太极拳促进神经结构重塑到功能优化的神经机制

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摘要：太极拳（Tai Chi）作为一种兼具运动与心身调控的传统干预方式，其综合效益明显区别于单一的有氧或抗阻训练。在柔和动作、呼吸调控与专注注意的协同作用下，太极拳展现出促进身心健康的多重优势。研究表明，太极拳不仅能够改善平衡能力与运动表现，还能提升认知功能并调节情绪，其神经生物学机制涉及脑区结构重塑、神经电活动改变以及由此带来的功能优化。在神经结构层面，磁共振成像（MRI）显示长期练习太极拳的成年人在前额叶皮层、海马和小脑等关键区域表现出更高的灰质体积与皮层厚度。这些脑区在执行功能、学习记忆和运动协调中发挥核心作用，其结构性保留有助于延缓与年龄相关的神经退行性改变。此外，弥散张量成像（DTI）结果表明，太极拳干预可改善额叶与海马之间的白质纤维完整性，从而提升神经信号传导效率，这一改变与注意维持和记忆保持密切相关。在功能网络层面，随机对照试验结果显示，在亚临床抑郁人群中，12 周太极拳训练显著降低前顶叶网络的结构–功能耦合度，从而提升额叶与扣带回的局部效率，这一变化与抑郁症状的缓解高度相关。然而，单纯的结构性重塑不足以解释太极拳对行为表现的改善，电生理研究为结构与功能之间的转化提供了重要证据。基于脑电图（EEG）的实验显示，太极拳能够显著调节额叶θ、α与β波段活动，这些频段分别对应注意力、放松觉醒与执行控制的神经机制。经过 12 周 24 式太极拳训练的大学生在 Stroop 冲突任务中的反应时间显著缩短，准确率提升，并伴随额叶θ/α/β波功率增强，提示前额叶加工效率改善。事件相关电位（ERP）研究进一步支持了这一结论，长期练习太极拳的个体在负性情绪刺激下仍能保持较高的抑制功能，其前额叶 ERP 的 N2 与 P3 成分显著增强，反映了注意资源分配能力的提升。这些结果表明了太极拳运动可以通过提高神经网络加工效率，使个体以低能量消耗完成更高水平的认知任务。近年来，多项实证研究与 Meta 分析证据一致表明，太极拳作为一种兼具运动与心身调控的传统干预方式，在认知、情绪与运动功能等多个领域均展现出广泛而显著的效益。对于轻度认知障碍（MCI）人群，太极拳训练能够显著提升蒙特利尔认知评估（MoCA）和简易精神状态检查（MMSE）等核心指标，其中执行功能与注意控制的改善尤为突出。这提示太极拳不仅具有延缓认知衰退的潜力，还可能通过促进额叶相关网络的重塑，增强个体在复杂任务中的信息加工与调控能力。在健康青年群体的研究中，以“八法五步”

为代表的太极拳训练被证实能够系统性提升刷新、转换与抑制三大执行功能成分。这些改善不仅体现在心理学测评的表现提升上，更与前额叶功能网络效率的增强高度一致，为“运动－认知功能改善”之间的神经学机制提供了直接证据。在情绪调控方面，太极拳的作用同样得到了广泛关注。研究显示，太极拳能够通过优化额叶－扣带回网络的连接效率，显著缓解个体的抑郁与焦虑水平。与传统的单一运动干预相比，太极拳的优势在于其动作、呼吸与专注意念的整合训练模式，有助于增强前额叶对边缘系统的调控功能，使个体在面对负性刺激时保持更高的认知抑制与情绪控制能力。这种神经网络层面的优化与情绪状态的改善之间存在紧密联系，进一步佐证了太极拳作为一种身心整合性训练在心理健康促进中的价值。在运动功能层面，大量系统综述与随机对照试验结果表明，太极拳能够有效提升老年人的平衡能力并显著降低跌倒风险。这一效应的潜在机制可能涉及小脑－前庭系统的适应性调整，以及感觉－运动皮层整合功能的增强。通过对姿势控制、重心转移及下肢稳定性的训练，太极拳帮助老年人在复杂环境下保持更高水平的运动协调性和安全性，为跌倒预防和康复干预提供了低风险、高收益的方案。综上，太极拳通过“神经结构－电生理－功能”的多层级作用链条实现健康促进：灰质体积增加、白质完整性提升和网络拓扑优化奠定了解剖学基础；额叶 EEG 与 ERP 的改善体现了神经效率的提升；最终表现为认知增强、情绪调控改善与运动功能优化。不仅揭示了太极拳作为促进大脑发育和的神经生物学机制，也为其在临床康复与公共健康中的应用提供了理论支持。未来研究需结合多模态影像、电生理与生化指标，开展长期随访与剂量－反应研究，以进一步阐明太极拳在不同人群及健康状态下的神经机制效应。

关键词：太极拳；神经机制；认知功能

The neural mechanisms underlying Tai Chi–induced neural structural remodeling and functional optimization

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Abstract: Tai Chi, as a traditional mind－body intervention integrating physical movement with mental regulation, exhibits comprehensive benefits distinct from those of single-form aerobic or resistance training. Through the coordinated effects of gentle movements, controlled breathing, and focused attention, Tai Chi demonstrates multifaceted advantages for physical and psychological health. Research has shown that Tai Chi not only enhances balance and motor performance but also improves cognitive function and emotional regulation. Its neurobiological mechanisms involve structural remodeling of brain regions,

alterations in neural electrophysiological activity, and consequent functional optimization. At the neural structural level, magnetic resonance imaging (MRI) studies have revealed that adults who practice Tai Chi regularly exhibit greater gray matter volume and cortical thickness in key regions such as the prefrontal cortex, hippocampus, and cerebellum. These areas play central roles in executive function, learning and memory, and motor coordination, and their structural preservation contributes to delaying age-related neurodegenerative changes. In addition, diffusion tensor imaging (DTI) findings indicate that Tai Chi practice enhances white matter integrity between the frontal and hippocampal regions, thereby improving the efficiency of neural signal transmission — an effect closely associated with sustained attention and memory retention. At the functional network level, randomized controlled trials have shown that 12 weeks of Tai Chi training significantly reduced the structural–functional coupling of the frontoparietal network in individuals with subclinical depression, enhancing local efficiency in the prefrontal cortex and cingulate gyrus — changes highly correlated with the alleviation of depressive symptoms. However, structural remodeling alone cannot fully explain behavioral improvements; electrophysiological studies provide critical evidence for the transformation between structure and function. EEG-based experiments have shown that Tai Chi significantly modulates frontal theta, alpha, and beta band activity, corresponding respectively to neural mechanisms of attention, relaxed alertness, and executive control. After 12 weeks of 24-form Tai Chi training, college students demonstrated shorter reaction times and higher accuracy in the Stroop conflict task, accompanied by enhanced frontal theta/alpha/beta power, suggesting improved prefrontal processing efficiency. Event-related potential (ERP) studies further support these findings: long-term Tai Chi practitioners maintain stronger inhibitory control under negative emotional stimuli, as reflected by enhanced N2 and P3 components in frontal ERP, indicating improved allocation of attentional resources. These results suggest that Tai Chi enhances neural network processing efficiency, enabling individuals to perform higher-level cognitive tasks with lower energy expenditure. In recent years, multiple empirical studies and meta-analyses have consistently demonstrated that Tai Chi, as a mind–body integrative exercise, exerts broad and significant effects across cognitive, emotional, and motor domains. For individuals with mild cognitive impairment (MCI), Tai Chi training significantly improves key cognitive assessment scores, such as the Montreal Cognitive Assessment (MoCA) and the Mini-Mental State Examination (MMSE), with particularly notable improvements in executive function and attentional control. This indicates that Tai Chi not only has the potential to slow cognitive decline but may also

enhance information processing and regulatory capacity in complex tasks through remodeling of prefrontal-related networks. In studies of healthy young adults, Tai Chi forms such as the “Eight Methods and Five Steps” have been shown to systematically improve the three core components of executive function—updating, shifting, and inhibition. These improvements are not only reflected in behavioral performance but also align with increased efficiency of prefrontal functional networks, providing direct neural evidence for the “exercise–cognition improvement” relationship. In the domain of emotional regulation, Tai Chi’s effects have also received extensive attention. Research indicates that Tai Chi can significantly reduce depression and anxiety levels by enhancing the connectivity efficiency of the prefrontal–cingulate network. Compared with traditional single-mode physical exercises, the strength of Tai Chi lies in its integrated training model combining movement, breathing, and mindfulness, which strengthens prefrontal regulation over the limbic system. This allows individuals to maintain higher cognitive inhibition and emotional control when facing negative stimuli. The close link between neural network optimization and emotional improvement further underscores Tai Chi’s value as a holistic mind–body practice for mental health promotion. Regarding motor function, numerous systematic reviews and randomized controlled trials have confirmed that Tai Chi effectively improves balance and significantly reduces fall risk among older adults. The potential mechanism may involve adaptive modulation of the cerebellar–vestibular system and enhanced sensory–motor cortical integration. Through training in postural control, weight shifting, and lower-limb stability, Tai Chi helps older adults maintain better motor coordination and safety in complex environments, providing a low-risk, high-benefit approach for fall prevention and rehabilitation. In summary, Tai Chi promotes health through a multilayered “neural structure–electrophysiology–function” pathway: increased gray matter volume, improved white matter integrity, and optimized network topology establish the anatomical foundation; enhanced frontal EEG and ERP activities reflect greater neural efficiency; and these culminate in improved cognition, emotional regulation, and motor function. Together, these findings reveal the neurobiological mechanisms underlying Tai Chi’s role in promoting brain health and development, offering theoretical support for its application in clinical rehabilitation and public health. Future studies should integrate multimodal imaging, electrophysiological, and biochemical indicators, and employ long-term follow-up and dose–response designs to further elucidate Tai Chi’s neural effects across populations and health conditions.

Keywords: Tai Chi; neural mechanisms; cognitive function