HiLL PUBLISHING

Scientific Access, 2025, 1(2), 107-114
https://www.hillpublisher.com/journals/sa/
ISSN Online: 3068-7500

Analysis of the Effect of Electroacupuncture on Repairing Hippocampal Mitochondrial Damage and Alleviating Anxiety Symptoms in PTSD Rats Based on the GPX4/ACSL4 Signaling Axis

Shijin Chen[1], Lianjun Min[1], Ganqi Chen[1], Jun Zhou[1,*], Ruolan Bi[2]

[1]Wuhan Jingkai Foreign Language School, Wuhan 430118, Hubei, China.
[2]The Village School, Houston, TX 77077, USA.

How to cite this paper: Shijin Chen, Lianjun Min, Ganqi Chen, Jun Zhou, Ruolan Bi. (2025) Analysis of the Effect of Electroacupuncture on Repairing Hippocampal Mitochondrial Damage and Alleviating Anxiety Symptoms in PTSD Rats Based on the GPX4/ACSL4 Signaling Axis. *Scientific Access*, 1(2), 107-114.
DOI: 10.26855/sa.2025.09.007

Received: November 30, 2025
Accepted: December 28, 2025
Published: January 26, 2026

***Corresponding author:** Jun Zhou, Wuhan Jingkai Foreign Language School, Wuhan 430118, Hubei, China.

Abstract

Objective: To explore the effect of electroacupuncture on repairing mitochondrial damage in the hippocampus and improving anxiety symptoms in PTSD rats based on the GPX4/ACSL4 signaling axis. **Methods:** 48 SPF-grade male SD rats were randomly divided into a control group, PTSD group, drug group, and EA group, with 12 rats in each group. A modified single prolonged stress combined with the foot-electrical stimulation method was used to establish the PTSD rat model. The control group and the PTSD group were not treated, while the EA group received acupuncture at "Baihui", "Shenting", and bilateral "Liver Shu" and "Kidney Shu", the drug group was given paroxetine suspension (10 mg/kg) by gavage, all for 21 days. After treatment, behavioral changes were evaluated through the open field test and elevated plus maze test. HE staining and Nissl staining were used to observe the pathological changes and nerve cell changes in the hippocampus, and real-time fluorescence quantitative PCR and immunofluorescence were used to detect the mRNA and protein expressions of GPX4, ACSL4, and caspase-3. **Results:** Compared with the control group, the total distance of open field activity in the PTSD group was significantly reduced ($P<0.01$); compared with the PTSD group, the total distance of open field activity in the EA group was significantly increased ($P<0.05$), and there was no statistically significant difference in the total distance of open field activity between the EA group and the drug group ($P>0.05$). Compared with the control group, the activity distance and time in the open arm area of the elevated plus maze in the PTSD group were significantly reduced ($P<0.01$); compared with the PTSD group, the activity distance and time in the open arm area of the elevated plus maze in the EA group were significantly increased ($P<0.05$), and there was no statistically significant difference in the activity distance and time in the open arm area of the elevated plus maze between the drug group and the PTSD group ($P>0.05$). Compared with the control group, the expression of GPX4 in the hippocampus of the PTSD group was significantly decreased, and the expressions of ACSL4 and caspase-3 were significantly increased ($P<0.01$); compared with the PTSD group, the expression of GPX4 in the hippocampus of the drug group and the EA group was significantly increased, and the expressions of ACSL4 and caspase-3 were significantly decreased ($P<0.05$), and there was no significant difference between the two groups compared with the drug group ($P>0.05$). **Conclusion:** Electroacupuncture treatment can significantly improve the anxiety behavior of PTSD rats, repair mitochondrial damage in the hippocampus, up-regulate the expression of GPX4, and down-regulate the expression of ACSL4 and caspase-3, exerting therapeutic effects on PTSD rats.

Keywords

Post-traumatic stress disorder; Electroacupuncture; Nerve cells; GPX4; ACSL4

1. Introduction

Post-traumatic stress disorder (PTSD) is a mental disorder triggered by traumatic events. Patients often experience symptoms such as traumatic re-experiencing, heightened alertness, anxiety, and depression [1]. The prevalence of PTSD in the general population ranges from 1 to 8%, while it is as high as 50% in mental health institutions. More than one-third of patients suffer from chronic and refractory symptoms. The pathogenesis of PTSD involves multiple biological processes such as inflammatory response, neuroplasticity changes, and dysregulation of neurotransmitter systems. Hippocampal mitochondrial damage plays a crucial role in the onset and symptom persistence of PTSD [2, 3]. Ferroptosis is a unique regulatory form of cell death characterized by significant mitochondrial shrinkage, increased membrane density, and reduced or disappearing mitochondrial cristae. The core of ferroptosis lies in the accumulation of iron-dependent lipid peroxides, which can be summarized as a cascade reaction of "iron overload - lipid oxidation - failure of antioxidant defense" [4]. Glutathione peroxidase 4 (GPX4) is the only enzyme in the cell that can reduce lipid peroxides and is crucial for inhibiting ferroptosis. Its activity depends on GSH (glutathione). Acyl-CoA synthetase long-chain family member 4 (ACSL4) is a key factor promoting lipid peroxidation, catalyzing the esterification of PUFAs with CoA to provide substrates for lipid peroxidation [5, 6]. The GPX4/ACSL4 signaling axis plays a key role in the regulation of ferroptosis. Acupuncture, as a traditional Chinese medical therapy, has been applied in the treatment of mental disorders. A large number of clinical and experimental studies have confirmed that acupuncture has certain clinical efficacy for PTSD, but the specific mechanism is not yet fully understood [7]. This study focuses on the GPX4/ACSL4 signaling axis to explore the repair effect of electro-acupuncture on hippocampal mitochondrial damage in PTSD rats and the mechanism of improving anxiety symptoms, providing a theoretical basis for electro-acupuncture treatment of PTSD.

2. Materials and Methods

2.1 Experimental animals

Forty-eight SPF-grade healthy male SD rats, with a body weight of 180-220g, were provided by the relevant animal experimentation center. The rats were randomly divided into a control group, PTSD group, drug group, and EA group, with 12 rats in each group. The rats were acclimated for 10 days before the experiment (counting from the date of purchase), during which the experimenter gently stroked the rats for 5 minutes each day to help the animals adapt to the experimenter's operation. All treatments of the rats during the experiment were carried out in accordance with the "Guidelines for the Care and Use of Laboratory Animals" issued by the Ministry of Science and Technology in 2006.

2.2 Establishment of the PTSD rat model

The modified single prolonged stress combined with the foot-puncture stimulation method was used to establish the PTSD rat model [8]. The specific steps were as follows: (1) Confined: Place the rat head towards the bottle mouth, tail exposed, and insert it into a plastic bottle, then place it horizontally for 2 hours. (2) Forced swimming: Place the confined rat in a rectangular water tank with a water depth of approximately 30cm and a water temperature of (24±2)℃ for forced swimming for 20 minutes. (3) Ether anesthesia: After forced swimming, the rat was retrieved from the cage and placed in an ether cylinder for anesthesia until loss of consciousness. (4) Foot-puncture stimulation: After the rat regained consciousness, give foot-puncture stimulation on the foot, with a current intensity of 1-2mA, each stimulation lasting 1-2 seconds, with an interval of 10-20 seconds, for a total of 20 foot-puncture stimulations.

2.3 Main experimental equipment and instruments

RNA extraction kit, reverse transcription kit, fluorescence quantitative kit, Dapi staining agent, GPX4, ACSL4, Caspase-3 antibody, environmentally friendly decalcification and transparency liquid, citrate antigen retrieval solution, PBST rinsing buffer, anti-fluorescence quenching mounting agent, HE staining kit, paroxetine hydrochloride

tablets (Beijing Wensheng Pharmaceutical Co., Ltd.); SDZ-II Huo Toa brand electro-acupuncture therapy instrument; Huo Toa brand disposable sterile acupuncture needles: standard "0.25×25 mm", fluorescence quantitative PCR instrument.

2.4 Intervention methods

The drug group was given paroxetine suspension (10 mg/kg) by gavage starting from the day after the modeling was completed, for 3 consecutive weeks, 5 times per week. The EA group selected the "Baihui", "Shenting", "Liver Shu ", and "Kidney Shu" acupoints for acupuncture. "Shenting" and the left "Liver Shu" were grouped together, and "Baihui" and the right "Kidney Shu" were also grouped together. The treatment used sparse and dense waves, with a frequency of 2Hz/100Hz, an intensity of 1mA, once a day, for 20 minutes each time, for a total of 21 days. The control group and the model group did not receive any treatment.

2.5 Observation indicators and detection methods

2.5.1 Open field experiment

Place the rats in the spontaneous activity detection box from the rat cage, allowing them to explore freely for 30 minutes, then remove the rats and return them to the rat cage. The video tracking system records and analyzes the horizontal activity distance of the rats, recording the horizontal activity distance of the rats during 6 blocks of 5 minutes each. A decrease in the horizontal activity distance reflects the anxiety behavior of the rats.

2.5.2 Elevated cross maze experiment

The elevated cross maze consists of two open arms and two closed arms, forming a cross shape. The maze is 50 cm above the ground. Place the rats in the central area of the maze, facing the open arms, and record the time and number of visits to the open arms and closed arms within 5 minutes. An increase in the number of visits to the open arms and the time spent in the open arms reflects a reduction in the anxiety behavior of the rats.

2.5.3 HE staining

Take the hippocampal tissue of the rats, place it in a xylene gradient for decolorization, and in an ethanol gradient for dehydration; add hematoxylin staining solution for 5 minutes, rinse with distilled water to remove the floating color; add differentiation solution for 3 minutes, rinse twice with tap water, once per minute; add eosin staining solution for 30 seconds, rinse with distilled water to remove the floating color; gradient ethanol dehydration, gradient xylene transparency; mix neutral gum and xylene evenly for mounting, observe the pathological changes of the hippocampus under a microscope.

2.5.4 Real-time fluorescence quantitative PCR detection of mRNA expression

Take the hippocampal tissue, extract total RNA using the Trizol method, and reverse transcribe to cDNA. Use cDNA as the template, perform real-time fluorescence quantitative PCR using the SYBR Green method to detect the expression of the GPX4 and ACSL4 genes. The primer sequences were designed and synthesized by relevant biological companies. GAPDH was used as the internal reference gene, and the relative expression level of the target genes was calculated using the $2^{-}\Delta\Delta Ct$ method.

2.5.5 Immunofluorescence detection of protein expression

Take the hippocampal tissue, make a wax section, decolorize with water, and perform antigen repair. Add 5% BSA to the section for 30 minutes, respectively add GPX4 and ACSL4 antibodies, and incubate at 4°C overnight. The next day, wash the section 3 times with PBS for 5 minutes each time, add fluorescent secondary antibody, and incubate at room temperature in the dark for 1 hour. Wash the section 3 times with PBS for 5 minutes each time, add DAPI staining solution, and incubate at room temperature in the dark for 10 minutes. Wash the section 3 times with PBS for 5 minutes each time, mount with anti-fluorescence quenching mounting agent, observe and take pictures under a fluorescence microscope, and analyze the fluorescence intensity using Image J software to reflect the expression level of the protein.

2.6 Statistical analysis

Use SPSS 29.0 software for statistical analysis. Quantitative data are expressed as mean ± standard deviation ($x \pm s$), and multi-group comparisons are performed using one-way analysis of variance, and pairwise comparisons are performed using the LSD-t test. $P < 0.05$ is considered statistically significant.

3. Results

3.1 Results of the open field test

Compared with the control group, the total distance of the rats in the PTSD group in the open field significantly decreased (P<0.01); compared with the PTSD group, the total distance of the rats in the EA group significantly increased (P<0.05), and there was no statistically significant difference in the total distance of the rats in the EA group compared with the drug group (P>0.05), as shown in Table 1.

Table 1. Comparison of open field experiments among different groups of rats (x±s)

Groups	n	Number of strokes (count)	Number of Standing Times (times)
Control group	12	95.48±16.32	18.45±2.36
PTSD group	12	60.12±12.68**	8.64±0.96**
Drug group	12	122.17±19.45△△	21.06±4.57△△
EA group	12	118.95±17.36△△	18.96±3.52△△
F value		12.593	28.402
P value		<0.001	0.000

Notes: Compared with the blank group, *P<0.05, **P<0.01; compared with the PTSD group, △P<0.05, △△P<0.01.

3.2 Results of the elevated plus maze test

Compared with the control group, the distance and time of the rats in the open arm area of the elevated plus maze in the PTSD group significantly decreased (P<0.01); compared with the PTSD group, the distance and time of the rats in the open arm area of the elevated plus maze in the EA group significantly increased (P<0.05). There was no statistically significant difference in the distance and time of the rats in the open arm area of the elevated plus maze between the drug group and the PTSD group (P>0.05), as shown in Table 2.

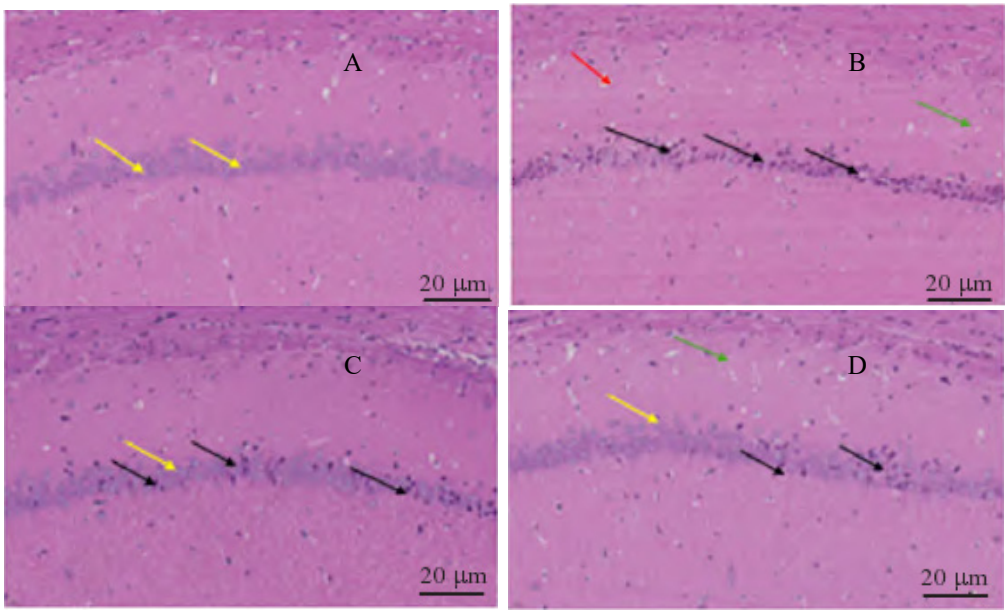
Table 2. Comparison of the elevated cross maze experiments among different groups of rats (x±s)

Groups	n	Percentage of times with open arms entering (%)	Percentage of extended arm holding time (%)
Control group	12	22.68±3.72	17.15±2.31
PTSD group	12	9.24±2.08**	2.64±0.79**
Drug group	12	20.13±3.94△△	13.56±3.48△△
EA group	12	18.94±3.65△△	12.07±3.26△△
F value		26.593	17.482
P value		0.000	<0.001

Notes: Compared with the blank group, *P<0.05, **P<0.01; compared with the PTSD group, △P<0.05, △△P<0.01.

3.3 Results of HE staining of the hippocampus in each group of rats

The results of HE staining of the hippocampus in each group of rats (as shown in Figure 1) showed that compared with the control group, the hippocampus of the PTSD group showed a large number of shrunk nerve cells, irregular cell morphology, reduced cell volume, and strong basophilia; at the same time, a large number of small-sized vacuoles were visible; a small amount of perivascular edema and widened intercellular spaces were observed. Compared with the PTSD group, the hippocampus of the drug group showed regular cell morphology, orderly and dense arrangement, large and round nuclei, less chromatin, and obvious nucleoli; only a small number of pyramidal cells showed shrinkage, irregular cell morphology, and reduced cell volume, with strong basophilia. The hippocampus of the EA group showed regular cell morphology, orderly and dense arrangement, large and round nuclei, less chromatin, and obvious nucleoli; a small number of pyramidal cells showed shrinkage, irregular cell morphology, and reduced cell volume, with strong basophilia; and a large number of small-sized vacuoles were visible in the hippocampus.



Notes: A - Control group, B - PTSD group, C - Drug group, D - EA group

Figure 1. Results of HE staining of the hippocampus in each group of rats (×200).

3.4 Expression of GPX4, ACSL4, and caspase-3 mRNA in each group of rats

Compared with the control group, the expression of GPX4 in the hippocampus of the PTSD group was significantly decreased, and the expressions of ACSL4 and caspase-3 were significantly increased (P<0.01); compared with the PTSD group, the expressions of GPX4 in the hippocampus of the drug group and the EA group were significantly increased, and the expressions of ACSL4 and caspase-3 were significantly decreased (P<0.05). There was no significant difference between the two groups compared with the drug group (P>0.05), as shown in Table 3 and Figure 2.

Table 3. Comparison of mRNA expression levels of GPX4, ACSL4, and caspase-3 in the hippocampus of each group of rats (x±s, n=12)

Groups	GPX4 mRNA	ACSL4 mRNA	caspase-3 mRNA
Control group	1.000±0.010	1.000±0.020	1.000±0.016
PTSD group	0.402±0.029**	2.064±0.048**	2.357±0.062**
Drug group	0.853±0.021△	1.142±0.035△	1.214±0.023△△
EA group	0.795±0.016△	1.226±0.026△	1.368±0.034△△
F value	12.859	14.436	45.281
P value	<0.001	<0.001	0.000

Notes: Compared with the blank group, *P<0.05, **P<0.01; compared with the PTSD group, △P<0.05, △△P<0.01.

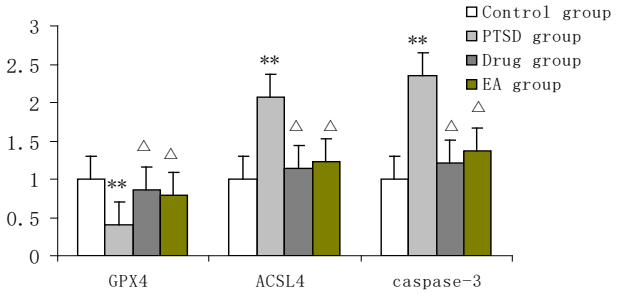


Figure 2. Expression levels of GPX4, ACSL4, and caspase-3 mRNA in the hippocampus of each group of rats.

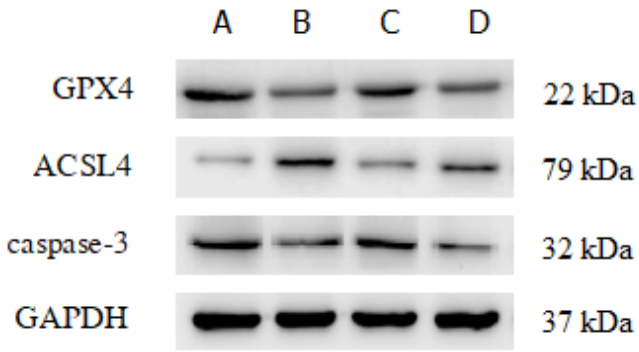
3.5 Protein expression of GPX4, ACSL4, and caspase-3 in each group of rats

Compared with the control group, the expression of GPX4 in the hippocampus of the PTSD group was significantly decreased, and the expressions of ACSL4 and caspase-3 were significantly increased (P<0.01); compared with the PTSD group, the expressions of GPX4 in the hippocampus of the drug group and the EA group were significantly increased, and the expressions of ACSL4 and caspase-3 were significantly decreased (P<0.05), and there was no significant difference between the two groups compared with the drug group (P>0.05), as shown in Table 4 and Figure 3.

Table 4. Comparison of protein expression levels of GPX4, ACSL4 and caspase-3 in the hippocampus of each group of rats (x±s, n=12)

Groups	GPX4 protein	ACSL4 protein	caspase-3 protein
Control group	0.652±0.043	0.182±0.032	0.253±0.029
PTSD group	0.327±0.021**	0.564±0.078**	0.748±0.065**
Drug group	0.583±0.056△	0.231±0.028△△	0.309±0.032△△
EA group	0.524±0.042△	0.316±0.035△	0.387±0.046△△
F value	18.024	56.293	38.075
P value	<0.001	0.000	0.000

Notes: Compared with the blank group, *P<0.05, **P<0.01; compared with the PTSD group, △P<0.05, △△P<0.01.



Note: A - Control group, B - PTSD group, C - Drug group, D - EA group

Figure 3. Protein expression results of GPX4, ACSL4, and caspase-3 in the hippocampus of each group of rats.

4. Discussion

4.1 The improvement effect of electroacupuncture treatment on anxiety behaviors in PTSD rats

This study found through behavioral experiments such as the open field test, the elevated plus maze test, and the conditioned fear response test that rats with PTSD exhibited obvious anxiety behaviors, such as a decrease in the total distance of open field activity, a reduction in the distance and time spent in the open arm area of the elevated plus maze, and an increase in the duration of freezing in the conditioned fear response [9-11]. Electroacupuncture treatment could significantly improve these anxiety behaviors in rats with PTSD, indicating that electroacupuncture treatment has an effective alleviating effect on the anxiety symptoms of rats with PTSD. This is consistent with previous research results and further confirms the effectiveness of acupuncture in the treatment of mental disorders.

4.2 The repair effect of electroacupuncture treatment on hippocampal mitochondrial damage in PTSD rats

Mitochondria are important sites for cellular energy metabolism and play a key role in cell survival and death [12, 13]. During ferroptosis, mitochondria undergo significant changes, such as atrophy, reduction in size, increased membrane density, and reduction or disappearance of cristae. The results of transmission electron microscopy observation

in this study showed that hippocampal mitochondria of rats with PTSD exhibited significant damage, while electroacupuncture treatment could significantly repair hippocampal mitochondrial damage, making the mitochondrial structure more complete [14]. This suggests that electroacupuncture treatment may repair hippocampal mitochondrial damage, improve cellular energy metabolism and function, and thereby exert therapeutic effects on rats with PTSD.

4.3 The mechanism of electroacupuncture treatment in improving anxiety symptoms in rats with PTSD by regulating the GPX4/ACSL4 signaling axis

GPX4 is a key enzyme that inhibits ferroptosis, and its activity decline leads to the accumulation of lipid peroxides and the induction of ferroptosis [15-17]. ACSL4 is a key factor that promotes lipid peroxidation, and its expression upregulation provides more substrates for lipid peroxidation and promotes ferroptosis [18, 19]. Caspase-3 is a key execution proteinase for apoptosis, and the upregulation of ACSL4 and caspase-3 indicates the activation of pro-apoptotic signals induced by PTSD [20]. This study found that compared with the control group, the expression of GPX4 in the hippocampus of rats with PTSD was significantly decreased, while the expressions of ACSL4 and caspase-3 were significantly increased; compared with the PTSD group, the expressions of GPX4 in the hippocampus of the drug group and the EA group were significantly increased, while the expressions of ACSL4 and caspase-3 were significantly decreased, and the differences between the two groups were not significant. The mRNA and protein expressions of GPX4 in the hippocampus of rats with PTSD decreased, while the mRNA and protein expressions of ACSL4 and caspase-3 increased, indicating that there are abnormal molecular mechanisms related to ferroptosis in the hippocampus of rats with PTSD. Electroacupuncture treatment could upregulate the expression of GPX4, down-regulate the expression of ACSL4, regulate the GPX4/ACSL4 signaling axis, and inhibit the occurrence of ferroptosis. This may be one of the important mechanisms by which electroacupuncture treatment repairs hippocampal mitochondrial damage and improves the anxiety symptoms of rats with PTSD.

5. Conclusion

This study shows that electroacupuncture treatment can significantly improve the anxiety behaviors of rats with PTSD, repair hippocampal mitochondrial damage, and its mechanism may be related to regulating the GPX4/ACSL4 signaling axis and inhibiting the occurrence of ferroptosis. This study provides a theoretical basis for electroacupuncture treatment of PTSD, but the specific molecular mechanism of electroacupuncture treatment for PTSD still needs further in-depth research to provide more effective clinical treatment plans.

References

[1] Jiang H, Chen L, Li Y, et al. Effects of acupuncture on regulating the hippocampal inflammatory response in rats exposed to post-traumatic stress disorder. Neurosci Lett. 2023;96(4):1370-5.

[2] Ma D, Cheng J, Zhang H, et al. Electroacupuncture improves post-traumatic stress disorder in rats by alleviating hippocampal mitochondrial injury via regulating Bcl-2/Bax/caspase-3 signaling. Nan Fang Yi Ke Da Xue Xue Bao. 2025;45(11):2375-84.

[3] Chen X, Liu C, Du K, et al. Effects and mechanisms of electroacupuncture on fear extinction and sleep phase in single prolonged stress mice. Zhongguo Zhen Jiu. 2024;44(8):923-30.

[4] Shao RJ, Sun YP, Li XY, et al. Effect of acupuncture on protein kinase R-like endoplasmic reticulum kinase/eukaryotic translation initiation factor 2α signaling pathway in hippocampus of rats with post-traumatic stress disorder. Zhen Ci Yan Jiu. 2023;48(6):564-70.

[5] Wang Y, Zheng X, Yan X. Effects of Shugan Tiaoshen acupuncture on anxiety-like behavior and PKC/ERK/CREB pathway in the bed nucleus of the stria terminalis in rats with post-traumatic stress disorder. Zhongguo Zhen Jiu. 2024;44(11):1281-6.

[6] Li M, Wang X, Yang L, et al. Acupuncture improves learning and memory ability of posttraumatic stress disorder model rats through epigenetic regulation of microglial phosphatidylinositol 3-kinase pathway. Technol Health Care. 2023;31(S1):409-21.

[7] Lo Y, Yi PL, Hsiao YT, et al. A prolonged stress rat model recapitulates some PTSD-like changes in sleep and neuronal connectivity. Commun Biol. 2023;6(1):716-22.

[8] Xie X, Ding Y, Yan Q, et al. Irisin alleviates anxiety and deficits in fear extinction in PTSD within SPS mouse model. Neuropeptides. 2025;13(4):1025-32.

[9] Lu J, Qin C, Wang C, et al. Lateral hypothalamic orexin neurons mediate electroacupuncture-induced anxiolytic effects in a rat model of post-traumatic stress disorder. Brain Res Bull. 2023;20(5):1107-12.

[10] Lee B. Neuroprotective Effect of Acupuncture against Single Prolonged Stress Induced Memory Impairments and Inflammation in Rat Brain via Modulation of Brain-Derived Neurotrophic Factor Expression. Evid Based Complement Alternat Med. 2022;22(5):443-7.

[11] Cheng J, Ma DD, Liu G, et al. Electroacupuncture alleviates anxiety-like behavior in PTSD rats via modulating glycolysis/H4K12la/HIF-1α signaling pathway. Zhen Ci Yan Jiu. 2026;51(1):106-14.

[12] Karimzadeh A, Nabavifard S, Beirami E, et al. Intranasal insulin administration improves anxiety- and depressive-like behaviors in PTSD-exposed rats. J Psychiatr Res. 2025;90(5):84-91.

[13] Zhao H, Li Y, Luo T, et al. Preventing Post-Traumatic Stress Disorder (PTSD) in rats with pulsed 810 nm laser transcranial phototherapy. Transl Psychiatry. 2023;13(1):281-6.

[14] Wang Z, van Bruggen R, Sandini T, et al. Wistar-Kyoto rats and chronically stressed Wistar rats present similar depression- and anxiety-like behaviors but different corticosterone and endocannabinoid system modulation. Prog Neuropsychopharmacol Biol Psychiatry. 2023;27(6):1108-14.

[15] Wang Z, Hu X, Wang Z, et al. Ketamine alleviates PTSD-like effect and improves hippocampal synaptic plasticity via regulation of GSK-3β/GR signaling of rats. J Psychiatr Res. 2024;78(5):259-69.

[16] Liu L, Li R, Wu L, et al. (2R,6R)-hydroxynorketamine alleviates PTSD-like endophenotypes by regulating the PI3K/AKT signaling pathway in rats. Pharmacol Biochem Behav. 2024;45(12):1738-43.

[17] Sep MSC, Sarabdjitsingh RA, Geuze E, et al. Pre-trauma memory contextualization as predictor for PTSD-like behavior in male rats. J Psychiatr Res. 2024;71(5):84-94.

[18] Chiacchierini G, Mancini GF, Di Cesare B, et al. A behavioral screening method for predicting PTSD-like phenotypes: Novel application to female rats. J Neurosci Methods. 2025;16(6):1180-5.

[19] Lisboa SF, Stern CAJ, Gazarini L, et al. Cannabidiol effects on fear processing and implications for PTSD: Evidence from rodent and human studies. Int Rev Neurobiol. 2024;77(6):235-50.

[20] Cheng J, Ma DD, Liu G, et al. Electroacupuncture alleviates anxiety-like behavior in PTSD rats via modulating glycolysis/H4K12la/HIF-1α signaling pathway. Zhen Ci Yan Jiu. 2026;51(1):106-14.