Review

The impact of cardiovascular exercise on human cognition

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Abstract

Cardiovascular exercise has been long practised. The dawn of its popularity began in the 1960s when it was known as 'aerobics'. Several studies have shown that cardiovascular exercise can increase levels of cognition in various subjects, both acutely and in the long term. Cognition was measured in terms of 'learning success', memory ability and attention, for example. Many individuals with existing neurodevelopmental disorders have had their symptoms alleviated by engaging in cardiovascular exercise. The brain's neuroplasticity is a widely acknowledged contributor to our fluctuating cognitive function. Common issues encountered when reviewing these studies are their small sample sizes and lack of homogeneity.

Abbreviations

ACC - anterior cingulate cortex
ADHD - attention deficit hyperactivity disorder
BDNF - brain-derived neurotrophic factor
CE - cardiovascular exercise
COPD - chronic obstructive pulmonary disease
CVD - cardiovascular disease
MRI - magnetic resonance imaging
ERP - event-related potential
ES - effect size
RCT - Randomised Controlled Trial
VEGF - vascular endothelial growth factor

Introduction

Cardiovascular exercise (CE) has been long practised. The dawn of its popularity began in the 1960s when it was known as 'aerobics'. It was a term coined by Dr Kenneth H Cooper who pioneered this concept, with the intention of developing a system of exercise to prevent complications involving the coronary arteries.[1,2] Today, this term is commonly shortened to 'cardio', and exercises range from swimming and walking to dancing and marathon running.[3,4]

There exists a considerable body of research on the influence of CE on human cognitive function, in particular the physiological theories underlying this hypothesis. Much of this research includes seminal studies which have greatly contributed to our understanding of cognitive processing.[5] However, it is evident that an abundance of this research entails the effects of CE on memory alone, failing to discuss human cognition as a whole. Cognition is defined as the mental processes involved in gaining knowledge and comprehension and can include attention, learning and perception, as well as memory.[6] Thus, this brief literature review will critically analyse some of the theories regarding the physiological mechanisms that are elicited through CE, that may contribute to human cognition. It will subsequently focus on the most widely discussed of these mechanisms, neuroplasticity, in order to bring forth a greater understanding of the neurobiology underlying exercise-induced cognitive enhancement.

Background

CE is physical activity that increases metabolic rate. Its name refers to the stresses placed on the cardiorespiratory system by these exercises, which involve consistent, dynamic movements.[7] Regular CE engagement can increase fitness and prevent the risk of/manage chronic conditions.[8] Middleton et al (2010) found that the risk of cognitive impairment was higher in women who remained inactive in their lifetime compared to those who later became active.[9]

Arousal theories have played an important role in research investigating the relationship between CE and cognition, such as the Yerkes-Dodson Model, which explains that an intermediate stress level optimises performance.[10]

Methods

A literature review was deemed the most appropriate method for this field of study. Research into the effects of exercise on cognitive processing is extensive, and so a literature review would facilitate an overview of the main findings and debates regarding this subject area. Seminal studies were included as well as less notable research. Excluded were those related to strength training and other forms of exercise that do not significantly raise heart rate. The database primarily used to search for literature was Ovid MEDLINE. Keywords and terms frequently entered into the search engine were 'cardiovascular exercise', 'cognition', 'memory' and 'learning'.

Discussion

The UK's ageing population highlights the importance of cheaper interventions to counteract age-related declines in cognitive function.[11] Kuhne et al (2023) investigated the correlation between CE and cognition, which they hypothesise is mediated by 'an altered immune response to exercise'. In their randomised controlled trial (RCT) participants engaged in either a bout of indoor cycling or stretching (control), immediately following an artificial vocabulary learning task. Blood samples were obtained to measure serum cytokine concentrations in both groups. 'Learning success' was measured by the number of correctly matched pseudoword-picture pairs.[12]

The results of this experiment, although conducive, may be of limited use in the attempts to corroborate a direct positive correlation between acute CE and cognition: The study showed no significant difference between the two groups for learning success. However, serum cytokine levels (IL-6) significantly increased in the CE group, and there was no such increase in the control group.

Nevertheless, the critical remark must be made that these results merely confirm that CE increases serum cytokine levels, not learning success. Kuhne et al conducted additional research that revealed CE-specific cytokines do, in fact, increase cognition.[12] However, this was not implicated in the RCT. By combining the results of the two studies it would be reasonable to infer that acute CE and enhanced cognitive function are positively correlated. However, doing so may be circuitous, and offers a post hoc justification for this relationship. A study with results establishing a direct relationship would be of greater use.

Two years earlier Kuhne et al conducted a study of a similar premise, this time investigating exercise-induced neurotrophic factors in lieu of the cytokines in the aforementioned study.[13] This study also failed to show a significant difference between the CE group and the control group in terms of memory ability, however a greater increase in brain-derived neurotrophic factor (BDNF) and vascular endothelial growth factor (VEGF) levels was observed in the CE group. BDNF and VEGF have been shown to increase memory consolidation in humans.[14] Although this poses the same notable criticism as the study above, it does shed light on another potential mechanism by which CE could impact cognition.

Neuroplasticity refers to the brain's ability to adapt in response to stimuli. Synaptic networks undergo growth and reorganisation in order to change their function. Such neural modifications can be prompted by both environmental and internal stimuli, such as brain injury and learning processes.[15] Recent research by Lehman et al (2020) suggests that the brain's neuroplasticity is a mediator of the association between CE and cognitive function - specifically, sustained attention. They prescribed the use of neuroimaging. They discovered that two weeks of regular CE increases sustained visual attention, and that the left middle frontal gyrus of the brain increases its intrinsic connectivity to facilitate this.[16]

Results from Winneke et al (2019) agree with the above. They theorise that cognitive function following a bout of CE improves due to the activation of attentional control resources. In the CE condition, participants completed indoor cycling training whilst their event-related potential (ERP) data was measured. They found exercise produced a shorter P3 ERP peak latency compared to the resting state, indicating an increase in neural processing.[17] Although this study provided a small sample size of 11, the p value was <0.001, allowing the acknowledgement of the link between CE and augmented attentional control.

A meta-analysis conducted by Lambourne and Tomporowski in 2010 found that exercise-induced cognitive function improved by a mean effect size (ES) of 0.2, especially in tasks that involved rapid decision-making.[18] In agreement with these findings, Etnier et al (1999) concluded that chronic obstructive pulmonary disease (COPD), age, pulmonary ventilation and aerobic fitness are all useful predictors of cognitive function. They discussed that the impact of the latter may be due to an increase in cerebral oxygenation during exercise. They also conducted a meta-analysis presenting 852 effects of acute CE on cognition, showing a significant positive ES of 0.16.[19] However, Lambourne and Tomporowski criticised its methodology, stating that they failed to employ a process to address the small sample sizes used in their study.[18] Furthermore, many studies investigating cognition tend to use mundane artificial cognitive tasks lacking ecological validity.

A number of authors have recognised that CE can enhance cognition in individuals who have suffered from disease, as well as those currently living with neurodevelopmental disorders. Research has shown that CE can help alleviate symptoms in individuals with attention deficit hyperactivity disorder (ADHD), for example by increasing attention span.[20] Additionally, CE has been found to increase sensorimotor control (mediated by cognitive regions in the brain) in stroke survivors and older individuals with cardiovascular disease (CVD).[21,22] However, these studies fail to consider potential confounders such as sleep quality, which can be increased by CE and prevents cognitive impairment.[23,24] It could be that participants in the CE condition began to sleep better and so any prior cognitive deficits restored themselves.

It is apparent that over time, extensive literature has developed on the impact of CE on brain neuroplasticity; this appears to be the most widely discussed mechanism by which CE may increase cognition. The results of previous studies are in agreement with the aforementioned study by Lehman et al. (2020). They show CE has led to neural angiogenesis, synaptogenesis and increased hippocampal plasticity in both humans and animals, and produces exerkines that induce long-term synaptic potentiation-related pathways.[25,26,27] Others have shown that CE is related to decreased atrophy in the anterior cingulate cortex (ACC) and medial temporal lobe.[28] Nonetheless, the impact of the type of CE is seldom addressed in these studies. Müller et al (2017) found a greater increase in grey matter in the brains of participants in the dancing condition compared to those in the cycling condition, indicating the effects of some aerobic exercises may be more potent.[29]

Conclusion

There is a plethora of CEs that people engage in to improve their fitness. Due to this large scope, it is an accessible way of minimising age-related declines in cognitive function.

Several studies report an increase in cognition through CE, although the potential mechanisms by which this takes place differs between studies. Some employed the use of blood sampling and others magnetic resonance imaging (MRI) scanning, for example. The most

commonly discussed theory was that the brain's neuroplasticity mediates an increase in cognition alongside CE.

Many studies in this field have small sample sizes and narrow age ranges. They also fail to consider potential confounding variables that may impact both CE and cognition and would therefore reduce their validity. As such, more research is needed that accounts for confounders and is accommodative of other populations, for example older people. Additionally, the cognitive tasks should be made less artificial, having greater real-life application. However, there are notable commonalities between studies that point toward future implementation of CE to enhance cognitive function.

References

1. Cooper KH (1982) Aerobics programme for total wellbeing: exercise, diet and emotional balance. New York: Bantam Books.
2. Encyclopedia Britannica (2014) Aerobics. Available at: https://www.britannica.com/sports/bodybuilding Accessed: 3 February 2023.
3. Medical News Today (2023) 20 cardio exercises to do at home with minimal equipment, from beginner to advanced. Available at: https://www.medicalnewstoday.com/articles/cardio-exercises-at-home Accessed: 3 February 2023.
4. Masterclass (2021) What is cardio? 12 Types of cardio exercises. Available at: https://www.masterclass.com/articles/what-is-cardio (Accessed 3 February 2023).
5. Gomez-Pinilla F, Hillman C (2013) The influence of exercise on cognitive abilities, Comprehensive Physiology, 3(1) pp. 403-428.
6. Verywell Mind (2023) What is Cognition? Available at: https://www.verywellmind.com/what-is-cognition-2794982 Accessed: 5 February 2023.
7. Castro EA, Peinado AB, Benito PJ, Galindo M, Gonzales-Gross M, Cupeiro R, the PRONAF study group (2017) What is the most effective exercise protocol to improve cardiovascular fitness in overweight and obese subjects?, Journal of Sport and Health Science, 6(4) pp. 454-461.
8. Mayo Clinic (2022) Aerobic exercise: top 10 reasons to get physical. Available at: https://www.mayoclinic.org/healthy-lifestyle/fitness/in-depth/aerobic-exercise/art-20045541 (Accessed: 5 February 2023).
9. Middleton LE, Barnes DE, Lui L, Yaffe K (2010) Physical activity over the life course and its association with cognitive performance and impairment in old age, Journal of the American Geriatrics Society, 58(7) pp. 1322-1326.
10. Healthline (2020) What the Yerkes-Dodson Law says about stress and performance. Available at: https://www.healthline.com/health/yerkes-dodson-law (Accessed: 5 February 2023.).
11. Hedden T, Gabrieli JDE (2004) Insights into the ageing mind: a view from cognitive neuroscience, Nature Reviews Neuroscience, 5(2) pp. 87-96.
12. Kuhne LA, Ksiezarczyk AM, Braumann KM, Reer R, Jacobs T, Roder B, Hotting K (2023) Cardiovascular exercise, learning, memory, and cytokines: results of a ten-week randomized controlled training study in young adults, Biological Psychology, 176 pp. 108466.
13. Kuhne LA, Ksiezarczyk AM, Braumann KM, Reer R, Jacobs T, Roder B, Hotting K (2021). The effects of acute cardiovascular exercise on memory and its associations with exercise-induced increases in neurotrophic factors. Frontiers in Aging Neuroscience, 13 pp. 750401.
14. Miranda M, Morici JF, Zanoni MB, Bekinschtein P (2019) Brain-derived neurotrophic factor: a key molecule for memory in the healthy and the pathological brain, Frontiers in Cellular Neuroscience, 13 pp. 363.
15. Costandi M (2016) Neuroplasticity. Cambridge Massachusetts: MIT Press
16. Lehman N, Villringer A, Taubert M (2020) Intrinsic connectivity changes mediate the beneficial effect of cardiovascular exercise on sustained visual attention, Cerebral Cortex Communications, 1(1).
17. Winneke AH, Hübner L, Godde B, Voelcker R (2019) Moderate cardiovascular exercise speeds up neural markers of stimulus evaluation during attentional control processes, Journal of Clinical Medicine, 8(9) pp. 1348.
18. Lambourne L, Tomporowski P (2010) The effect of exercise-induced arousal on cognitive task performance: a meta-regression analysis, Brain Research, 1341 pp. 12-24.
19. Etnier J, Johnston R, Dale D, Pollard JR, Rejeski JW, Michael B (1999) The relationships among pulmonary function, aerobic fitness, and cognitive functioning in older COPD patients, Chest, 116(4), pp. 953–960.
20. Den Heijer AE, Groen Y, Tucha L, Fuermaier ABM, Koertes J, Lange KW, Thome J, Tucha O (2017) Sweat it out? The effects of physical exercise on cognition and behavior in children and adults with ADHD: a systematic literature review, Journal of Neural Transmission 124 (1) pp. 3–26.
21. Quaney BM, Boyd LA, McDowd JM, Zahner LH, He J, Mayo MS, Macko RF (2009) Aerobic exercise improves cognition and motor function poststroke, Neurorehabilitation and Neural Repair 23(9) pp. 879-885.
22. Hayes SM, Alosco ML, Forman DE (2014) The effects of aerobic exercise on cognitive and neural decline in aging and cardiovascular disease, Current Geriatrics Reports, 3(4) pp. 282-290.
23. Diekelmann S (2014) Sleep for cognitive enhancement, Frontiers in Systems Neuroscience, 8(46).
24. Johns Hopkins Medicine (2018) Exercising for better sleep. Available at: https://www.hopkinsmedicine.org/health/wellness-and-prevention/exercising-for-better-sleep Accessed: 21 February 2023.
25. Hötting K, Röder B (2013) Beneficial effects of physical exercise on neuroplasticity and cognition, Neuroscience & Behavioral Reviews, 37(9).
26. Vints WAJ, Levin O, Fujiyama H, Verbunt J, Masiulis N (2022) Exerkines and long-term synaptic potentiation: mechanisms of exercise-induced neuroplasticity, Frontiers in Neuroendocrinology, 66.
27. Suwabe K, Hyodo K, Byun K, Ochi G, Fukuie T, Shimizu T, Kato M, Yassa M, Soya H (2017) Aerobic fitness associates with mnemonic discrimination as a mediator of physical activity effects: evidence for memory flexibility in young adults, Scientific Reports, 7(1) pp. 5410.
28. Chao Y, Wu CW, Lin L, Lai C, Wu H, Hsu A, Chen C (2020) Cognitive load of exercise influences cognition and neuroplasticity of healthy elderly: an exploratory investigation, Journal of Medical and Biological Engineering, 40(3) pp. 391-399.
29. Müller P, Rehfeld K, Schmicker M, Hökelmann A, Dordevic M, Lessmann V, Brigadski T, Kaufmann J, Müller N (2017) Evolution of neuroplasticity in response to physical activity in pld age: the case for dancing, Frontiers in Aging Neuroscience, 9

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Hi! I am a second-year medical student at the University of Bristol. I am particularly interested in gastroenterology and integrative medicine, and how alternative therapies can be used alongside conventional approaches in mainstream medical practice. I enjoy sports, cooking and reading.