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Commentary

Expertise, brain plasticity, and resting state

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Studies on training/expertise in the context of neuroplasticity have attracted continuous scientific attention. A recent study delved into the intriguing domain of how lifelong musicianship affects brain function and structure, particularly focusing on resting-state functional connectivity (Eierud *et al.*, 2023). Leveraging resting-state functional magnetic resonance imaging (fMRI), the investigation contrasts the neural connectivity patterns of professional musicians with those of non-musician controls. The core aim is to elucidate the nuanced ways in which sustained musical training might enhance brain and cognitive reserves. The findings reveal notable differences in the functional connectivity between the two groups, with musicians displaying an age-related increase in connectivity across several brain networks, including the default mode network, sensory-motor network, visual network, and auditory network. This contrasts with the control group, where a decline in connectivity with age was more typical. Such outcomes suggest that lifelong musical engagement might bolster cognitive resilience (Matziorinis *et al.*, 2023), potentially offering protective benefits against cognitive decline and enhancing neuroplasticity (Zhang *et al.*, 2023). On the other hand, the investigation contributes to a growing body of literature emphasizing the cognitive and neural benefits of engaging in highly skilled activities, such as musical training, throughout one's life (Fauvel *et al.*, 2014). It underscores music's potential role in sustaining cognitive function and promoting brain health into later life, aligning with theories of cognitive reserve that suggest engaging in complex cognitive activities can mitigate age-related cognitive decline (Park and Bischof, 2013) . Also, the study collectively emphasize the transformative potential of expertise in enhancing the brain's resilience, efficiency, and adaptability, underscoring the importance of sustained practice and engagement in expert activities for cognitive health and development.

Expertise Models and Brain Plasticity

The human brain undergoes dynamic changes in response to experience/training throughout the life span. In more advanced scenarios, extensive training normally leads to the mastery of a skill, namely expertise (Dong *et al.*, 2014), which is normally investigated by involving individuals who have developed a high level of skill in a particular domain (Ericsson and Lehmann, 1996). Expertise models focus on long-term, real-world skill acquisition processes, which normally consist of experts in a specific professional domain, such as radiologists (Wang *et al.*, 2021), chess players (Song *et al.*, 2020), musicians (Herholz and Zatorre, 2012), taxi drivers (Maguire *et al.*, 2000), meditators (Ganesan *et al.*, 2022), rock climbers (Di Paola *et al.*, 2013), gymnasts (Wang *et al.*, 2013), and acupuncturists (Dong *et al.*, 2014). Experts often demonstrate peak levels of performance, providing insights into the upper end of the continuum in brain plasticity. Studying such individuals can reveal how the brain adapts and reorganizes to support exceptional abilities. Traditional laboratory models typically involve controlled, short-term interventions, frequently utilizing longitudinal designs to explore cause–effect relationships. Expertise models study real-world skill acquisition over extended periods and emphasize the ecological validity and long-term nature of learning, which serve as a valuable surrogate for studying the human brain's adaptability and potential for change (Ericsson *et al.*, 2006; Day and Hunter, 2020). Compared with traditional laboratory models, they offer a nuanced and rich perspective that is often absent in laboratory settings, such as simple learning tasks, as well as relevance to real-world skills and experiences (Day *et al.*, 2020). Moreover, expertise development typically occurs over the years, providing a unique opportunity to study long-term brain plasticity (Draganski and May, 2008). Laboratory models often rely on short-term interventions that may not capture the full extent of neural changes (Hogan and Collins, 2012). Last but not least,

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experts are highly motivated and engaged in their practice, which is a significant factor in neural plasticity (Ericsson and Lehmann, 1996; Dong *et al.*, 2014). This contrasts with laboratory models, where participants may lack intrinsic motivation, potentially affecting the outcomes of plasticity studies. By focusing on complex, real-world skills and experiences, these models offer unique insights into the neural mechanisms underlying long-term skill acquisition, individual differences in brain plasticity, and even provides the impetus of practical applications for education and rehabilitation. For instance, techniques used by musicians to master complex pieces could be adapted to enhance motor learning in stroke patients (Grau-Sánchez *et al.*, 2020). However, it is important to note that laboratory models also have their strengths, such as the ability to control variables precisely and establish causality through experimental manipulation. We suggest that combining both approaches can offer a more robust and comprehensive understanding of human brain plasticity.

We propose evaluating four key factors to determine whether a group of individuals can serve as a potential expertise model. First, individuals in the group must possess a high level of proficiency and skill in a specific domain, significantly above average, typically acquired through extensive training and practice over an extended period. Second, clear and measurable outcomes or markers of expertise should be present and assessable. These may include performance metrics, neuroimaging results, or other physiological indicators. Third, the group should have a history of consistent and intensive training or practice in their domain of expertise. This ensures that any observed changes can be attributed to practice and not other variables. Last, the individuals in the group should be easily accessible to ensure a sufficient number of subjects for scientific research. When these factors are met, a group of individuals can serve as a potential expertise model, enabling researchers to study the relationship between extensive practice, skill acquisition, and brain plasticity. Musicianship provides a rich model for exploring expertise, involving intricate coordination of fine motor skills and auditory perception, as well as the integration of emotional, cognitive, and memory processes, supported by comprehensive engagement of the brain's systems (Herholz *et al.*, 2012). In sum, studying experts often requires a multidisciplinary approach, integrating insights from neuroscience, psychology, and the specific domain of expertise. This integrative approach can yield more holistic and innovative understandings of brain plasticity.

Expertise and Resting State fMRI

Resting-state fMRI (rs-fMRI) captures spontaneous brain activity, mainly related to mind wandering, and prospective and episodic autobiographic memory, when the participant is not engaged in any specific task (Biswal *et al.*, 1995). rs-fMRI allows for the exploration of brain activity independent of specific tasks, providing unique insights into experience-driven brain plasticity in humans (Guerra-Carrillo *et al.*, 2014). In particular, resting-state brain activity, is thought to be crucial for sustaining internal representations (Dong *et al.*, 2014; Albert *et al.*, 2009) related to encoding anticipated sensory inputs, planning future motor actions, and recalling past experiences (Dong *et al.*, 2022). Consequently, the advent of rs-fMRI has significantly broadened and deepened our understanding of expertise across various domains, and provided a unique perspective on the neural basis of expertise. This approach has proven particularly valuable in understanding the neural architecture underlying various forms of expertise, from visual and spatial skills to more abstract cognitive abilities.

Changes in brain activity levels in the sensory-motor system are thought to follow the Hebbian principle (Klintsova and Greenough, 1999), a fundamental mechanism of synaptic plasticity where an increase in synaptic efficacy results from the repeated and persistent stimulation of one cell by another (Hebb, 2005). In other words, this principle is encapsulated in the notion that neurons that regularly "fire together, wire together." Such increased synaptic connectivity can lead to enhanced local and global synchronization, as indicated by rs-fMRI signals, which reflect neuronal activity (Dong *et al.*, 2014). These temporal correlations are suggested to reflect the prior history of co-activation between brain regions (Guerra-Carrillo *et al.*, 2014). Accordingly, research utilizing rs-fMRI has revealed that musicians exhibit unique neural connectivity patterns, reflecting the profound impact of long-term musical training on the brain's functional networks (Eierud *et al.*, 2023; Fauvel *et al.*, 2014). These patterns of connectivity are not as readily observable in task-based fMRI studies, highlighting the distinct advantage of rs-fMRI in capturing the enduring neural adaptations attributed to expertise. The enhanced connectivity observed in musicians spans several critical brain networks, including the default mode network, sensory-motor network, visual network, and auditory network, highlighting the complex interplay between motor skills, motivation, perceptual abilities, and autobiographical memories (Sachs *et al.*, 2016). This shift has particularly illuminated our understanding of the intricate neural orchestration underlying musicianship, a domain that exemplifies the culmination of cognitive, motor, and auditory skills honed over extensive training periods.

Cross-Sectional and Longitudinal Experimental Design in Expertise Study

Our understanding of neuroplasticity in relation to expertise has significantly advanced through cross-sectional and longitudinal experimental designs. Each approach offers unique insights into how the brain adapts to various experiences, distinguished by their methodologies and the data they generate.

Cross-sectional studies provide a snapshot of brain plasticity at a single point in time, typically involving multiple subjects of varying ages or developmental stages. This design effectively maps the breadth of expertise effects across a population, delivering immediate insights into structural and functional brain differences between novices and experts without prolonged study durations (Gilaie-Dotan *et al.*, 2012). This approach can efficiently highlight correlations between brain anatomy and cognitive function across different demographic groups. However, it is important to note that the cross-sectional design is inherently limited in its ability to infer causal relationships or developmental progressions in expertise acquisition (Lindenberger, 2014). Observed differences between expertise groups may be confounded by cohort effects or other uncontrollable variables, such as innate predispositions (Elliott *et al.*, 2019) or selection biases (Seidler *et al.*, 2010), where individuals with specific cognitive or neural advantages are more likely to attain higher skill levels.

Longitudinal studies, in contrast, involve repeated observations of the same participants over time, providing a dynamic view of brain plasticity as it unfolds. This design is well-suited to examining how specific interventions or experiences, such as learning a new skill, affect brain structure and function over time (Erickson *et al.*, 2011). Longitudinal studies reveal causative links and the temporal sequence of changes, thereby enhancing our understanding of brain plasticity mechanisms by offering a robust framework for understanding the mechanisms of brain plasticity. For instance, a longitudinal study might track changes in the hippocampal volume of participants who undergo a memory training program over several months, thereby identifying the neural correlates of training-induced cognitive improvements (Thomas *et al.*, 2016). Despite their strengths, longitudinal designs are resource-intensive and pose logistical challenges, including participant attrition and the need for consistent measurement tools. They also require significant time commitments from both participants and researchers, which can limit their feasibility for certain types of expertise (Zatorre, 2005). Additionally, repeated testing may introduce practice effects that could confound results.

A judicious application of both designs is essential to capturing the multifaceted phenomenon of expert performance. Cross-sectional studies can facilitate initial exploration and hypothesis generation, while longitudinal studies offer validation and a deeper understanding of observed phenomena. For example, a cross-sectional study might reveal that musicians have larger corpus callosum areas than non-musicians, prompting a longitudinal study to investigate whether musical training in novices leads to similar structural changes over time. Moreover, these study designs enhance our understanding of lifespan trajectories related to skill development and their impact on executive functions, such as inhibitory control (Reilly *et al.*, 2022). By leveraging the strengths of both designs, researchers can obtain a comprehensive picture of brain plasticity, from broad patterns to detailed mechanisms, ultimately contributing to more effective interventions for neurodegenerative diseases, cognitive impairments, and brain injuries.

The Interplay of Nature and Nurture in the Development of Expertise

The development of expertise is intricately linked to the nature–nurture debate. Nature encompasses an individual's genetic predispositions and biological characteristics, while nurture involves the environmental factors that shape these inherent traits. Together, they provide a framework for understanding how expertise emerges across various domains, extending beyond musical talent (Zatorre, 2013) to include visual arts, sports, academia, and beyond (Plomin and Deary, 2015).

Genetic and biological factors significantly influence personality traits, motivation, cognitive styles, and sensory-motor abilities (Williams, 1988). These factors affect responses to training, persistence in challenges, and overall trajectories toward expertise. For instance, innate abilities, such as a genetic predisposition for pitch perception, can enhance capabilities in music (Zatorre, 2003). Conversely, nurture encompasses the environmental influences shaping development, including education, practice, mentorship, and social interactions. The quality and quantity of deliberate practice are vital for achieving high levels of expertise, often surpassing the role of innate talent (Plomin and Deary, 2015).

The nature–nurture debate illustrates the interplay between genetic predispositions and environmental enrichment. Nature provides a foundational blueprint, with recent genetic research revealing variations that influence physical and cognitive abilities (Plomin and Von Stumm, 2018). However, the realization of these genetic potentials is heavily shaped by environmental factors. Training and deliberate practice enhance brain connectivity and plasticity, facilitating skill acquisition and mastery (Ericsson, 2014). This interplay indicates that expertise is neither strictly determined by genetics nor solely shaped by environmental experiences, but arises from a complex integration of both (Johnson, 2007).

We propose a dynamic model of expertise development, where genetic factors establish potential abilities, and environmental factors regulate their realization. This gene–environment interaction highlights the complexity of expertise, suggesting that optimal environments can amplify genetic advantages and mitigate disadvantages (Baker *et al.*, 2012). Environmental stimuli activate genetic potentials and compensate for shortcomings, emphasizing the adaptability of human development. Ultimately, the journey to expertise results from a nuanced synergy between inherent capacities and life experiences. Acknowledging the dual contributions of nature and nurture enhances our understanding of expertise and informs personalized strategies for education and training across diverse fields.

Author contributions

Jia Wu (Conceptualization, Writing – original draft), Jianheng Wang (Validation), Janniko R. Georgiadis, (Validation, Writing – review & editing), Jimin Liang (Conceptualization), Guangming Shi (Validation), and Minghao Dong (Conceptualization, Funding acquisition, Supervision, Writing – review & editing)

Conflict of interest

None declared.

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