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The Influence of Exercise on Brain Structure and Function in Athletes comprehensive review

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Abstract

Background and goal:
The brain plays a crucial role in athleticism, as it is responsible for coordinating movement, reaction time, decision making, and overall performance. The structure of the brain in athletes is not significantly different from that of non-athletes, but research has shown that certain areas of the brain may be more developed or specialized in athletes due to the demands of their sport. Therefore, the aim of the current research was the effect of exercise on the structure and function of the brain in athletes
Method:
To search for articles, English-language articles from 2018 to 2024 were collected by searching databases including Scopus, PubMed, Springer, Google Scholar, WOS, and Science Direct Keywords such as Brain structure, Brain function, Athletes, and exercise were used to extract.
Findings:
Different types of physical exercise can affect the brain in unique ways, leading to neurological differences between athletes. Athletes also show differences in pain processing and brain structure compared to non-athletes. Overall, physical activity and exercise can have a positive impact on brain function, mental health, and cognitive abilities.
Conclusion:
Exercise has a significant impact on the structure and function of the brain in athletes, demonstrating the connection between physical activity and brain health. This highlights the importance of regular exercise for maintaining cognitive function and overall brain health.

KEYWORDS: Behaviour, Athlete, Brain structure, Brain function.

Introduction

Increasing research indicates that elite athletes need more than exceptional physical prowess; they also depend on advanced cognitive skills to perform at the upper echelons of competition. (1) Certainly, the body of empirical research indicates that top-tier athletes exhibit superior performance in certain cognitive skills, such as executive functions, when compared to their non-elite counterparts (2). Physical activity is commonly recommended as a therapeutic intervention in both wellness and illness contexts. The positive impact of physical activity on disease prevention and management is well-documented and undeniable. Studies indicate that individuals of both genders who engage in higher levels of physical activity and exhibit greater fitness levels experience a significant decrease in the risk of mortality, ranging from 20% to 35%. Recent findings also point to the fact that even slight increases in energy output through exercise (approximately 1000 kcal weekly) or an enhancement in physical fitness by 1 MET (metabolic equivalent) can correlate with a roughly 20% reduction in death rates. In contrast, women in their middle years who participate in less than one hour of physical activity weekly are shown to have a 52% higher risk of dying from any cause, a twofold increase in the risk of death due to cardiovascular issues, and a 29% greater chance of succumbing to cancer compared to their counterparts who are more physically active (3). The advantageous impacts of running exercise are widely recognized to stem from a variety of distinct elements. These include alterations in synaptic plasticity, changes in spine density, fluctuations in neurotrophin levels, and transformations in the microenvironment within neurogenic niches. Collectively, these factors may contribute to the enhancement of learning and memory capabilities, reduction in the likelihood of developing neurodegenerative conditions, and postponement of cognitive deterioration linked with the aging process (4). Numerous regions within the brain, such as the prefrontal cortex along with the superior and inferior cortical areas, are crucial for the functioning of working memory. Research has consistently demonstrated that exercise and physical activity are key factors influencing the performance of working memory (5). also Research by Martinez et al. has demonstrated that aerobic exercise significantly enhances working memory (6). Endogenously produced neurotrophins, which facilitate brain plasticity, are thought to play a key role in the positive impact of physical activity on brain function. Research has shown that regular physical activity can lead to an increase in the volume of brain regions associated with higher-level cognitive processes. Additionally, it has been observed to enhance cognitive abilities in children diagnosed with cerebral palsy and to improve phonemic capabilities in school-aged children experiencing difficulties with reading. Investigations into the optimal intensity of physical activity for maximizing neurotrophin levels indicate that a balanced approach is beneficial. Long-term, low-intensity exercise has been associated with sustained elevations in neurotrophin concentrations. Conversely, in a rat model of brain injury, exercise of a higher intensity has been linked to increased levels of the stress hormone corticosterone (7). Exercise has been shown to enhance cognitive abilities and bolster memory retention. Studies indicate that engaging in regular physical activity can result in the enlargement of the hippocampus, an essential brain area involved in the creation and preservation of memories. Such expansion of the hippocampal region is associated with better memory performance and cognitive improvements in those who maintain a consistent exercise regimen (8). Engaging in regular physical exercise enhances cerebral circulation, thereby fostering the development of novel neuronal cells and reinforcing synaptic linkages (9). also Physical exercise has been repeatedly associated with enhancements in neurocognitive performance throughout an individual's life. Nonetheless, the processes that explain this association are multifaceted. The intermediaries encompass modifications in the architecture and activity of the brain, adjustments in neurotransmitter pathways, regulation of neurotrophic elements, and advancements in cardiovascular well-being (10). also Regular physical activity might confer a safeguarding influence on cerebral function and morphology, possibly mitigating the intensity of concussive injuries and facilitating expedited recuperation (11). The findings from the research indicated that individuals who have experienced sports-related concussions exhibited changes in both the structural and functional aspects of their brains when contrasted with individuals who have not suffered from concussions. Notably, there were observable variances in the integrity of white matter, the thickness of the cortex, and the functional interconnectivity within brain areas responsible for cognitive processing and motor regulation. Such evidence implies that the impact of sports concussions on the brain could be enduring (12). In a study conducted by (Yapeng et al,2021), the effects of prolonged training in sports that demand high levels of strategic thinking on the white matter structure of the brain in expert athletes were investigated using diffusion tensor imaging (DTI). The results revealed that expert athletes exhibited significantly higher fractional anisotropy (FA) values in various brain regions compared to non-athletes, indicating enhanced white matter integrity and connectivity. These findings suggest that engaging in long-term training in strategic sports may induce structural adaptations in the brain that improve cognitive functions associated with decision-making, planning, and problem-solving (13). In a study conducted by (Yapeng et al,2024), titled "Altered spontaneous regional brain activity in ventromedial prefrontal cortex and visual area of expert table tennis athletes," it was found that compared to non-athletes, table tennis athletes exhibited changes in spontaneous brain activity in the ventromedial prefrontal cortex (vmPFC) and visual areas. Specifically, athletes demonstrated increased connectivity within the vmPFC and enhanced functional connectivity between the vmPFC and visual areas. These results suggest that expert table tennis athletes possess a more efficient neural network in regions associated with decision-making and visual processing, potentially contributing to their exceptional performance in the sport (14). Additionally, in the study conducted by(Bai et al,2020). regarding the impact of badminton training on structural plasticity during early adulthood, it was determined that individuals engaging in this form of training exhibit changes in their brain's structural plasticity (15). Also the results of the research In the case of basketball players, it was that motor imagery in basketball players leads to expertise-level-dependent functionally plastic changes in the brain (16). According to the above , and the importance of research in this study, we're looking at the impact of exercise on brain structure and function in athletes.

Materials And Methods

The present study was a systematic review. The aim of this study was the effect of exercise on the structure and function of the brain in athletes. To search for articles, English-language articles from 2018 to 2024 were collected by searching databases including Scopus, PubMed, Springer, Google Scholar, WOS, and Science Direct Keywords such as Brain structure, Brain function, Athletes, and exercise were used to extract. The input and output criteria of the research were: articles in the field of the The Influence of Exercise on Brain Structure and Function in Athletes, recent and high-quality studies, articles whose subjects had other diseases, or articles in which people Or Those who underwent surgery for The Brain were excluded from the study. finally 73 article titles were obtained based on keywords. After review based on inclusion and exclusion criteria, 14 high-quality articles on the The Influence of Exercise on Brain Structure and Function in Athletes were selected and reviewed by researchers. In addition, Figure 1 shows the process of selecting articles in the present research.

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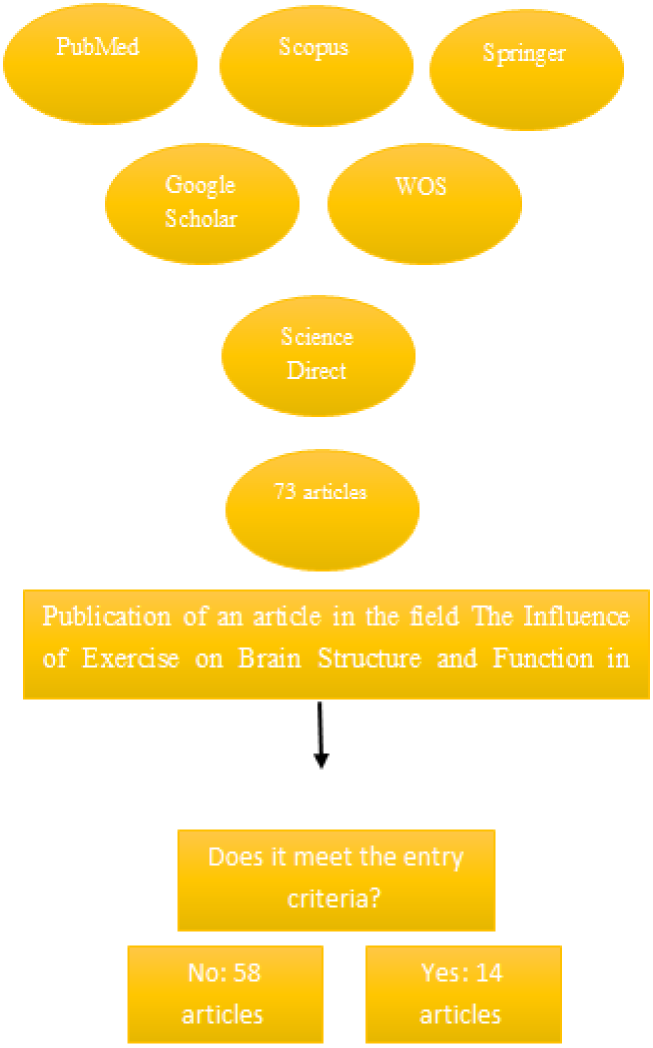

Figure 1. The process of searching, reviewing and selecting articles.

Results

Out of the 73 articles obtained through keyword search, 14 article titles were evaluated based on entry and exit criteria. The findings of the study indicate that. 1_Brain activation indicated that long-term training in badminton caused a better performance in high-load working memory tasks **(17)**. 2_The increase in the volume of gray matter, shows that taekwondo exercise contributes to physical, spiritual and mental development **(18)**. 3_ This findings that physical exercise enhances brain connectivity in central autonomic and sensorimotor networks and highlight the close link between brain and heart **(19)**. 4_ brain responds differently to various exercise intensities, which could help understand the neural distinctions between athletes from different sports (20). 5_ Athletes in static sports demonstrated the fastest visuo-perceptual processing among all groups (21). 6_ athletes do not only differ in behavioral variables compared to nonathletes, but also in the neural processing of pain elicited by noxious heat **(22)**. 7_ revealed a significant difference between elite ice-skating athletes and non-athletes both in structural and functional plasticity **(23)**. 8_ the white matter microstructure properties of both the dorsal and ventral pathways in expert table tennis athletes significantly differed from those in non-athletes (24). 9_ physical activity and sports should be encouraged to aid in enhancing resilience and resting-state brain cortical function, and consequently, improving mental health (25). 10_ Whole-brain analyses revealed that those who participate in ultra-endurance training have increased grey (< 0.0001) **(26)**. 11_ brain function coupling in high-level shooting athletes is more connected than that in non-athletes **(27)**. 12_It is revealed that brain-heart systemic interaction is organized in the form of a few clusters and has individual and typological features in athletes (28). 13_ there are significant differences analyzing the cortical excitability in athletes, compared to non-athletes (29). 14_ It has been revealed that increased GM volume values of inferior/superior temporal, occipital, premotor cortex, and temporal pole superior were present for the elite athletes (30).

Table 1. Investigating the effect The Influence of Exercise on Brain Structure and Function in Athletes

name	**year of publication and journal**	**Structure of the study**	**The variable under consideration**	**Conclusion**
(Song et al.) **(17)**	2024 Brain and Cognition	In this study, we assessed behavioral performance and cerebral oxygenation in the prefrontal lobe, using functional near-infrared spectroscopy, with 22 athletes and 30 non-athletes. Each participant was evaluated while performing 1-back, 2-back, and 3-back tasks. The area under the curve (AUC) of HbO (oxyhemoglobin) is used as an indicator of cortical brain oxygenation.	Brain activation Working memory tasks	The behavioral performance results indicated no difference between badminton athletes and non-athletes in the n-back task. We observed significantly different activation in channels of left FPA, right DLPFC, and left VLPFC when performing 3-back tasks. Brain activation indicated that long-term training in badminton caused a better performance in high-load working memory tasks.
(.Kurtoğlu et al.) **(18)**	2023 Journal of Chemical Neuroanatomy	30 taekwondo athletes and 15 control groups were included in this study. Diffusion tensor MR images of each participant were taken. Total brain volume and volumes of white matter, gray matter, frontal lobe, precentral gyrus, corticospinal tract, basal nuclei, postcentral gyrus, hippocampus and amigdala and the ratio of these volumes to total brain volume were evaluated statistically between the groups using MriCloud software and ROIEditor program.	Brain morphological **structure**	The increase in the volume of gray matter, frontal lobe, postcentral gyrus and corticospinal tract together with the brain volume shows that taekwondo exercise contributes to physical, spiritual and mental development.
(de la Cruz et al.) **(19)**	2022 Scientific Reports	Here we investigate the effects of intensive exercise on brain regions involved in cardiac autonomic regulation using resting-state functional connectivity (rsFC). We explored rsFC of six core regions within CAN, namely ventromedial prefrontal cortex, dorsolateral anterior cingulate cortex, left/right amygdala, and left/right anterior insula, in 20 endurance athletes and 21 non-athletes.	Central autonomic network	We showed that athletes had enhanced rsFC within CAN and sensorimotor areas compared to non-athletes. This findings prove that physical exercise enhances brain connectivity in central autonomic and sensorimotor networks and highlight the close link between brain and heart.
(Zhang et	2022	. The current study recruited 50	Exercise	A study found that

al.) (20)	Frontiers in Human Neuroscience	elite track-and-field athletes. None of these athletes had a history of neurological disorders or movement disorders. All subjects completed the scanning. But two of them were eliminated because of too much head motion, leaving a sample of 48 athletes. A group of 23 runners who had participated in aerobic exercise for many years were allocated to the aerobic group. Meanwhile, 25 sprinters who participated in anaerobic exercise for many years were allocated to the anaerobic group .	Intensity and Brain Plasticity	aerobic exercise increased gray matter volume in the cerebellum and temporal lobe, while anaerobic exercise did so in the basal ganglia. The aerobic group also had higher brain activity in the motor and parietal areas, as well as the frontal gyrus. Conversely, the anaerobic group showed increased activity in the cerebellum posterior lobe. These results suggest that the brain responds differently to various exercise intensities, which could help understand the neural distinctions between athletes from different sports.
(Yongtawee et al.) **(21)**	2022 International Journal of Sport and Exercise Psychology	We classified sports as interceptive, static, or strategic. A total of 120 individuals participated in this study, including 30 boxers (interceptive), 30 competitive shooters (static), 30 soccer players (strategic), and 30 non-athletes. To measure the executive function (inhibition and cognitive flexibility), spatial ability, and information processing speed of the participants, we administered the trail making test (TMT), mental rotation test (MRT), design fluency test (DFT), flanker task (FKT), and tests of simple reaction time (SRT) and choice reaction time (CRT) using an original computer program.	cognitive functions	We found differences in dominant cognitive functions across sport types. Athletes in interceptive sports demonstrated advanced visuospatial functioning and processing speed, while athletes in strategic sports showed superior executive function, including working memory and cognitive flexibility. Athletes in static sports demonstrated the fastest visuo-perceptual processing among all groups.
(Geisler et al.) **(22)**	2021 Human Brain Mapping	Analyzed the pain processing of 18 male athletes and 19 healthy male nonathletes using functional magnetic resonance imaging.	**Neural mechanisms of pain processing**	The results demonstrate for the first time that endurance athletes do not only differ in behavioral variables compared to nonathletes, but also in the neural processing of pain elicited by noxious heat
(Zhang et al	2021	The current study investigated	Structural and	In conclusion, the

al.) **(23)**	Human Movement Science	21 elite ice-skating athletes and 15 non-athlete controls. None of them had a history of neurological or movement disorders. a sample of 19 elite ice-skating athletes and 15 controls .All athletes and controls were right-handed. All of the participating elite ice-skating athletes were members of the Chinese national ice-skating team, had trained for 10.84 ± 3.86 years, and had achieved the level of "master athlete" in China.	functional neuropalasticity	present research revealed a significant difference between elite ice-skating athletes and non-athletes both in structural and functional plasticity. Specifically, elite ice-skating athletes showed larger gray matter volume in the posterior cerebellum, frontal lobe, temporal lobe, posterior cingulate, caudate, and thalamus. The functional plasticity changes were primarily concentrated in the posterior cerebellar lobe.
(Yamashita et al.) (24)	*2021 Psychologica Sinica*	An investigational group of 31 expert table tennis athletes (20.06 ± 1.69 years of age) and a control group of 28 college students (20.68 ± 1.66 years of age) who had no professional training in table tennis were recruited for the study. The table tennis athletes were members of university teams, and each athlete had more than 7 years of table tennis training. Diffusion tensor imaging techniques were used to compare white matter microstructure properties of the brain between expert athletes and non-athletes. Statistical analyses were performed using independent t-tests	**long-term trainingbrain white matter structure**	the white matter microstructure properties of both the dorsal and ventral pathways in expert table tennis athletes significantly differed from those in non-athletes. Specifically, FA values in the bilateral corticospinal fibers, which mainly connect brain regions in the dorsal sensorimotor system, were higher in experts than in non-athletes. By contrast, no white matter region showed a higher FA value in non-athletes than in expert athletes, and no region was found with axial diffusivity difference between the groups.
(Cevada et al.) (25)	2020 The Open Sports Sciences Journal	Ninety participants were divided into three groups, athlete (n=30), physically active (n=30) and sedentary (n=30), and asked to fill out the international physical activity questionnaire – short version (IPAQ), the resilience scale, the Beck depression inventory (BDI) and the trait and state anxiety inventory (STAI). Moreover, resting-state brain	Resilience Psychological Characteristics Brain Cortical Activity	The results suggest that the physically active and athlete groups may have built a more resilient profile (compared to sedentary), have similar anxiety and depressive symptoms, and present a divergent resting-state brain

		cortical activity was recorded by using an EEG to compute the standardized low-resolution brain electromagnetic tomography (sLORETA) analyses.		cortical activity from the sedentary group, mainly in prefrontal areas. These findings suggest that regular physical activity and sports should be encouraged to aid in enhancing resilience and resting-state brain cortical function, and consequently, improving mental health.
(Paruk et al.) **(26)**	2020 Sports Medicine and Health Science	We performed whole brain volumetric analyses and voxel-based morphometry on 12 ultra-endurance athletes (1078.75 ± 407.86 min of MVPA/week) and 9 sedentary persons (18.0 ± 56.9 min of MVPA/week	Structural brain	Whole-brain analyses revealed that those who participate in ultra-endurance training have increased grey (< 0.0001), while regional analyses revealed that ultra-endurance athletes have smaller regional grey matter volume in the right primary sensory and motor cortex, inferior and middle frontal gyrus, and left thalamus.
(Gong et al.) **(27)**	2019 Biomedical Signal Processing and Control	To test this hypothesis, electroencephalograms (EEGs) from 20 high-level shooting athletes and 20 age- and gender-matched non-athletes are collected in an eyes-closed resting state. The frequency spectrum was divided into four bands according to the individual alpha frequency of each participant: delta, theta, alpha1, and alpha2. The phase-locking values of the EEG in each frequency band are calculated and graph theory is used to analyze the topology of the EEG brain functional network based on the phase-locking-value connection.	Brain networks	The results show that, compared with non-athletes, high-level shooters have higher connectivity in the left-temporal region, left-posterior temporal region, left-frontal region, left-central region, and right-parietal region. The network-clustering coefficients and small-world characteristics of athletes in the theta and alpha1 bands are significantly greater than that of non-athletes. These results support the hypothesis that brain function coupling in high-level shooting athletes is more connected than that in non-athletes.

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Liliia et al. (28)	2019 Journal of Sports Science and Medicine	In 83 athletes while mental working were simultaneously registered: 1) electroencephalogram (EEG), central hemodynamics and heart rate variability (HRV); 2) cerebral hemodynamics and HRV; 3) EEG, HRV and electrical resistance of the skin. Individual and typological features of CNS were determined by functional mobility, strength, and equilibrium of the nervous processes.	**brain and heart rate**	It is revealed that brain-heart systemic interaction is organized in the form of a few clusters and has individual and typological features in athletes. The analysis of indicators of neurophysiological and vegetative functions of the surveyed persons indicates that during the processing of information, the interaction of the brain and the cardiovascular system of human was determined by the level of individual and typological properties of the higher parts of the CNS. This is manifested in athletes also during physical load. Conclusions: Brain-heart systemic interaction is caused by individual-typological properties of central nervous system. It is important for sport orientation, clinical prognosis of cardiovascular and neurological deviations, and optimization of rehabilitation measures.
(Sessa et al) (29)	2018 Sport sciences for health	Three neurophysiologic parameters (rMT, MEP latency and MEP amplitude) were investigated using transcranial magnetic stimulation (TMS). TMS was applied to the primary motor cortex (M1) of 30 right-handed young karate athletes recruited. To evaluate ANS, HR (at rest and during exercise) and GSR (at rest and post-exercise) were measured. All data were matched with the records obtained by 30 non-athletes. All statistical analyses were performed using R.	**Sport training and adaptive change**	This data suggest that there are significant differences analyzing the cortical excitability in athletes, compared to non-athletes. Furthermore, this data confirmed that the exercise training influences the parasympathetic tone, reducing HR. Moreover, a significant reduction in GSR parameters was reported

(Duru et al.) (30)	2018 Journal of Healthcare Engineering	13 elite karate athletes and age-gender matched 13 volunteers who have not performed regular exercises participated in the study. Magnetic resonance imaging was used to acquire the anatomical and functional maps.T1-weightedanatomical images were segmented to form gray and white matter images.Voxelbasedmorphometry is used to elucidate the differences between the groups. Moreover, resting state functional measurements had been done, and group independent component analysis was implemented in order to exhibit the resting state networks.	**Functional and Structural Plasticity of Brain**	It has been revealed that increased GM volume values of inferior/superior temporal, occipital, premotor cortex, and temporal pole superior were present for the elite athletes. Additionally, WM values were found to be increased in caudate nucleus, hypothalamus, and mammillary region for the elite karate players. Similarly, for the elite karate players, the brain regions involved in the movement planning and visual perception are found to have higher connectivity values.

Modified Downs and Black checklist for randomized and non-randomized studies.

rs	*et al.)* ***(17)***	*rtoğlu et al.)* ***(18)***	*la Cruz et al.)* ***(19)***	*ng et al.) (20)*	*gtawee et al.)* ***(21)***	*sler et al.)* ***(22)***	*ng et al.)* ***(23)***	*mashita et al.) (24)*	*ada et al.) (25)*	*uk et al.)* ***(26)***	*g et al.)* ***(27)***	*a et al. (28)*	*a et al) (29)*	*u et al.) (30)*
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	0	1	0	1	1	1	1	1	1	1	1	1	1	1
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5	1	1	1	1	1	1	1	1	1	0	1	0	1	0
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7	0	1	1	1	1	1	1	0	1	1	1	1	1	1
8	1	0	1	1	0	0	1	1	0	1	1	0	0	0
9	1	1	1	0	0	1	1	1	0	1	0	1	1	1
10	1	1	1	1	1	1	1	1	1	1	1	1	0	1
11	1	1	**UTD**	1	1	1	1	1	1	**UTD**	**1**	1	1	**0**
12	**1**	1	0	0	0	1	1	1	1	1	0	1	0	1
13	1	1	1	1	1	1	0	**UTD**	0	1	1	1	1	1
14	0	1	0	1	0	0	0	0	1	0	0	1	0	0
15	1	0	1	1	1	0	**UTD**	1	1	1	1	0	1	0
16	UTD	0	1	0	**UTD**	1	1	0	0	1	0	1	1	1
17	1	0	0	0	**0**	1	0	1	1	**UTD**	1	**UTD**	0	1
18	1	UTD	1	**0**	1	1	1	1	1	0	0	1	**UTD**	0
19	1	1	1	1	0	1	1	0	0	1	1	0	1	1
20	1	1	1	1	1	1	1	1	1	1	1	1	0	0
21	1	1	1	1	1	1	0	1	1	0	0	1	1	1
22	1	1	**UTD**	0	1	UTD	1	1	1	1	**0**	**1**	1	**UTD**
23	1	1	1	1	1	1	1	1	1	1	1	1	1	1
24	1	1	1	1	0	1	1	1	1	1	1	0	0	1
25	0	0	1	0	0	0	0	1	1	0	0	0	0	0
26	0	1	1	0	1	1	1	1	0	1	**UTD**	1	1	1
27	1	1	1	1	1	1	1	1	1	1	1	1	0	**1**
Total	21	22	21	20	18	22	20	22	21	20	18	20	17	19

Risk of Bias Assessment (No: score-0; Yes: score-1, UTD-Unable to determine)

Discussion

The aim of the present study was to The Influence of Exercise on Brain Structure and Function in Athletes. The results of the study demonstrate compelling evidence that consistent physical activity plays a crucial role in promoting neuroplasticity, which is the brain's ability to adapt and reorganize itself. The findings indicate that athletes who engage in regular exercise exhibit enhanced brain structure and function, including increased grey matter volume, improved cognitive function, and better overall mental health. Concordant studies on the positive effect of exercise on brain structure and function in athletes consistently show improvements in brain health and function. These studies demonstrate that regular exercise, particularly aerobic exercise, can lead to increased brain volume, improved cognitive function, and reduced risk of neurodegenerative diseases. Additionally, these studies often show improved performance on various cognitive tasks and enhanced memory and learning abilities in athletes who exercise regularly (31, 32). However, it's important to note that there are conflicting studies that suggest the relationship between exercise and brain structure and function in athletes may not be as clear-cut. Some research has found no significant differences in brain structure and function between athletes who exercise regularly and non-athletic individuals. Additionally, there are mixed findings on the impact of exercise on specific brain regions and cognitive functions, with some studies showing no

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significant improvements in certain areas. This highlights the need for further research to fully understand the complex relationship between exercise and the brain (33, 34). In addition, the research suggests that physical activity can have a beneficial effect on different elements of brain function, such as the generation of new neurons, the ability of synapses to adapt and change, and the promotion of factors that support the growth and survival of neurons. These biological changes in the brain can enhance cognitive function, regulate emotions, and improve overall mental health in individuals who engage in regular exercise (35, 36). Physical activity‹It also has a powerful effect on the brain. For athletes, this means that their training not only makes them physically stronger and more capable, but also strengthens them mentally and emotionally. It's an important reminder that exercise isn't just about looking good, it's about feeling and thinking better. So, going to the gym and running isn't just about working out your body, it's also giving your brain a valuable workout (24, 37). In addition, these discoveries carry significant implications for the wider community, underscoring the significance of regular exercise in preserving and enhancing brain health. The outcomes of the study provide compelling evidence that physical activity should be given precedence as a vital component of a comprehensive strategy to foster brain health and ward off cognitive deterioration.

Nevertheless, it is crucial to acknowledge that this study is limited in its scope as it only focuses on researching the long-term impact of exercise on brain structure and function. Additionally, it does not delve into the specific mechanisms through which exercise delivers its beneficial effects to the brain. Further research is necessary to fully understand these aspects.

Conclusion

The findings indicate that exercise has a notable impact on the structure and function of the brain in athletes, shedding light on the link between physical activity and brain health. This is significant for athletes and the general population, highlighting the importance of regular exercise in maintaining cognitive function and overall brain health. More research is needed to fully comprehend how exercise influences the brain and to devise strategies for promoting brain health through physical activity.

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