

体育运动与认知功能关系的研究综述

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摘要

近年来, 体育运动对认知功能的影响逐渐成为心理学和神经科学研究的重点方向。随着人们对身体活动和大脑健康关系认识的加深, 越来越多的实证研究表明, 规律的锻炼不仅能够增强身体素质, 还对认知能力产生积极的促进作用。文章系统总结了不同类型的运动对各类认知功能的影响, 结合其神经生化机制和理论假说, 以揭示体育运动对大脑的潜在益处。此外, 文章进一步探讨了运动对认知功能的促进作用中的时间因素(如运动频率、持续时间)及个体差异(如年龄、健康状况), 以便更全面地理解体育运动在不同人群中的认知效果。通过梳理这些因素, 文章不仅为认知障碍人群的运动干预提供了科学依据, 还为青少年儿童的认知发展提供了有益的建议, 最终推动个体健康与认知功能的全面发展。

关键词

运动, 认知, 神经机制, 影响因素

A Review of the Relationship between Physical Activity and Cognitive Function

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Abstract

In recent years, the impact of physical exercise on cognitive function has increasingly become a focal point in psychology and neuroscience research. With a deepening understanding of the relationship between physical activity and brain health, an expanding body of empirical studies suggests that regular exercise not only enhances physical fitness but also exerts a positive influence on cognitive abilities. This paper systematically reviews the effects of various types of exercise on different aspects of cognitive function, exploring the neurobiochemical mechanisms and theories underlying

these benefits to reveal the potential advantages of physical activity for brain health. Additionally, this paper examines temporal factors (e.g., exercise frequency, duration) and individual differences (e.g., age, health status) in the cognitive benefits of exercise to provide a more comprehensive understanding of its effects across diverse populations. By analyzing these factors, this paper offers scientific guidance for exercise interventions for individuals with cognitive impairments and provides constructive recommendations for promoting cognitive development in children and adolescents, ultimately contributing to the holistic development of individual health and cognitive function.

Keywords

Exercise, Cognition, Neural Mechanisms, Influencing Factors

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1. 引言

由于现代社会学习和工作的性质要求,长时间的久坐成为当代学生及许多白领和科研人员的生活常态。除此之外,电子产品的过度依赖和熬夜等不良生活习惯在年轻人中普遍存在。现代生活的种种特点也使得一些慢性疾病如脊柱侧弯、高血压、糖尿病等呈现出年轻化的趋势[1][2]。从身心医学的角度来看,心理状态和身体健康是统一的整体,人的各个方面彼此交互相互影响[3],不良生活习惯所诱导的亚健康状态也会进一步影响到个体的心理状态及认知能力,因此寻找合适的应对策略至关重要。研究表明,体育运动会对人体产生多方面的影响。个人健康状况以及运动量、强度和持续时间能够成为影响运动对男性生育能力影响的有效辅助因素[4]。体育运动能够促进身体和心理健康,有助于提高个体的主观幸福感[5]。近年来,体育运动对认知功能的影响成为研究热点[6]-[8]。但是,开展体育运动的不同群体和体育运动的不同类型及强度对个体心理的影响并不总是一致的[9],清晨运动和夜晚运动会有差异[10],有氧运动与无氧运动影响不同[11]。由于不同的体育运动类型对认知表现的影响机制和理论假说不同[12],也相应受到多种调节因子的影响,本综述将重点关注体育运动对认知表现的影响,探讨其背后的理论假说、生理机制以及各种调节因子,从而提出适当的建议以利用体育运动促进认知发展。

2. 认知功能的定义及分类

认知能力是教育和职业表现、社会经济成就、健康和寿命的重要预测指标。认知能力的下降与老年人日常功能的障碍有关[13]。在基础心理学中,研究人员通常区分两大类非社会认知能力[14][15]。一类是主要依赖于认知处理或是问题解决方面的能力,通常被称为流体能力。这些能力又包括心理运动速度、记忆力和抽象推理能力。从更加广泛性的角度来看人们通常研究的流体能力主要是心理运动速度和记忆力。另一类认知能力主要反映从一个人的社会文化环境中明确获得的陈述性和程序性知识,通常被称为晶体能力,包括词汇、读写能力、计算能力、世界历史和时事知识以及专业领域的知识和技能。除此之外,涉及感知、编码、存储、检索和控制有关自己和他人的知识的社会认知过程在老化研究中受到关注[16]。

3. 体育运动与认知功能关系的研究方法

体育运动与认知功能关系的研究以干预性研究为主[17]-[19],通常会对被试进行定期的体育训练(每

周至少三次以上,持续时间为 2 周到 24 周不等),训练前后分别测量其认知功能的改变。体育运动的类型分为有氧运动和无氧运动两大类,有氧运动与无氧运动的鉴定通过心率监测器监测受试者的心率,以确保运动强度保持在规定的水平。通常使用的运动方式为跑步和骑自行车。在青少年儿童群体中还会以球类运动作为体育训练的方式,例如乒乓球、篮球、排球、足球等。中国传统运动方式如八段锦、太极和五禽戏也有一些研究[20][21]。对于认知功能的测量包括工作记忆,注意力,执行控制功能三个方面,但大多数研究都是通过行为学范式测量认知功能的执行控制功能和工作记忆能力,很少有研究同时测量了认知功能的这三个方面。其中,工作记忆的测量范式一般以词汇记忆任务为主,注意力和执行控制功能的测量通过经典的 stroop 范式和 Flanker 范式。体育锻炼是阿尔兹海默症的治疗手段之一,所以在这个病人群体的研究中,认知功能的测量主要借助简易精神状态量表(MMSE)和阿尔茨海默病评估量表-认知子量表(ADAS-Cog)来评估患者经过运动干预训练后整体认知功能的变化[22]。除了干预研究,纵向跟踪研究也是该领域的经典研究方法。有研究通过大规模人口样本长达 14 年的跟踪研究,通过行为测量、个人访谈、量表测量三种认知行为测量方式系统检验了身体活动对整个生命周期中认知功能的不同影响[23]。

4. 体育锻炼影响认知功能的理论假说

体育锻炼影响认知功能的相关理论分为急性无氧运动和慢性长期性有氧运动两种类型。急性运动被证明对认知表现具有积极影响,但是这种影响的效应量较小[24]。急性运动影响认知表现的假说有三种,分别是倒 U 形假说[25][26],中央疲劳假说[27]以及短暂性前额叶功能减退假说[28]。长期性有氧运动被证明能够有效促进认知发展,这种改善能力的解释有前额叶假说[29]和认知储备假说[30]。

4.1. 倒 U 形假说

倒 U 形假说最初由 Yerkes 和 Dodson 提出,用以解释生理应激与表现效率之间的关系。原始假设是,随着应激的增加,表现会受到曲线状的影响。Davey 将这种方法应用于运动诱导的应激和认知表现,提出在运动期间或直接运动后的认知表现应该会从应激的增加中受益,直到某个点,之后更高的应激水平会阻碍表现。尽管有一些实证证据支持这种曲线关系[31][32],但也有一些相反的证据[33],这说明倒 U 形假说在预测认知方面的有效性方面存在局限。

4.2. 中央疲劳假说

中央疲劳假说,它将觉醒分为三个维度:能量、情绪和计算[27]。根据这一假说,当身体需求超过个体所能轻松满足的程度时,能量处理(被描述为多种功能战略性地分配注意力资源)将在整个系统中比计算处理(被描述为多个结构协同工作)更占据主导。因此,当中枢神经系统的资源受到更高生理需求的压力时,依赖计算处理(即记忆、反应选择和刺激编码)的认知表现会受到影响[34]。受这一假说指导的研究通常关注由过度运动导致的脱水、热应激和低血糖的影响。尽管有一些实证证据表明,导致脱水和热应激的运动会导致认知障碍[35],但当 Brisswalter 及其同事回顾了所有相关文献后[36],他们得出结论,过度运动通常会导致认知功能的改善,这与中央疲劳假说相悖。

4.3. 短暂性前额叶功能减退假说

由于前额叶皮质(PFC)神经活动减少,从事高强度急性运动时,高阶认知功能可能会受到影响,这种现象被称为短暂性额叶功能减退效应。然而这一理论假说的使用范围具有局限性,短暂性额叶功能减退效应与认知任务类型密切相关,急性运动影响前额叶依赖型任务而不影响非前额叶依赖型任务[37]。

4.4. 前额叶假说

前额叶假说认为,随着年龄的增长,包括大脑前额区和前额前区在内的脑区会出现选择性退化[29]。就体育活动对认知表现的益处而言,这意味着体育活动可能会有益于依赖前额叶和前额前脑区的执行控制任务的表现[38]。实证证据表明[29][39],儿童和老年人参与长期体育活动计划后,在执行功能指标上显著改善,但在非执行任务的表现上则没有改善,这支持了前额叶衰老假说的可行性,元分析的结果也支持这一点,即执行过程的影响显著大于其他认知过程的影响[40]。有证据表明,体育活动对儿童和老年人的认知表现的益处大于对年轻人的益处,这与关于发展和衰老的前额叶假说是一致的。就发展而言,有证据表明,前额叶以及执行前额叶依赖任务的能力在青春期相对较晚才发育成熟[41]。

4.5. 认知储备假说

认知储备假说最初是为了解释与年龄相关的认知能力下降而提出的。这一假说认为,拥有更大认知储备的个体将经历较少的与年龄相关的认知衰退,并且患痴呆症的风险较低[42]。将这一假说应用于身体活动,是基于进一步的假设,即包括身体活动在内的生活方式因素能够增强认知储备[30]。因此,那些身体活动更多的人将拥有更大的认知储备,这使他们即使在面临年龄增长或其他变量(例如,慢性疾病或阿尔茨海默病的遗传易感性,这些变量被预测会降低认知储备)的情况下,也能在认知方面表现良好。支持这一假说的证据来自研究表明,身体活动对认知的最大影响在那些预计对认知储备需求最大的人身上最为明显。

5. 体育锻炼影响认知功能的神经生化机制

体育锻炼在增强各年龄段人群的认知功能方面发挥着关键作用,它可以提高脑血流量和生长因子的水平,包括脑源性神经营养因子和神经递质(如多巴胺和去甲肾上腺素)以及血管内皮生长因子(VEGF)和胰岛素样生长因子(IGF-1),从而增强神经可塑性和血管生成[43][44]。多项研究已经建立了体育活动和认知任务的整合模型。此外,还分析了体育活动的变化及其对认知状态的影响。对于患有中度认知障碍的老年人群来说,为期20周的体育锻炼计划取得了干预后改善的成果[45],而为期12周的体育活动计划与认知锻炼相结合时,则可增强老年人群的认知功能和大脑激活度。临床研究表明,身体活跃且健康的儿童和青春前期儿童拥有丰富的海马和基底神经节体积、更高的白质完整性、高效的大脑活动以及优异的认知表现和学业成绩。研究表明,身体健康和定期锻炼对前额叶皮层、大脑功能性连接以及执行和记忆功能有积极的影响[46]。在Colcombe等人进行的一项随机对照试验中,他们比较了参加6个月有氧运动或伸展运动计划的健康老年志愿者的脑容量。干预前后的MRI成像显示,有氧运动组的前额叶和颞叶皮质的脑容量均显著增加。这两个区域都介导高阶认知功能,并会受到与年龄相关的认知能力下降的影响[47]。与无氧对照组相比,干预组的前扣带皮层、右侧颞上回、右侧中额叶和胼胝体前部白质束的脑容量损失风险平均降低了42.1%、33.7%、27.2%和27.3%。通过增加心脏输出量,体育锻炼会增加脑血流量,如果定期重复,可以对神经功能产生积极影响,并减少氧化应激[48]。

6. 体育锻炼影响认知功能的调节因子

体育锻炼对认知功能的作用受到各个方面的影响,如果把个体的年龄性别等生理特征,体育运动的类型,外界环境天气的变化看作一个整体中的各个不同系统。那么这些不同系统中存在的不同因素将会影响体育锻炼对认知能力的作用。生理性别被认为是锻炼对大脑健康功效的一个重要变量,女性表现出更大的认知增益[49][50]。青少年研究同样发现体育活动有助于提高学业成绩,但这主要发生在女性身上。这项研究强调需要进行进一步的实验,以了解性别、运动强度和心理变量的作用[51]。这表明运动对认知

能力的促进与潜在机制的性别差异有关。流体能力会随着年龄而下降而晶体能力在不断增长从而起到一定的代偿作用。因此年轻人和老年人本身存在的能力结构的差异可能会导致同样体育运动训练下的不同效果。一项对社区中年轻人和老年人运动与认知变化的研究使用侧翼任务考察了 15~71 岁社区居民的身体活动与认知之间的关系, 这些居民的任务需要不同程度的执行控制。结果表明在控制混杂变量后, 在一致和不一致的侧翼条件下都观察到与年龄相关的反应时减慢。然而, 无论年龄大小, 在这些条件下, 身体活动都与更快的反应时相关。反应准确性研究结果表明, 对于老年人群, 只有在不一致条件下, 增加身体活动才与更好的表现相关。这说明体育锻炼可能对认知的一般和选择性方面都有益处, 尤其是对老年人而言[52]。除了广泛运用于认知老化的改善, 体育运动训练与认知表现的提升也在儿童和青少年中广泛运用。几项针对学龄儿童的研究表明体力活动量越大, 身体状况越好, 与认知表现和学业成绩越好呈正相关[53]。因为儿童和青少年的大脑发育阶段对环境刺激最为敏感[54]体力锻炼干预提供了变化的环境刺激因而能够有助于促进大脑发育。

体育运动的类型也是造成不同认知改善效果的重要影响因素, 区分锻炼类型的概念有很多种, 其中一种分类是通过针对性的技能来将锻炼类型分为协调训练、耐力训练和混合运动[55]。协调训练旨在促进运动技能的习得和完善, 而耐力训练主要是为了提高心血管健康。当这些目标结合在一起而没有明确的优先顺序时, 体育活动就被归类为混合运动。协调性和耐力锻炼的潜在机制可能不同, 与耐力锻炼相比, 混合和协调性锻炼后更一致和/或更具体的益处。然而, 耐力锻炼也有益于工作记忆, 但前提是能量系统的负荷通过高强度的训练而增加。一项针对不同类型体育锻炼影响认知功能的元分析发现高强度心血管训练被证明能有效提高参与者的注意力和分析能力, 而一般的耐力训练仅能改善实践能力[56]。一些作者认为, 与单一类型的训练相比, 综合干预措施(如力量训练加有氧训练或是体育运动训练与工作记忆训练相结合)可以有效降低认知风险因素[57] [58]。根据运动强度不同可以将运动分为有氧运动和无氧运动两种类型[59]。无氧运动的特点是短时间内高强度活动, 而有氧运动则与前面提到的耐力运动相重合。虽然少量研究表明无氧运动能够调节情绪[60], 但是认知功能的实验室测试似乎对剧烈无氧运动产生的假定疲劳状态具有很强的抵抗力, 短时间内剧烈的无氧运动并不能提高认知任务的表现[61]。而有氧运动对身体健康和认知促进的影响已经得到广泛的证明[62]-[64]。具体来说, 有氧运动训练有助于增加额叶皮质的厚度[65], 而额叶是负责注意和认知控制的主要脑区, 额叶的皮质功能的增强能够提高个体的认知灵活性。为期 6 个月的心肺运动能够促进老年人脑血管的调节从而改善认知能力[66]。因此有氧运动已成为治疗轻度认知障碍的一种有希望的干预措施。而不同运动项目均已证实一天中不同时间的运动表现波动, 而且这种波动似乎对耐力运动和无氧运动都有影响。不同的研究发现, 与早晨锻炼相比, 下午锻炼对糖尿病患者的整体健康和血糖有改善[67] [68], 而对于肥胖患者来说持续性进行晨练更有助于促进减肥[69]。研究发现认知表现的最大提升是在早上, 早晨进行一次中等强度的运动可改善老年人的血清 BDNF 和工作记忆或执行功能[70]。

7. 结论

由于大脑具有很强的可塑性, 运动对于一生的发展都是至关重要的。对于儿童和青少年来说, 定期的运动训练不仅有助于维持身体健康也有助于提高认知水平和促进学业进步。对于老年人来说, 多进行有氧运动能够调节脑内血流动力变化从而延缓认知衰老, 起到预防认知障碍相关疾病的作用。正常人群体中进行开展体育运动能够提高免疫力和认知灵活性, 从而提高公众的身体健康水平, 也是应对当代工作久坐不动对身体带来损失的有效策略。而在认知相关的疾病如老年痴呆症患者这一群体中, 虽然进行性遗忘的进程是不可逆的, 但药物治疗辅以体育训练也成为广泛应用的治疗手段。运动训练也常常被用于治疗肥胖症, 糖尿病, 孤独症障碍谱系等多种生理疾病。相比于无氧运动, 有氧运动的研究更为广泛, 对于认知发展的促进作用更显著。由于个体的昼夜节律存在差异, 有的人习惯早睡早起而有的人习惯晚

睡晚起，每个人的运动习惯也不一样。但根据以往研究经验来看，下午运动有助于糖尿病的治疗而早晨运动能够提高认知任务的表现。综上所述，我们在推广体育锻炼的同时应当考虑到多种影响因素的协调，从而使体育运动的效果达到最大。

参考文献

- [1] 李赞, 刘喜洋, 贺卓佳, 等. 1999-2019 年中国糖尿病疾病负担的调查研究[J]. 解放军医学杂志, 2024, 49(7): 776-782.
- [2] 蒋国金. 慢性病患者年轻化的原因及预防[J]. 青春期健康, 2024, 22(2): 43.
- [3] 王春艺, 李雨桐, 杨宇溪, 等. 从发生学探析中医“形神一体观”理论源流[J/OL]. 中医学报, 2024: 1-5. <http://kns.cnki.net/kcms/detail/41.1411.R.20240912.1901.089.html>, 2024-10-13.
- [4] Minas, A., Fernandes, A.C.C., Maciel Júnior, V.L., Adami, L., Intasqui, P. and Bertolla, R.P. (2022) Influence of Physical Activity on Male Fertility. *Andrologia*, **54**, e14433. <https://doi.org/10.1111/and.14433>
- [5] 马超, 石振国, 王先亮, 等. 体育活动与幸福感的互促互进: 基于大学生同伴关系与自我认知的中介效应[J]. 中国健康心理学杂志, 2022, 30(6): 893-899.
- [6] Feter, N., Ligeza, T.S., Bashir, N., Shanmugam, R.J., Montero Herrera, B., Aldabbagh, T., *et al.* (2024) Effects of Reducing Sedentary Behaviour by Increasing Physical Activity, on Cognitive Function, Brain Function and Structure across the Lifespan: A Systematic Review and Meta-Analysis. *British Journal of Sports Medicine*, **58**, 1295-1306. <https://doi.org/10.1136/bjsports-2024-108444>
- [7] Garrett, J., Chak, C., Bullock, T. and Giesbrecht, B. (2024) A Systematic Review and Bayesian Meta-Analysis Provide Evidence for an Effect of Acute Physical Activity on Cognition in Young Adults. *Communications Psychology*, **2**, Article No. 82. <https://doi.org/10.1038/s44271-024-00124-2>
- [8] Wang, J., Rang, Y. and Liu, C. (2024) Effects of Caloric Restriction and Intermittent Fasting and Their Combined Exercise on Cognitive Functioning: A Review. *Current Nutrition Reports*, **13**, 691-700. <https://doi.org/10.1007/s13668-024-00570-8>
- [9] Mehren, A., Diaz Luque, C., Brandes, M., Lam, A.P., Thiel, C.M., Philipsen, A., *et al.* (2019) Intensity-Dependent Effects of Acute Exercise on Executive Function. *Neural Plasticity*, **2019**, Article ID: 8608317. <https://doi.org/10.1155/2019/8608317>
- [10] Siranart, N., Tokavanich, N., Keawkanha, P., Sowalertrat, W., Pajareya, P., Joensahakij, S. and Chokesuwattanaskul, R. (2024) Evening Exercise Does Not Affect Sleep Health: A Systematic Review and Meta-Analysis. <https://doi.org/10.21203/rs.3.rs-4583679/v1>
- [11] Hasan, S., Shaw, S.M., Gelling, L.H., Kerr, C.J. and Meads, C.A. (2018) Exercise Modes and Their Association with Hypoglycemia Episodes in Adults with Type 1 Diabetes Mellitus: A Systematic Review. *BMJ Open Diabetes Research & Care*, **6**, e000578. <https://doi.org/10.1136/bmjdr-2018-000578>
- [12] Acevedo, E.O. (2012) *The Oxford Handbook of Exercise Psychology*. Oxford University Press.
- [13] Lövdén, M., Fratiglioni, L., Glymour, M.M., Lindenberger, U. and Tucker-Drob, E.M. (2020) Education and Cognitive Functioning across the Life Span. *Psychological Science in the Public Interest*, **21**, 6-41. <https://doi.org/10.1177/1529100620920576>
- [14] Baltes, P.B., Staudinger, U.M. and Lindenberger, U. (1999) Lifespan Psychology: Theory and Application to Intellectual Functioning. *Annual Review of Psychology*, **50**, 471-507. <https://doi.org/10.1146/annurev.psych.50.1.471>
- [15] Cattell, R.B. (1987) *Intelligence: Its Structure, Growth and Action*. Elsevier.
- [16] Green, M.F., Horan, W.P. and Lee, J. (2019) Nonsocial and Social Cognition in Schizophrenia: Current Evidence and Future Directions. *World Psychiatry*, **18**, 146-161. <https://doi.org/10.1002/wps.20624>
- [17] Cooper, S.B., Bandelow, S., Nute, M.L., Dring, K.J., Stannard, R.L., Morris, J.G., *et al.* (2016) Sprint-Based Exercise and Cognitive Function in Adolescents. *Preventive Medicine Reports*, **4**, 155-161. <https://doi.org/10.1016/j.pmedr.2016.06.004>
- [18] 李钟婷, 付全. 不同运动干预对大学生工作记忆和认知灵活性的影响[C]//中国体育科学学会. 第十三届全国体育科学大会论文摘要集——专题报告(运动心理分会). 2023: 452-454.
- [19] 童新梅, 钟名阳, 杨春晓, 等. 运动干预对改善认知衰弱老年人身体和认知功能的系统评价和 Meta 分析[J]. 全科护理, 2024, 22(3): 420-425.
- [20] 林家玥, 徐婷, 曹文婷, 等. 中医传统运动对轻度认知障碍老年人干预效果的范围综述[J]. 护士进修杂志, 2024, 39(13): 1368-1374.

- [21] 宋美, 王金成, 许顺江, 等. 太极运动对老年人认知功能、睡眠与情绪的影响[J]. 神经疾病与精神卫生, 2016, 16(1): 46-49.
- [22] Toots, A., Littbrand, H., Boström, G., Hörnsten, C., Holmberg, H., Lundin-Olsson, L., et al. (2017) Effects of Exercise on Cognitive Function in Older People with Dementia: A Randomized Controlled Trial. *Journal of Alzheimer's Disease*, **60**, 323-332. <https://doi.org/10.3233/jad-170014>
- [23] Gaertner, B., Buttery, A.K., Finger, J.D., Wolfsgruber, S., Wagner, M. and Busch, M.A. (2018) Physical Exercise and Cognitive Function across the Life Span: Results of a Nationwide Population-Based Study. *Journal of Science and Medicine in Sport*, **21**, 489-494. <https://doi.org/10.1016/j.jsams.2017.08.022>
- [24] Lambourne, K. and Tomporowski, P. (2010) The Effect of Exercise-Induced Arousal on Cognitive Task Performance: A Meta-Regression Analysis. *Brain Research*, **1341**, 12-24. <https://doi.org/10.1016/j.brainres.2010.03.091>
- [25] Yerkes, R.M. and Dodson, J.D. (1908) The Relation of Strength of Stimulus to Rapidity of Habit-Formation. *Journal of Comparative Neurology and Psychology*, **18**, 459-482. <https://doi.org/10.1002/cne.920180503>
- [26] Easterbrook, J.A. (1959) The Effect of Emotion on Cue Utilization and the Organization of Behavior. *Psychological Review*, **66**, 183-201. <https://doi.org/10.1037/h0047707>
- [27] Douchamps-Riboux, F., Heinz, J.K. and Douchamps, J. (1989) Arousal as a Tridimensional Variable: An Exploratory Study of Behavioural Changes in Rowers Following a Marathon Race. *International Journal of Sport Psychology*, **20**, 31-41.
- [28] Dietrich, A. (2006) Transient Hypofrontality as a Mechanism for the Psychological Effects of Exercise. *Psychiatry Research*, **145**, 79-83. <https://doi.org/10.1016/j.psychres.2005.07.033>
- [29] Dempster, F.N. (1992) The Rise and Fall of the Inhibitory Mechanism: Toward a Unified Theory of Cognitive Development and Aging. *Developmental Review*, **12**, 45-75. [https://doi.org/10.1016/0273-2297\(92\)90003-k](https://doi.org/10.1016/0273-2297(92)90003-k)
- [30] Whalley, L.J., Deary, I.J., Appleton, C.L. and Starr, J.M. (2004) Cognitive Reserve and the Neurobiology of Cognitive Aging. *Ageing Research Reviews*, **3**, 369-382. <https://doi.org/10.1016/j.arr.2004.05.001>
- [31] Arent, S.M. and Landers, D.M. (2003) Arousal, Anxiety, and Performance: A Reexamination of the Inverted-U Hypothesis. *Research Quarterly for Exercise and Sport*, **74**, 436-444. <https://doi.org/10.1080/02701367.2003.10609113>
- [32] Brisswalter, J., Durand, M., Delignieres, D. and Legros, P. (1995) Optimal and Non-Optimal Demand in a Dual Task of Pedalling and Simple Reaction Time: Effects on Energy Expenditure and Cognitive Performance. *Journal of Human Movement Studies*, **29**, 15-34.
- [33] McMorris, T. and Graydon, J. (2000) The Effect of Incremental Exercise on Cognitive Performance. *International Journal of Sport Psychology*, **31**, 66-81.
- [34] Hogervorst, E., Riedel, W., Jeukendrup, A. and Jolles, J. (1996) Cognitive Performance after Strenuous Physical Exercise. *Perceptual and Motor Skills*, **83**, 479-488. <https://doi.org/10.2466/pms.1996.83.2.479>
- [35] Gopinathan, P.M., Pichan, G. and Sharma, V.M. (1988) Role of Dehydration in Heat Stress-Induced Variations in Mental Performance. *Archives of Environmental Health: An International Journal*, **43**, 15-17. <https://doi.org/10.1080/00039896.1988.9934367>
- [36] Brisswalter, J., Collardeau, M. and Ren, A. (2002) Effects of Acute Physical Exercise Characteristics on Cognitive Performance. *Sports Medicine*, **32**, 555-566. <https://doi.org/10.2165/00007256-200232090-00002>
- [37] Jung, M., Ryu, S., Kang, M., Javadi, A. and Loprinzi, P.D. (2021) Evaluation of the Transient Hypofrontality Theory in the Context of Exercise: A Systematic Review with Meta-Analysis. *Quarterly Journal of Experimental Psychology*, **75**, 1193-1214. <https://doi.org/10.1177/17470218211048807>
- [38] Kramer, A.F., Hahn, S., Cohen, N.J., Banich, M.T., McAuley, E., Harrison, C.R., et al. (1999) Ageing, Fitness and Neurocognitive Function. *Nature*, **400**, 418-419. <https://doi.org/10.1038/22682>
- [39] Atkinson, H.H., Rosano, C., Simonsick, E.M., Williamson, J.D., Davis, C., Ambrosius, W.T., et al. (2007) Cognitive Function, Gait Speed Decline, and Comorbidities: The Health, Aging and Body Composition Study. *The Journals of Gerontology: Series A*, **62**, 844-850. <https://doi.org/10.1093/gerona/62.8.844>
- [40] Colcombe, S. and Kramer, A.F. (2003) Fitness Effects on the Cognitive Function of Older Adults: A Meta-Analytic Study. *Psychological Science*, **14**, 125-130. <https://doi.org/10.1111/1467-9280.t01-1-01430>
- [41] Giedd, J.N. (2008) The Teen Brain: Insights from Neuroimaging. *Journal of Adolescent Health*, **42**, 335-343. <https://doi.org/10.1016/j.jadohealth.2008.01.007>
- [42] Fratiglioni, L., Paillard-Borg, S. and Winblad, B. (2004) An Active and Socially Integrated Lifestyle in Late Life Might Protect against Dementia. *The Lancet Neurology*, **3**, 343-353. [https://doi.org/10.1016/s1474-4422\(04\)00767-7](https://doi.org/10.1016/s1474-4422(04)00767-7)
- [43] Dietz, P. (2013) The Influence of Sports on Cognitive Task Performance—A Critical Overview. In: *Cognitive Enhancement*, Springer, 67-72. https://doi.org/10.1007/978-94-007-6253-4_7

- [44] Paillard, T. (2015) Preventive Effects of Regular Physical Exercise against Cognitive Decline and the Risk of Dementia with Age Advancement. *Sports Medicine—Open*, 1, Article No. 20. <https://doi.org/10.1186/s40798-015-0016-x>
- [45] Bademli, K., Lok, N., Canbaz, M. and Lok, S. (2018) Effects of Physical Activity Program on Cognitive Function and Sleep Quality in Elderly with Mild Cognitive Impairment: A Randomized Controlled Trial. *Perspectives in Psychiatric Care*, 55, 401-408. <https://doi.org/10.1111/ppc.12324>
- [46] Erickson, K.I., Hillman, C.H. and Kramer, A.F. (2015) Physical Activity, Brain, and Cognition. *Current Opinion in Behavioral Sciences*, 4, 27-32. <https://doi.org/10.1016/j.cobeha.2015.01.005>
- [47] Colcombe, S.J., Erickson, K.I., Scalf, P.E., Kim, J.S., Prakash, R., McAuley, E., et al. (2006) Aerobic Exercise Training Increases Brain Volume in Aging Humans. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, 61, 1166-1170. <https://doi.org/10.1093/gerona/61.11.1166>
- [48] Erickson, K.I., Voss, M.W., Prakash, R.S., Basak, C., Szabo, A., Chaddock, L., et al. (2011) Exercise Training Increases Size of Hippocampus and Improves Memory. *Proceedings of the National Academy of Sciences*, 108, 3017-3022. <https://doi.org/10.1073/pnas.1015950108>
- [49] Barha, C.K. and Liu-Ambrose, T. (2020) Sex Differences in Exercise Efficacy: Is Midlife a Critical Window for Promoting Healthy Cognitive Aging? *The FASEB Journal*, 34, 11329-11336. <https://doi.org/10.1096/fj.202000857r>
- [50] Barha, C.K., Hsiung, G.R., Best, J.R., Davis, J.C., Eng, J.J., Jacova, C., et al. (2017) Sex Difference in Aerobic Exercise Efficacy to Improve Cognition in Older Adults with Vascular Cognitive Impairment: Secondary Analysis of a Randomized Controlled Trial. *Journal of Alzheimer's Disease*, 60, 1397-1410. <https://doi.org/10.3233/jad-170221>
- [51] Esteban-Cornejo, I., Tejero-Gonzalez, C.M., Sallis, J.F. and Veiga, O.L. (2015) Physical Activity and Cognition in Adolescents: A Systematic Review. *Journal of Science and Medicine in Sport*, 18, 534-539. <https://doi.org/10.1016/j.jsams.2014.07.007>
- [52] Hillman, C.H., Motl, R.W., Pontifex, M.B., Posthuma, D., Stubbe, J.H., Boomsma, D.I., et al. (2006) Physical Activity and Cognitive Function in a Cross-Section of Younger and Older Community-Dwelling Individuals. *Health Psychology*, 25, 678-687. <https://doi.org/10.1037/0278-6133.25.6.678>
- [53] Castelli, D.M., Hillman, C.H., Buck, S.M. and Erwin, H.E. (2007) Physical Fitness and Academic Achievement in Third- and Fifth-Grade Students. *Journal of Sport and Exercise Psychology*, 29, 239-252. <https://doi.org/10.1123/jsep.29.2.239>
- [54] Jakowec, M.W., Wang, Z., Holschneider, D., Beeler, J. and Petzinger, G.M. (2016) Engaging Cognitive Circuits to Promote Motor Recovery in Degenerative Disorders. Exercise as a Learning Modality. *Journal of Human Kinetics*, 52, 35-51. <https://doi.org/10.1515/hukin-2015-0192>
- [55] Ludyga, S., Gerber, M. and Kamijo, K. (2022) Exercise Types and Working Memory Components during Development. *Trends in Cognitive Sciences*, 26, 191-203. <https://doi.org/10.1016/j.tics.2021.12.004>
- [56] Iuliano, E., di Cagno, A., Aquino, G., Fiorilli, G., Mignogna, P., Calcagno, G., et al. (2015) Effects of Different Types of Physical Activity on the Cognitive Functions and Attention in Older People: A Randomized Controlled Study. *Experimental Gerontology*, 70, 105-110. <https://doi.org/10.1016/j.exger.2015.07.008>
- [57] Kelly, M.E., Loughrey, D., Lawlor, B.A., Robertson, I.H., Walsh, C. and Brennan, S. (2014) The Impact of Cognitive Training and Mental Stimulation on Cognitive and Everyday Functioning of Healthy Older Adults: A Systematic Review and Meta-Analysis. *Ageing Research Reviews*, 15, 28-43. <https://doi.org/10.1016/j.arr.2014.02.004>
- [58] Ludyga, S., Held, S., Rappelt, L., Donath, L. and Klatt, S. (2022) A Network Meta-Analysis Comparing the Effects of Exercise and Cognitive Training on Executive Function in Young and Middle-Aged Adults. *European Journal of Sport Science*, 23, 1415-1425. <https://doi.org/10.1080/17461391.2022.2099765>
- [59] Zhang, K., Jan, Y., Liu, Y., Zhao, T., Zhang, L., Liu, R., et al. (2022) Exercise Intensity and Brain Plasticity: What's the Difference of Brain Structural and Functional Plasticity Characteristics between Elite Aerobic and Anaerobic Athletes? *Frontiers in Human Neuroscience*, 16, Article ID: 757522. <https://doi.org/10.3389/fnhum.2022.757522>
- [60] Bernstein, E.E. and McNally, R.J. (2016) Acute Aerobic Exercise Helps Overcome Emotion Regulation Deficits. *Cognition and Emotion*, 31, 834-843. <https://doi.org/10.1080/02699931.2016.1168284>
- [61] Tomporowski, P.D. (2003) Effects of Acute Bouts of Exercise on Cognition. *Acta Psychologica*, 112, 297-324. [https://doi.org/10.1016/s0001-6918\(02\)00134-8](https://doi.org/10.1016/s0001-6918(02)00134-8)
- [62] Lojovich, J.M. (2010) The Relationship between Aerobic Exercise and Cognition: Is Movement Medicinal? *Journal of Head Trauma Rehabilitation*, 25, 184-192. <https://doi.org/10.1097/htr.0b013e3181dc78cd>
- [63] Masley, S., Roetzheim, R. and Gualtieri, T. (2009) Aerobic Exercise Enhances Cognitive Flexibility. *Journal of Clinical Psychology in Medical Settings*, 16, 186-193. <https://doi.org/10.1007/s10880-009-9159-6>
- [64] Nuechterlein, K.H., McEwen, S.C., Ventura, J., Subotnik, K.L., Turner, L.R., Boucher, M., et al. (2022) Aerobic Exercise Enhances Cognitive Training Effects in First-Episode Schizophrenia: Randomized Clinical Trial Demonstrates Cognitive and Functional Gains. *Psychological Medicine*, 53, 4751-4761. <https://doi.org/10.1017/s0033291722001696>

-
- [65] Stern, Y., MacKay-Brandt, A., Lee, S., McKinley, P., McIntyre, K., Razlighi, Q., *et al.* (2019) Effect of Aerobic Exercise on Cognition in Younger Adults: A Randomized Clinical Trial. *Neurology*, **92**, e905-e916. <https://doi.org/10.1212/wnl.0000000000007003>
- [66] Guadagni, V., Drogos, L.L., Tyndall, A.V., Davenport, M.H., Anderson, T.J., Eskes, G.A., *et al.* (2020) Aerobic Exercise Improves Cognition and Cerebrovascular Regulation in Older Adults. *Neurology*, **94**, e2245-e2257. <https://doi.org/10.1212/wnl.0000000000009478>
- [67] Savikj, M., Gabriel, B.M., Alm, P.S., Smith, J., Caidahl, K., Björnholm, M., *et al.* (2018) Afternoon Exercise Is More Efficacious than Morning Exercise at Improving Blood Glucose Levels in Individuals with Type 2 Diabetes: A Randomised Crossover Trial. *Diabetologia*, **62**, 233-237. <https://doi.org/10.1007/s00125-018-4767-z>
- [68] Sandoval, R., Pesquera, M., Kim, A., Dickerson, C., Dedick, J. and Brown, N. (2021) Noon Is the Best Time to Perform a Dual Task While Cognitive Performance May Be Boosted by Concurrent Performance of a Physical Task. *Gait & Posture*, **87**, 95-100. <https://doi.org/10.1016/j.gaitpost.2021.04.016>
- [69] Schumacher, L.M., Thomas, J.G., Raynor, H.A., Rhodes, R.E. and Bond, D.S. (2020) Consistent Morning Exercise May Be Beneficial for Individuals with Obesity. *Exercise and Sport Sciences Reviews*, **48**, 201-208. <https://doi.org/10.1249/jes.0000000000000226>
- [70] Wheeler, M.J., Green, D.J., Ellis, K.A., Cerin, E., Heinonen, I., Naylor, L.H., *et al.* (2019) Distinct Effects of Acute Exercise and Breaks in Sitting on Working Memory and Executive Function in Older Adults: A Three-Arm, Randomised Cross-Over Trial to Evaluate the Effects of Exercise with and without Breaks in Sitting on Cognition. *British Journal of Sports Medicine*, **54**, 776-781. <https://doi.org/10.1136/bjsports-2018-100168>