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IMPACT OF PHYSICAL ACTIVITY ON THE ANATOMY AND PHYSIOLOGY OF THE BRAIN IN CONTEXT OF ITS POTENTIAL USE IN THERAPY AND DISEASE PREVENTION

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ABSTRACT

Introduction an purpose of the research. Physical activity and exercise stimulate our brain on several levels, including improving neuroplasticity, while promoting the formation of new synaptic connections and reshaping its anatomical structures, particularly the hippocampus. The aim of the review was to determine the current state of knowledge about the impact of physical activity and exercise on brain function and their potential therapeutic use in dementia, Alzheimer's disease and depression.
Material and methods. The search process included searching PubMed and Google Scholar by keyword. The selection of articles was based on the title and abstract.
Results. Muscles, under the influence of movement, begin to produce myokines and other substances that affect the nervous system. Only some of them are able to cross the blood-brain barrier. They affect the formation of new synaptic connections and changing of the brain structure, in particular the hippocampus. A special place in muscle-brain communication is occupied by BDNF, which stimulates the process of neuroplasticity, tissue regeneration and cognitive functions, and its production is increased by the work of skeletal muscles. These changes impact the development of cognitive functions and counteract the pathomechanisms of some diseases, such as dementia or Alzheimer's disease. The positive effect of physical exercise in the treatment of depression has also been proven.
Conclusions. Processes occurring in the human body during physical exercise affect the structure and function of the brain. Some studies show promising results with incorporating exercise into the treatment of dementia, Alzheimer's disease and depression.

KEYWORDS

Physical Activity, Neuroplasticity, Reshaping Brain, Dementia, Depression, Alzheimer Disease

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Introduction.

The human body has the ability to change over the course of life. This is a well-known process of adaptation, present not only in humans but also in animals and other forms of life. The human brain and nervous system have their own unique ability to adapt. Neuroplasticity is a complex process that involves three different types of changes in the brain: adaptive, structural and functional, under the influence of some triggers. After an injury, the human brain begins to reorganize itself, changing its structure, connections and functions, adapting to the new situation. In the literature, we have divided the time after injury into three phases, depending on the time after injury. In the first 48 hours after brain tissue damage, we have the advantage of cell death and neuronal loss, while other mechanisms and networks are involved in maintaining brain function. The second phase is when synaptic plasticity occurs. Neurons begin to organize and new neuronal connections are recreated. The final phase lasts from several weeks to several months. Brain tissue is constantly remodeling and changing its organization, trying to adapt to the new situation(Puderbaugh & Emmady, 2025). The mechanisms of neuroplasticity are not yet fully understood. One of them may be the mechanism of stimulation of the synaptic space, which increases the number of postsynaptic receptors when more neurotransmitters from the presynaptic neuron stimulate them. This leads to a lower threshold of the release potential(Vints i in., 2022). There are several factors that improve synaptic changes. Physical activity (PA) increases the potential in the synaptic space, accelerating changes(Boa Sorte Silva i in., 2024; Devanne & Allart, 2019). Exercise affects brain functions in both adults(Boa Sorte Silva i in., 2024) and children(Donnelly i in., 2016; Erickson i in., 2019). Many studies show a correlation between PA and improved brain function. Measurements were not only carried out using questionnaires and clinical observation, but also included examining patients using Magnetic Resonance Imaging (MRI). Some brain structures are more sensitive to physical activity than others,

and we can observe changes in MRI(Boa Sorte Silva i in., 2024; Erickson i in., 2019). Not every type of PA could influence the brain with the same effect and its responsiveness and sensitivity remain under some conditions. While aerobic exercises help us stop the negative brain changes associated with aging(Iso-Markku i in., 2022), other types of PA show less or no neuroprotective effect(Sanders i in., 2020). Changes in our body and in the brain depend on intensity and form of training as well as time of regular exercise/physical activity. During the aging process or disease, the brain may undergo changes that negatively affect its structure. Many diseases whose pathomechanisms change the anatomy of the brain, resulting in worsening cognitive functions, memory, concentration and affecting mood. Conditions such as depression, dementia or Alzheimer's disease (which is the most common type of dementia) affect millions of people around the world(De La Rosa i in., 2020a) as isolated diseases, accompanying other diseases or co-occurring with each other.

Aim of the study

The purpose of this comprehensive review was to describe how physical activity and exercise can influence the anatomy, physiology, and function of the human brain, with particular emphasis on the role of neuroplasticity. In this study, we would like to present the current state of knowledge on the possibilities of using PA in the therapeutic process and prevention of dementia, Alzheimer's disease and depression.

Materials and method

In this review, we used articles retrieved from PubMed and Google Scholar based on title and abstract. We included research articles, reviews with meta-analyses, reviews, and umbrella reviews. Some of the studies included both human and animal models. Our search was targeted by the key words “brain function physical activity”, “exercise brain function”, “physical activity neuroplasticity”, “exercise cerebrum structure”, “physical activity depression”, “exercise depression”, “physical activity cognitive function”, “Alzheimer disease physical activity”, “exercise Alzheimer disease”, “physical activity depression”, “exercise depression”, “brain muscle crosstalk”. Selected studies were analyzed and included if they directly focused on the effects of physical activity/exercise on brain function and neuroplasticity in healthy individuals, in depression, or in Alzheimer’s disease or dementia.

Influence of the physical activity on the brain structure

Physical activity has pleiotropic influence on human anatomy and physiology (fig.1). It changes the molecular and anatomical structure of the brain. In recent studies we can find that frontal and temporal regions with hippocampus included, noted most positive effects of PA. Exercises reduce grey and white matter atrophy, decreases lesions in white matter simultaneously increasing volume of the whole brain structure(F.-T. Chen i in., 2020; Herold i in., 2019). Erickson et al. found in his research physical activity in older adults causes changes in the structure of the hippocampus. Aerobic exercises led to increasing volume of the both (anterior and posterior) hippocampal regions(Erickson i in., 2011a). The effects of physical activity are also visible as increased circulation in the brain structures and greater transport of the metabolic substances to the brain. In animals, adaptations in cell density and molecular structures have been observed. In human research, scientists use neuroimaging techniques to observe most modifications in human brain structure, so our knowledge is not complete due to the limitations of the research method(Thomas i in., 2012; Voss i in., 2019). This knowledge may prove important in protecting against aging. MRI shows many structural changes in neurodegenerative disorders such as dementia or Alzheimer's disease. The mechanism of depression also has its anatomical basis. Moreover, in people without dementia, the volume of the hippocampus decreases by 1-2% each year, increasing the risk of developing cognitive impairment(Erickson i in., 2011b).

Muscle-brain crosstalk

How can muscles and the brain communicate? When we exercise, our body secretes many molecules from tissues and internal organs. Skeletal muscles should also be considered as a secretory organ because of the myokines and other exercise mediators they produce which have effects on other tissues in the human body. Since studies have demonstrated the effects of myokines on muscle regeneration, signaling between abdominal organs, the vascular bed, and potentially anti-cancer effects, it is important to consider whether they have any effect on the nervous system. Both the brain and skeletal muscles are considered as insulin-sensitive organs, while cerebral function uses approximately 25% of the glucose delivered by blood to the entire body. Studies have shown that type 2 diabetes and sarcopenia in animal models have a negative effect on cognitive function. Chang et al. found a positive correlation between sarcopenia and cognitive impairment in their meta-analysis,

which is important because we know that sarcopenia is very common in elderly patients. Muscles secrete molecules, mainly cytokines, during exercise. Some studies show that lowering insulin-like growth factor 1 (IGF-1) levels in sarcopenia also leads to a deterioration in brain function. However, there is no evidence that exogenous IGF-1 factors improve cognitive function, but we know that it is not indifferent to our brain(Han i in., 2023; Severinsen & Pedersen, 2020). Brain-Derived Neurotrophic Factor (BDNF) plays a huge role in neuroplasticity, cognition, development and regeneration of brain tissue. It is also a growth factor for the hippocampus(Severinsen & Pedersen, 2020). The main source of BDNF is the nervous system, where it is widely expressed, but recent studies show that it is also produced by skeletal muscles. PA is considered as a factor stimulating the body to produce BDNF. One theory is that the release of beta-endorphins during training stimulates cells to produce BDNF. In addition, the effect of PA on brain tissue causes increased blood flow, which results in better oxygenation and increased nutrients supply to the brain(Oyovwi i in., 2025). Higher plasma BDNF levels are associated with improved memory and larger hippocampal volume(Erickson i in., 2011b). Irisin levels also increase with exercise. An important feature of this substance is the ability of irisin to cross the blood-brain barrier (unlike BDNF, which does not have this ability). Irisin is a protein secreted from skeletal muscles with proven beneficial effects both on them and on the brain. It accelerates lipid and glucose metabolism in muscles, protecting them from atrophy. In mice, irisin levels decrease with age and its removal by genetic engineering led to impaired cognitive functions. Administration of exogenous irisin in an animal model prevented sarcopenia and improved cognitive functions. Some interleukins have dual roles and affect brain function when released from skeletal muscles. IL-15 and IL-6 occupy a unique place in the interaction between muscle and brain. IL-6 can have both anti-inflammatory and pro-inflammatory effects. Increased levels of this interleukin have been found in patients with Alzheimer's disease and have been linked to age-related brain neurodegeneration. The anti-inflammatory IL-6 is released from skeletal muscles, so when sarcopenia occurs in elderly patients, this positive effect begins to be overshadowed by the inflammatory IL-6. IL-15 is a myokine released from muscles, among others, which plays pleiotropic role in metabolism and protects muscles from degradation. Like IL-6, it can have pro-inflammatory and anti-inflammatory functions. Released from muscles, it has anti-inflammatory effects and hypothetically also can balance its pro-inflammatory effects(Han i in., 2023).

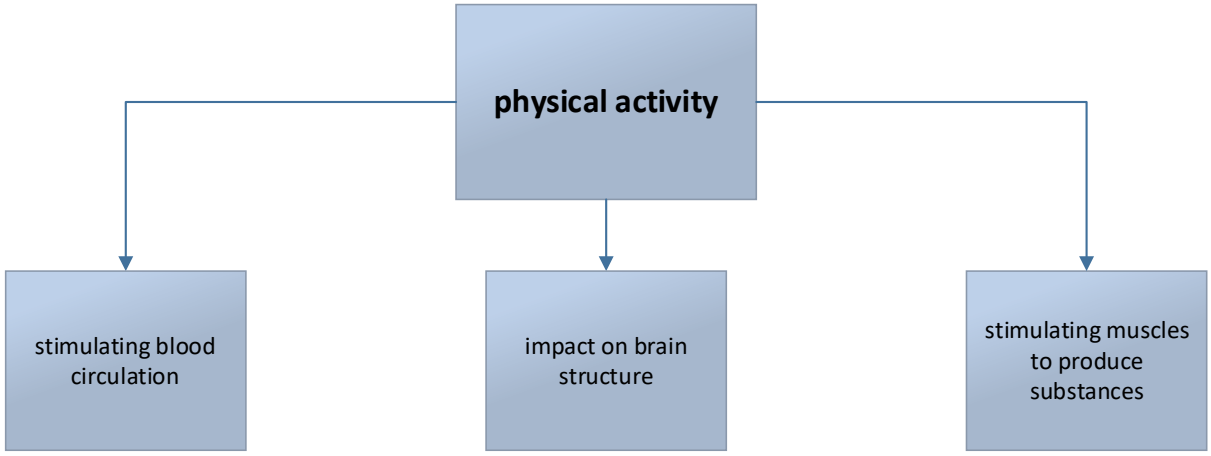

Fig. 1. *Anatomical and physiological changes in the human body during physical exercise*

Role of physical activity in dementia

In our population number of elderly people still rises and there are prognosis of continuing of that trend in the future. Public healthcare concentrates in this area on many aspects. Many researchers seek the role of exercise in prevention of diseases involving elderly patients in both prophylaxis and therapeutic aspects. Considering all we know for now about reshaping the brain in molecular, physiological and structural aspects, researchers are focusing on finding the right amount and intensity of physical activity to provoke changes reversing diseases like dementia or Alzheimer disease. Exercising for a patient with dementia should be considered as a part of person-centered approaches with dual goals. It may be essential in dementia therapy because every day routine and socializing helps the patients feel like part of society(Russell, 2023). Tsuk et al. concluded in his research focused on a group of healthy young people, that moderate intensity training sessions

have positive influence on cognitive function in this group(Tsuk i in., 2019). Iso-Markku et al. concluded in meta-analysis (more than 250 000 participants) that a group of participants with more PA showed less incidences of all types of dementia, Alzheimer disease and vascular dementia altogether. Long term PA (more than 20 years) was a protective factor, so it is not simply reversing cause of dementia but should be seen as a preventive factor(Iso-Markku i in., 2022). What happens when we stop exercising? Physical inactivity in fact, is a risk factor of neurodegenerative disorders and cognitive decline(Pastor i in., 2022). Erickson et al. observed improvements in executive functions in addition to improvements in episodic memory, visuospatial function, verbal fluency, and processing speed, but not all types of PA had the same results. Aerobic exercise has its special place in boosting executive functions and indicates more effect on rest of the areas than resistance and muti-modal training(Erickson i in., 2019).

Positive effect in therapy against Alzheimer disease

One of the most common types of dementia is Alzheimer's disease. We know several factors that increase or decrease the risk of developing AD during life, and among them physical activity may have a special place. This devastating disease affects also mental health. Physical barriers and social exclusion are associated with huge socio-economic costs for whole society. In the pathophysiology of the disease we can find a neurodegenerative process, with the hippocampus and neocortex being particularly effected. In AD, synapses and pyramidal neurons disappear simultaneously with the progressive impairment of cognitive functions. Is that confirmed that physical exercise is a non-pharmacological approach to improving and delaying the symptoms of dementia? In the literature, we can find data informing about a 45% lower risk of developing AD in people who exercise regularly, which was proven by an analysis of 160,000 people(De La Rosa i in., 2020b). Human studies are still lacking, but several reports conducted in transgenic mice show that exercise causes a reduction in the size and overall number of Aβ plaques(Adlard i in., 2005; Ohia-Nwoko i in., 2014). The effect of exercise can be seen as early as one month after starting regular exercise(Adlard i in., 2005). According to Zhang et al. exercise below 30 minutes per session, 150 minutes in total in maximum a week and frequency about three times weekly maintains most effective and reflects in significantly better Mini-Mental State Examination results (MMSE)(S. Zhang i in., 2022). Lopez-Ortiz in a meta-analysis presents strong evidence indicating physical activity as a factor reducing the risk of AD in the future by 30-40%. Moreover, the meta-analysis showed that physical exercise improves global cognitive functions, but it failed to indicate the exact characteristics of physical exercise that have the greatest impact on the above-mentioned changes(López-Ortiz i in., 2023). There are assumptions that lactates released during physical exercise modulate AD-related neuroinflammation and hippocampal neurogenesis along with angiogenesis. Another important aspect is the reduction of oxidative stress, which can be said to be a hallmark of AD. Chronic inflammation accompanying Alzheimer's disease is considered a secondary response to the accumulation of pathological beta amyloid and is identified as one of the causes of neurodegenerative changes(Valenzuela i in., 2020). Enette et al. showed that physical exercise significantly improves the quality of life of AD patients in aspects such as, among others: sense of physical health, humor (the largest statistical correlation), money, family, memory, energy(Enette i in., 2020). There is a certain group that derives greater benefit from exercise than other people in the population. These are people with ε4 alleles (APOE allele) in their genotype. In these individuals, physical activity can delay the onset of AD by up to two decades(Kou i in., 2019).

Influence of the physical activity on individuals during depression treatment

According to WHO, depression affects 5% of adults worldwide(*Depressive Disorder (Depression)*, b.d.). This complex disease is a major burden for society in many areas. Depressive disorders are associated with a higher risk of comorbidities and premature death. The heterogeneity of symptoms is very characteristic and requires complex and specialist help through the provision of physical and mental treatment of the disease. A patient with depressive disorders may be burdened with anxiety, sleep disorders, mood changes, anhedonia, but also reduced psychomotor activity(Tartt i in., 2022). In a meta-analysis, Schuch et al. indicate that physical activity increases the likelihood of avoiding depression in the future, a conclusion supported by 49 studies. We can also find data confirming that PA is a protective factor patients in all ages, regardless of ethnicity(Schuch i in., 2018) in both aerobic and endurance exercises, e.g. playing football, dancing, cycling(Zhao i in., 2020) with a risk reduction of up to 30%(C. Chen i in., 2022). MRI imaging in patients with depression shows a picture of structural changes in the brain. The hippocampus was found to be smaller in patients suffering from depression than in healthy controls. Changes also affected other parts of the brain, mainly reported as reduced volume of the frontal lobes, but also involving the thalamus, striatum, and parietal lobe(F. Zhang i in., 2018) Neuroplasticity is considered a fundamental

mechanism of adaptive brain shifts in the protection against stress(Trifu i in., 2020). It was explained why the hippocampus plays such an important role in pathogenesis and the mechanism of action was identified. Its role in the hypothalamic–pituitary–adrenal (HPA) axis and direct connection with areas involved in mood regulation—the amygdala and anterior cingulate cortex—makes the hippocampus play a key role in well-being(Tartt i in., 2022). Harvey et al. in a cohort study found that regular exercise, even at low intensity, is a protective mechanism against future depression(Harvey i in., 2018). Patients taking pharmacotherapy concomitantly with exercise show significantly better cognitive function than those relying on antidepressants alone(C. Chen i in., 2022). Philippot et al. conducted a very important randomized controlled trial involving 52 hospital patients undergoing treatment for depression and anxiety. They organized and planned an exercise program for patients who were also receiving pharmacological treatment. Each patient was involved in a 20-hour structured exercise program and followed a specific plan. The next step was to evaluate the results using a specially designed scale, the Hospital Anxiety Depression Scale. The results showed that the exercise program reduced depression from severe to moderate with an average decrease of about 0.11 points, while in the control reduction was equal to 0.03 points (participants remain in range for severe depression). There was no effect on anxiety in either group(Philippot i in., 2022).

Discussion

In our review, we highlighted the importance and impact of physical activity and exercise on brain function. Physical activity refers to any movement of our body, while exercise is performed in a specific and organized training system. Both of them contribute to the movement of skeletal muscles. This results in an improvement in metabolic rate and increased circulation in muscles, which produce specific substances that can cause changes in brain structures(Han i in., 2023; Severinsen & Pedersen, 2020). This specificity of brain transformation under the influence of sports is opposite(Augusto-Oliveira i in., 2023) to the processes determining the changes and pathophysiology of dementia(F.-T. Chen i in., 2020), Alzheimer's disease(S. Zhang i in., 2022) and depression(Kandola i in., 2019). While many studies have shown an improvement in brain function after training programs, we can still find cases in the literature in which there was no effect on cognition in dementia and no improvement in intellectual functions. What was different in these studies and may be a potential cause of variance is the duration of PA in participants. The negative correlation was described in the short duration of exercise, when the greatest effects were associated with long-term regular PA, the earlier we start, the better. Even though much evidence of PA reducing depression symptoms, it doesn't have a specific place in the therapeutic process. It may be effective but still pharmacotherapy has better results. There is some speculation about using PA in the situation where we cannot administer medication to patients with contraindications and where it is no longer effective(C. Chen i in., 2022; Russell, 2023). Many studies are confirming this thesis but we still lack information when exactly we should start to exercise to avoid or minimize risk of neurodegenerative disorder or what is minimal or maximal intensity of necessary training(Boa Sorte Silva i in., 2024). Despite many efforts therapy of dementia is insufficient. No pharmacotherapy can reverse brain tissue atrophy so the cure still relies on symptomatic treatment using cholinesterase inhibitors with behavioral intervention additionally(Tisher & Salardini, 2019). Alzheimer disease affecting over 50 million people worldwide. With progressive prognosis of growing number of patients, only two types of drugs are approved for therapy. Neither acetylcholine esterase nor N-metylo D-aspartate antagonist (NMDA) reverse changes in cerebrum so treatment targeted to reverse or alter pathway of changes in AD is still beyond our capabilities(Breijyeh & Karaman, 2020).

Conclusions

Physical activity beyond doubt has a positive impact on brain function. Our muscles during exercise produce and secrete many substances e.g. myokines that influence cerebrum not only directly but also in secondary processes. Many studies proved the contribution of PA in creating new interconnections and reshaping brain structure. In literature we can find researches where positive aspects of exercise and PA were shown on cognitive function and treatment of Alzheimer disease and depression.

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REFERENCES

1. Adlard, P. A., Perreau, V. M., Pop, V., & Cotman, C. W. (2005). Voluntary Exercise Decreases Amyloid Load in a Transgenic Model of Alzheimer's Disease. *The Journal of Neuroscience*, *25*(17), 4217–4221. https://doi.org/10.1523/JNEUROSCI.0496-05.2005
2. Augusto-Oliveira, M., Arrifano, G. P., Leal-Nazaré, C. G., Santos-Sacramento, L., Lopes-Araújo, A., Royes, L. F. F., & Crespo-Lopez, M. E. (2023). Exercise Reshapes the Brain: Molecular, Cellular, and Structural Changes Associated with Cognitive Improvements. *Molecular Neurobiology*, *60*(12), 6950–6974. https://doi.org/10.1007/s12035-023-03492-8
3. Boa Sorte Silva, N. C., Barha, C. K., Erickson, K. I., Kramer, A. F., & Liu-Ambrose, T. (2024). Physical exercise, cognition, and brain health in aging. *Trends in Neurosciences*, S0166223624000626. https://doi.org/10.1016/j.tins.2024.04.004
4. Breijyeh, Z., & Karaman, R. (2020). Comprehensive Review on Alzheimer's Disease: Causes and Treatment. *Molecules*, *25*(24), 5789. https://doi.org/10.3390/molecules25245789
5. Chen, C., Beaunoyer, E., Guitton, M. J., & Wang, J. (2022). Physical Activity as a Clinical Tool against Depression: Opportunities and Challenges. *Journal of Integrative Neuroscience*, *21*(5). https://doi.org/10.31083/j.jin2105132
6. Chen, F.-T., Hopman, R. J., Huang, C.-J., Chu, C.-H., Hillman, C. H., Hung, T.-M., & Chang, Y.-K. (2020). The Effect of Exercise Training on Brain Structure and Function in Older Adults: A Systematic Review Based on Evidence from Randomized Control Trials. *Journal of Clinical Medicine*, *9*(4), 914. https://doi.org/10.3390/jcm9040914
7. De La Rosa, A., Olaso-Gonzalez, G., Arc-Chagnaud, C., Millan, F., Salvador-Pascual, A., García-Lucerga, C., Blasco-Lafarga, C., Garcia-Dominguez, E., Carretero, A., Correas, A. G., Viña, J., & Gomez-Cabrera, M. C. (2020a). Physical exercise in the prevention and treatment of Alzheimer's disease. *Journal of Sport and Health Science*, *9*(5), 394–404. https://doi.org/10.1016/j.jshs.2020.01.004
8. De La Rosa, A., Olaso-Gonzalez, G., Arc-Chagnaud, C., Millan, F., Salvador-Pascual, A., García-Lucerga, C., Blasco-Lafarga, C., Garcia-Dominguez, E., Carretero, A., Correas, A. G., Viña, J., & Gomez-Cabrera, M. C. (2020b). Physical exercise in the prevention and treatment of Alzheimer's disease. *Journal of Sport and Health Science*, *9*(5), 394–404. https://doi.org/10.1016/j.jshs.2020.01.004
9. *Depressive disorder (depression)*. (b.d.). Pobrano 25 maj 2025, z https://www.who.int/news-room/fact-sheets/detail/depression
10. Devanne, H., & Allart, E. (2019). Boosting brain motor plasticity with physical exercise. *Neurophysiologie Clinique*, *49*(2), 91–93. https://doi.org/10.1016/j.neucli.2019.01.003

11. Donnelly, J. E., Hillman, C. H., Castelli, D., Etnier, J. L., Lee, S., Tomporowski, P., Lambourne, K., & Szabo-Reed, A. N. (2016). Physical Activity, Fitness, Cognitive Function, and Academic Achievement in Children: A Systematic Review. *Medicine & Science in Sports & Exercise*, *48*(6), 1197–1222. https://doi.org/10.1249/MSS.0000000000000901
12. Enette, L., Vogel, T., Merle, S., Valard-Guiguet, A.-G., Ozier-Lafontaine, N., Neviere, R., Leuly-Joncart, C., Fanon, J. L., & Lang, P. O. (2020). Effect of 9 weeks continuous vs. interval aerobic training on plasma BDNF levels, aerobic fitness, cognitive capacity and quality of life among seniors with mild to moderate Alzheimer's disease: A randomized controlled trial. *European Review of Aging and Physical Activity*, *17*(1), 2. https://doi.org/10.1186/s11556-019-0234-1
13. Erickson, K. I., Hillman, C., Stillman, C. M., Ballard, R. M., Bloodgood, B., Conroy, D. E., Macko, R., Marquez, D. X., Petruzzello, S. J., & Powell, K. E. (2019). Physical Activity, Cognition, and Brain Outcomes: A Review of the 2018 Physical Activity Guidelines. *Medicine & Science in Sports & Exercise*, *51*(6), 1242–1251. https://doi.org/10.1249/MSS.0000000000001936
14. Erickson, K. I., Voss, M. W., Prakash, R. S., Basak, C., Szabo, A., Chaddock, L., Kim, J. S., Heo, S., Alves, H., White, S. M., Wojcicki, T. R., Mailey, E., Vieira, V. J., Martin, S. A., Pence, B. D., Woods, J. A., McAuley, E., & Kramer, A. F. (2011a). Exercise training increases size of hippocampus and improves memory. *Proceedings of the National Academy of Sciences*, *108*(7), 3017–3022. https://doi.org/10.1073/pnas.1015950108
15. Erickson, K. I., Voss, M. W., Prakash, R. S., Basak, C., Szabo, A., Chaddock, L., Kim, J. S., Heo, S., Alves, H., White, S. M., Wojcicki, T. R., Mailey, E., Vieira, V. J., Martin, S. A., Pence, B. D., Woods, J. A., McAuley, E., & Kramer, A. F. (2011b). Exercise training increases size of hippocampus and improves memory. *Proceedings of the National Academy of Sciences*, *108*(7), 3017–3022. https://doi.org/10.1073/pnas.1015950108
16. Han, X., Ashraf, M., Tipparaju, S. M., & Xuan, W. (2023). Muscle–Brain crosstalk in cognitive impairment. *Frontiers in Aging Neuroscience*, *15*, 1221653. https://doi.org/10.3389/fnagi.2023.1221653
17. Harvey, S. B., Øverland, S., Hatch, S. L., Wessely, S., Mykletun, A., & Hotopf, M. (2018). Exercise and the Prevention of Depression: Results of the HUNT Cohort Study. *American Journal of Psychiatry*, *175*(1), 28–36. https://doi.org/10.1176/appi.ajp.2017.16111223
18. Herold, F., Törpel, A., Schega, L., & Müller, N. G. (2019). Functional and/or structural brain changes in response to resistance exercises and resistance training lead to cognitive improvements – a systematic review. *European Review of Aging and Physical Activity*, *16*(1), 10. https://doi.org/10.1186/s11556-019-0217-2
19. Iso-Markku, P., Kujala, U. M., Knittle, K., Polet, J., Vuoksimaa, E., & Waller, K. (2022). Physical activity as a protective factor for dementia and Alzheimer's disease: Systematic review, meta-analysis and quality assessment of cohort and case–control studies. *British Journal of Sports Medicine*, *56*(12), 701–709. https://doi.org/10.1136/bjsports-2021-104981
20. Kandola, A., Ashdown-Franks, G., Hendrikse, J., Sabiston, C. M., & Stubbs, B. (2019). Physical activity and depression: Towards understanding the antidepressant mechanisms of physical activity. *Neuroscience & Biobehavioral Reviews*, *107*, 525–539. https://doi.org/10.1016/j.neubiorev.2019.09.040
21. Kou, X., Chen, D., & Chen, N. (2019). Physical Activity Alleviates Cognitive Dysfunction of Alzheimer's Disease through Regulating the mTOR Signaling Pathway. *International Journal of Molecular Sciences*, *20*(7), 1591. https://doi.org/10.3390/ijms20071591
22. López-Ortiz, S., Lista, S., Valenzuela, P. L., Pinto-Fraga, J., Carmona, R., Caraci, F., Caruso, G., Toschi, N., Emanuele, E., Gabelle, A., Nisticò, R., Garaci, F., Lucia, A., & Santos-Lozano, A. (2023). Effects of physical activity and exercise interventions on Alzheimer's disease: An umbrella review of existing meta-analyses. *Journal of Neurology*, *270*(2), 711–725. https://doi.org/10.1007/s00415-022-11454-8
23. Ohia-Nwoko, O., Montazari, S., Lau, Y.-S., & Eriksen, J. L. (2014). Long-term treadmill exercise attenuates tau pathology in P301S tau transgenic mice. *Molecular Neurodegeneration*, *9*(1), 54. https://doi.org/10.1186/1750-1326-9-54
24. Oyovwi, M. O., Ogenma, U. T., & Onyenweny, A. (2025). Exploring the impact of exercise-induced BDNF on neuroplasticity in neurodegenerative and neuropsychiatric conditions. *Molecular Biology Reports*, *52*(1), 140. https://doi.org/10.1007/s11033-025-10248-1
25. Pastor, D., Ballester-Ferrer, J. A., Carbonell-Hernández, L., Baladzhaeva, S., & Cervello, E. (2022). Physical Exercise and Cognitive Function. *International Journal of Environmental Research and Public Health*, *19*(15), 9564. https://doi.org/10.3390/ijerph19159564
26. Philippot, A., Dubois, V., Lambrechts, K., Grogna, D., Robert, A., Jonckheer, U., Chakib, W., Beine, A., Bleyenheuft, Y., & De Volder, A. G. (2022). Impact of physical exercise on depression and anxiety in adolescent inpatients: A randomized controlled trial. *Journal of Affective Disorders*, *301*, 145–153. https://doi.org/10.1016/j.jad.2022.01.011
27. Puderbaugh, M., & Emmady, P. D. (2025). Neuroplasticity. W *StatPearls*. StatPearls Publishing. http://www.ncbi.nlm.nih.gov/books/NBK557811/

28. Russell, C. (2023). “We Can Do This!”: The Role of Physical Activity in What Comes Next for Dementia. *International Journal of Environmental Research and Public Health*, *20*(15), 6503. https://doi.org/10.3390/ijerph20156503
29. Sanders, L. M. J., Hortobágyi, T., Karssemeijer, E. G. A., Van Der Zee, E. A., Scherder, E. J. A., & Van Heuvelen, M. J. G. (2020). Effects of low- and high-intensity physical exercise on physical and cognitive function in older persons with dementia: A randomized controlled trial. *Alzheimer’s Research & Therapy*, *12*(1), 28. https://doi.org/10.1186/s13195-020-00597-3
30. Schuch, F. B., Vancampfort, D., Firth, J., Rosenbaum, S., Ward, P. B., Silva, E. S., Hallgren, M., Ponce De Leon, A., Dunn, A. L., Deslandes, A. C., Fleck, M. P., Carvalho, A. F., & Stubbs, B. (2018). Physical Activity and Incident Depression: A Meta-Analysis of Prospective Cohort Studies. *American Journal of Psychiatry*, *175*(7), 631–648. https://doi.org/10.1176/appi.ajp.2018.17111194
31. Severinsen, M. C. K., & Pedersen, B. K. (2020). Muscle–Organ Crosstalk: The Emerging Roles of Myokines. *Endocrine Reviews*, *41*(4), 594–609. https://doi.org/10.1210/endrev/bnaa016
32. Tartt, A. N., Mariani, M. B., Hen, R., Mann, J. J., & Boldrini, M. (2022). Dysregulation of adult hippocampal neuroplasticity in major depression: Pathogenesis and therapeutic implications. *Molecular Psychiatry*, *27*(6), 2689–2699. https://doi.org/10.1038/s41380-022-01520-y
33. Thomas, A. G., Dennis, A., Bandettini, P. A., & Johansen-Berg, H. (2012). The Effects of Aerobic Activity on Brain Structure. *Frontiers in Psychology*, *3*. https://doi.org/10.3389/fpsyg.2012.00086
34. Tisher, A., & Salardini, A. (2019). A Comprehensive Update on Treatment of Dementia. *Seminars in Neurology*, *39*(02), 167–178. https://doi.org/10.1055/s-0039-1683408
35. Trifu, S. C., Trifu, A. C., Aluaş, E., Tătaru, M. A., & Costea, R. V. (2020). Brain changes in depression. *Romanian Journal of Morphology and Embryology*, *61*(2), 361–370. https://doi.org/10.47162/RJME.61.2.06
36. Tsuk, S., Netz, Y., Dunsky, A., Zeev, A., Carasso, R., Dvolatzky, T., Salem, R., Behar, S., & Rotstein, A. (2019). The Acute Effect of Exercise on Executive Function and Attention: Resistance Versus Aerobic Exercise. *Advances in Cognitive Psychology*, *15*(3), 208–215. https://doi.org/10.5709/acp-0269-7
37. Valenzuela, P. L., Castillo-García, A., Morales, J. S., De La Villa, P., Hampel, H., Emanuele, E., Lista, S., & Lucia, A. (2020). Exercise benefits on Alzheimer’s disease: State-of-the-science. *Ageing Research Reviews*, *62*, 101108. https://doi.org/10.1016/j.arr.2020.101108
38. Vints, W. A. J., Levin, O., Fujiyama, H., Verbunt, J., & Masiulis, N. (2022). Exerkines and long-term synaptic potentiation: Mechanisms of exercise-induced neuroplasticity. *Frontiers in Neuroendocrinology*, *66*, 100993. https://doi.org/10.1016/j.yfrne.2022.100993
39. Voss, M. W., Soto, C., Yoo, S., Sodoma, M., Vivar, C., & Van Praag, H. (2019). Exercise and Hippocampal Memory Systems. *Trends in Cognitive Sciences*, *23*(4), 318–333. https://doi.org/10.1016/j.tics.2019.01.006
40. Zhang, F., Peng, W., Sweeney, J. A., Jia, Z., & Gong, Q. (2018). Brain structure alterations in depression: Psychoradiological evidence. *CNS Neuroscience & Therapeutics*, *24*(11), 994–1003. https://doi.org/10.1111/cns.12835
41. Zhang, S., Zhen, K., Su, Q., Chen, Y., Lv, Y., & Yu, L. (2022). The Effect of Aerobic Exercise on Cognitive Function in People with Alzheimer’s Disease: A Systematic Review and Meta-Analysis of Randomized Controlled Trials. *International Journal of Environmental Research and Public Health*, *19*(23), 15700. https://doi.org/10.3390/ijerph192315700
42. Zhao, J., Jiang, W., Wang, X., Cai, Z., Liu, Z., & Liu, G. (2020). Exercise, brain plasticity, and depression. *CNS Neuroscience & Therapeutics*, *26*(9), 885–895. https://doi.org/10.1111/cns.13385