, A. A., Bandegi, A. R., & Rashidy-Pour, A. (2008). Serotonergic and noradrenergic lesions suppress the enhancing effect of maternal exercise during pregnancy on learning and memory in rat pups. *Neuroscience*, *151*(4). https://doi.org/10.1016/j.neuroscience.2007.10.051

Antunes, B. M., Rossi, F. E., Teixeira, A. M., & Lira, F. S. (2020). Short-time high-intensity exercise increases peripheral BDNF in a physical fitness-dependent way in healthy men. *European Journal of Sport Science*, *20*(1). https://doi.org/10.1080/17461391.2019.1611929

Bessières, B., Travaglia, A., Mowery, T. M., Zhang, X., & Alberini, C. M. (2020). Early life experiences selectively mature learning and memory abilities. *Nature Communications*, *11*(1). https://doi.org/10.1038/s41467-020-14461-3

Braun, K., Lange, E., Metzger, M., & Poeggel, G. (1999). Maternal separation followed by early social deprivation affects the development of monoaminergic fiber systems in the medial prefrontal cortex of Octodon degus. *Neuroscience*, *95*(1). https://doi.org/10.1016/S0306-4522(99)00420-0

Conrad, C. D. (2010). A critical review of chronic stress effects on spatial learning and memory. *Progress in Neuro-Psychopharmacology and Biological Psychiatry*, *34*(5). https://doi.org/10.1016/j.pnpbp.2009.11.003

Cooke, L. (2007, August). The importance of exposure for healthy eating in childhood: A review. *Journal of Human Nutrition*

[DOI: 10.61186/ijmcl.5.2.21]

and Dietetics. https://doi.org/10.1111/j.1365-277X.2007.00804.x

Czarnabay, D., Dalmago, J., Martins, A. S., Queiroz, A., Sperling, L.-E., Reis, K. P., … Benetti, F. (2019). Repeated three-hour maternal deprivation as a model of early-life stress alters maternal behavior, olfactory learning and neural development. *Neurobiology of Learning and Memory*, *163*. https://doi.org/10.1016/j.nlm.2019.107040

Daniels, W. M. U., Marais, L., Stein, D. J., & Russell, V. A. (2012). Exercise normalizes altered expression of proteins in the ventral hippocampus of rats subjected to maternal separation. *Experimental Physiology*, *97*(2). https://doi.org/10.1113/expphysiol.2011.061176

DastAmooz, S., Tahmasebi Boroujeni, S., Shahbazi, M., & Vali, Y. (2018). Physical activity as an option to reduce adverse effect of EMF exposure during pregnancy. *International Journal of Developmental Neuroscience*, *71*. https://doi.org/10.1016/j.ijdevneu.2018.07.009

DastAmooz, Sima, Tahmasebi Boroujeni, S., Shahbazi, M., & Vali, Y. (2018). *Physical activity as an option to reduce adverse effect of EMF exposure during pregnancy*. *International Journal of Developmental Neuroscience* (Vol. 71). International Society for Developmental Neuroscience. https://doi.org/10.1016/j.ijdevneu.2018.07.009

Dimitrijević, L., Aleksandrović, M., Madić, D., Okičić, T., Radovanović, D., & Daly, D. (2012). The Effect of Aquatic Intervention on the Gross Motor Function and Aquatic Skills in Children with Cerebral Palsy. *Journal of Human Kinetics*, *32*(2012). https://doi.org/10.2478/v10078-012-0033-5

e Silva-Gondim, M. B., de Souza, T. K. M., Rodrigues, M. C. A., & Guedes, R. C. A. (2019). Suckling in litters with different sizes, and early and late swimming exercise differentially modulates anxiety-like behavior, memory and electrocorticogram potentiation after spreading depression in rats. *Nutritional Neuroscience*, *22*(7). https://doi.org/10.1080/1028415X.2017.1407472

Faure, J., Uys, J. D. K., Marais, L., Stein, D. J., & Daniels, W. M. U. (2007). Early maternal separation alters the response to traumatization: resulting in increased levels of hippocampal neurotrophic factors. *Metabolic Brain Disease*, *22*(2). https://doi.org/10.1007/s11011-007-9048-3

Fries, A. B. W., Shirtcliff, E. A., & Pollak, S. D. (2008). Neuroendocrine dysregulation following early social deprivation in children. *Developmental Psychobiology*, *50*(6). https://doi.org/10.1002/dev.20319

Gomes da Silva, S., de Almeida, A. A., Fernandes, J., Lopim, G. M., Cabral, F. R., Scerni, D. A., … Arida, R. M. (2016). Maternal Exercise during Pregnancy Increases BDNF Levels and Cell Numbers in the Hippocampal Formation but Not in the Cerebral Cortex of Adult Rat Offspring. *PLOS ONE*, *11*(1). https://doi.org/10.1371/journal.pone.0147200

Håkansson, K., Ledreux, A., Daffner, K., Terjestam, Y., Bergman, P., Carlsson, R., … Mohammed, A. K. H. (2017). BDNF Responses in Healthy Older Persons to 35 Minutes of Physical Exercise, Cognitive Training, and Mindfulness: Associations with Working Memory Function. *Journal of Alzheimer's Disease*, *55*(2), 645–657. https://doi.org/10.3233/JAD-160593

Huang, T., Larsen, K. T., Ried-Larsen, M., Møller, N. C., & Andersen, L. B. (2014). The effects of physical activity and exercise on brain-derived neurotrophic factor in healthy humans: A review. *Scandinavian Journal of Medicine & Science in Sports*, *24*(1). https://doi.org/10.1111/sms.12069

Iñiguez, S. D., Parise, L. F., Lobo, M. K., Flores-Ramirez, F. J., Garcia-Carachure, I., Warren, B. L., & Robison, A. J. (2019). Upregulation of hippocampal extracellular signal-regulated kinase (ERK)–2 induces antidepressant-like behavior in the rat forced swim test. *Behavioral Neuroscience*, *133*(2). https://doi.org/10.1037/bne0000303

Irandoost, K., Taheri, M., Dev, A. S.-J. M. L., & 2014, U. (2014). The effects swimming and running training protocol on motor function, learning, spatial memory of old rats. *Motor Learning and Growth*, *2*(14), 1–16.

Janetsian-Fritz, S. S., Timme, N. M., Timm, M. M., McCane, A. M., Baucum II, A. J., O'Donnell, B. F., & Lapish, C. C. (2018). Maternal deprivation induces alterations in cognitive and cortical function in adulthood. *Translational Psychiatry*, *8*(1). https://doi.org/10.1038/s41398-018-0119-5

Kiernan, K. E., & Huerta, M. C. (2008). Economic deprivation, maternal depression, parenting and children's cognitive and emotional development in early childhood1. *The British Journal of Sociology*, *59*(4). https://doi.org/10.1111/j.1468-4446.2008.00219.x

Kim, H., Lee, S. H., Kim, S. S., Yoo, J. H., & Kim, C. J. (2007). The influence of maternal treadmill running during pregnancy on short-term memory and hippocampal cell survival in rat pups. *International Journal of Developmental Neuroscience*, *25*(4), 243–249. https://doi.org/10.1016/j.ijdevneu.2007.03.003

Lee, H. H., Kim, H., Lee, J. W., Kim, Y. S., Yang, H. Y., Chang, H. K., … Kim, C. J. (2006). Maternal swimming during pregnancy enhances short-term memory and neurogenesis in the hippocampus of rat pups. *Brain and Development*, *28*(3), 147–154. https://doi.org/10.1016/j.braindev.2005.05.007

Lévy, F., Melo, A. I., Galef, B. G., Madden, M., & Fleming, A. S. (2003). Complete maternal deprivation affects social, but not spatial, learning in adult rats. *Developmental Psychobiology*, *43*(3). https://doi.org/10.1002/dev.10131

Loi, M., Mossink, J. C. L., Meerhoff, G. F., Den Blaauwen, J. L., Lucassen, P. J., & Joëls, M. (2017). Effects of early-life stress on cognitive function and hippocampal structure in female rodents. *Neuroscience*, *342*. https://doi.org/10.1016/j.neuroscience.2015.08.024

McLaughlin, K. J., Baran, S. E., Wright, R. L., & Conrad, C. D. (2005). Chronic stress enhances spatial memory in ovariectomized female rats despite CA3 dendritic retraction: Possible involvement of CA1 neurons. *Neuroscience*, *135*(4). https://doi.org/10.1016/j.neuroscience.2005.06.083

Naghdi, N., Majlessi, N., & Bozorgmehr, T. (2005). The effect of intrahippocampal injection of testosterone enanthate (an androgen receptor agonist) and anisomycin (protein synthesis inhibitor) on spatial learning and memory in adult, male rats. *Behavioural Brain Research*, *156*(2). https://doi.org/10.1016/j.bbr.2004.05.032

Pollock, B. S., Peacock, C. A., Ryan, E. J., Spitznagel, M. B., & Ridgel, A. L. (2019). A multifaceted exercise intervention did not alter cognitive function and cerebral perfusion in individuals with Parkinson's disease. *Science and Sports*. https://doi.org/10.1016/j.scispo.2019.05.008

Rees, S. L., Akbari, E., Steiner, M., & Fleming, A. S. (2008). Effects of early deprivation and maternal separation on pup-directed behavior and HPA axis measures in the juvenile female rat. *Developmental Psychobiology*, *50*(4). https://doi.org/10.1002/dev.20292

Robinson, A. M., & Bucci, D. J. (2014). Physical exercise during pregnancy improves object recognition memory in adult offspring. *Neuroscience*, *256*. https://doi.org/10.1016/j.neuroscience.2013.10.012

Roceri, M., Hendriks, W., Racagni, G., Ellenbroek, B. A., & Riva, M. A. (2002). Early maternal deprivation reduces the expression of BDNF and NMDA receptor subunits in rat hippocampus. *Molecular Psychiatry*, *7*(6). https://doi.org/10.1038/sj.mp.4001036

Shahroodi, A., Mohammadi, F., Vafaei, A. A., Miladi-Gorji, H., Bandegi, A. R., & Rashidy-Pour, A. (2020). Impact of different intensities of forced exercise on deficits of spatial and aversive memory, anxiety-like behavior, and hippocampal BDNF during morphine abstinence period in male rats. *Metabolic Brain Disease*, *35*(1). https://doi.org/10.1007/s11011-019-00518-w

[DOI: 10.61186/ijmcl.5.2.21]

Sherif, F., & Oreland, L. (1995). Effect of the GABA-transaminase inhibitor vigabatrin on exploratory behaviour in socially isolated rats. *Behavioural Brain Research*, *72*(1–2). https://doi.org/10.1016/0166-4328(96)00047-2

Song, M. K., Kim, E. J., Kim, J. K., Park, H. K., & Lee, S. G. (2019). Effect of regular swimming exercise to duration-intensity on neurocognitive function in cerebral infarction rat model. *Neurological Research*, *41*(1), 37–44. https://doi.org/10.1080/01616412.2018.1524087

Swain, R. ., Harris, A. ., Wiener, E. ., Dutka, M. ., Morris, H. ., Theien, B. ., … Greenough, W. . (2003). Prolonged exercise induces angiogenesis and increases cerebral blood volume in primary motor cortex of the rat. *Neuroscience*, *117*(4). https://doi.org/10.1016/S0306-4522(02)00664-4

Szuhany, K. L., & Otto, M. W. (2020). Assessing BDNF as a mediator of the effects of exercise on depression. *Journal of Psychiatric Research*, *123*. https://doi.org/10.1016/j.jpsychires.2020.02.003

Tanapat, P., Hastings, N. B., Rydel, T. A., Galea, L. A. M., & Gould, E. (2001). Exposure to fox odor inhibits cell proliferation in the hippocampus of adult rats via an adrenal hormone-dependent mechanism. *The Journal of Comparative Neurology*, *437*(4). https://doi.org/10.1002/cne.1297

Tashman, L. S., & Tenenbaum, G. (2013). Sport Psychology Service Delivery Training: The Value of an Interactive, Case-Based Approach to Practitioner Development. *Journal of Sport Psychology in Action*, *4*(2), 71–85. https://doi.org/10.1080/21520704.2012.744375

Venkataramaiah, C., Swathi, G., & Rajendra, W. (2018). Morris Water Maze – A Bench Mark Test For Learning And Memory Disorders In Animal Models: A Review. *Asian Journal of Pharmaceutical and Clinical Research*, *11*(5). https://doi.org/10.22159/ajpcr.2018.v11i5.24292

Wang, D., Li, B., Wu, Y., & Li, B. (2019). The Effects of Maternal Atrazine Exposure and Swimming Training on Spatial Learning Memory and Hippocampal Morphology in Offspring Male Rats via PSD95/NR2B Signaling Pathway. *Cellular and Molecular Neurobiology*, *39*(7). https://doi.org/10.1007/s10571-019-00695-3

Wiersma, J. E., Hovens, J. G. F. M., van Oppen, P., Giltay, E. J., van Schaik, D. J. F., Beekman, A. T. F., & Penninx, B. W. J. H. (2009). The Importance of Childhood Trauma and Childhood Life Events for Chronicity of Depression in Adults. *The Journal of Clinical Psychiatry*, *70*(7). https://doi.org/10.4088/JCP.08m04521

Yarrow, J. F., White, L. J., McCoy, S. C., & Borst, S. E. (2010). Training augments resistance exercise induced elevation of circulating brain derived neurotrophic factor (BDNF). *Neuroscience Letters*, *479*(2). https://doi.org/10.1016/j.neulet.2010.05.058

Zhang, Xianqiang, Li, H., Sun, H., Jiang, Y., Wang, A., Kong, Y., … Sun, L. (2020). Effects of BDNF Signaling on Anxiety-Related Behavior and Spatial Memory of Adolescent Rats in Different Length of Maternal Separation. *Frontiers in Psychiatry*, *11*. https://doi.org/10.3389/fpsyt.2020.00709

Zhang, Xuliang, Wang, B., Jin, J., An, S., Zeng, Q., Duan, Y., … Cao, X. (2014). Early deprivation reduced anxiety and enhanced memory in adult male rats. *Brain Research Bulletin*, *108*. https://doi.org/10.1016/j.brainresbull.2014.08.005

[DOI: 10.61186/ijmcl.5.2.21]