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能動者的認知控制：大腦輔助運動區在音樂活動中的重要性

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摘　要

2018 年有一篇腦造影研究指出，人們在聆聽音樂時某個腦區的活化，可以預測其未來學習樂器的成效，這個關鍵的腦區即為額葉上方中央的輔助運動區。本文根據腦科學文獻，釐清輔助運動區的多元功能，重新檢視音樂演奏、聆聽、創作，以及音樂治療之間的關係。音樂活動不僅可以強化運動功能，也能強化許多執行控制功能，包括注意力控制、抑制控制、工作記憶、序列處理，以及認知靈活性。在即興演出時，這些功能特別會跟自我意志緊密結合，讓音樂演出者成為能動者，以極具創意又妥善組織的音樂，來表達個人意圖。在這種音樂活動中，輔助運動區扮演著關鍵角色。

關鍵詞：認知科學、音樂與大腦、即興、意志、動作控制

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Cognitive Control in Agents: On the Importance of Supplementary Motor Area in the Brain for Music Activities

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Abstract

A brain imaging research published in 2018 showed that the activation of a brain region when people listen to music can predict their future performance in learning a musical instrument. This key brain area involved is the supplementary motor area located in the superior and medial aspects of the frontal lobe. Based on the literature of brain science, this article reviews the multiple functions of the supplementary motor area and clarifies the relationships between music performance, listening, creation, and music therapy. Music activities not only stimulate motor functions, but also enhance executive control functions, including attention control, inhibitory control, working memory, sequence processing, and cognitive flexibility. These functions are further integrated with volition in musical improvisation, which transforms the role of musical performers to creative "agents" when they can more fully express themselves through structured music. The supplementary motor area plays a key role in this music activity.

Keywords: cognitive science, music and the brain, improvisation, volition, motor control

* This article, written on the subject of cognitive science, uses APA format.

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Summary

In recent years, brain-imaging studies on music show the involvement of the supplementary motor area (SMA) in the dorsomedial frontal cortex. The article aims to elucidate the relationships between music and the following functions of pre-SMA, SMA-proper, and rostral cingulate zone (RCZ): sensorimotor processing, auditory imagery, sequence processing, cognitive control, and volition. In 2018, a brain-imaging study reported that pre-SMA activation in response to music can predict the future effectiveness of a person's learning of a musical instrument. This may reflect that pre-SMA plays a key role in organizing sounds and movements in a flexible way. Moreover, SMA contributes to the anticipatory imagery of music and the voluntary initiation of musical imagery.

Sequence processing often entails the establishment of nonadjacent dependencies to grasp the deep structure of a sequence. This explains why pre-SMA participates in comprehension and prediction of language and music. Chunking is often used when processing language and music messages, that is, connecting smaller pieces of information into bigger blocks or chunks. It is well-established that pre-SMA plays a critical role in chunking. In songs, the structure of antecedent followed by a consequent involves the sequence processing of melody and harmony, which may engage SMA. Another important aspect of sequence processing is the ability to encode the time points of events. Therefore,

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sequence processing is closely related to musical beats, meters, and rhythms. Past studies have shown that if patients have their SMA removed during neurosurgery, they cannot accurately replicate rhythms. In addition, if the metrical structure of a musical excerpt is clear, and the ratio of the length of the notes is a small integer ratio, significant activity in the striatum and SMA can be observed. The striatum and SMA may represent a metrical structure for encoding rhythms with a small integer ratio of time intervals.

Music activities can enhance the executive control functions of SMA, including attention control, inhibitory control, working memory, and cognitive flexibility. A brain-imaging study exploring the influence of music training on Stroop's task finds that compared with children who did not receive music training, those who did have more intense SMA/RCZ activity when performing Stroop task. When participating in music activities, one often employs attention control and inhibition control. For example, when listening to polyphonic music, attention control is necessary to concentrate on listening to a certain voice. When sight-reading music, special attention is given to key signatures and accidentals.

There is increasing evidence which demonstrates that the inferior frontal gyrus and pre-SMA support working memory and sequence processing. A brain-imaging study validates that there is more activity recorded in the inferior frontal gyrus and pre-SMA for musicians without absolute pitch when listening to note sequences compared to those with absolute pitch. Musicians without absolute pitch may have better ability to process the relationship between musical pitches, usually recruiting the inferior frontal gyrus and pre-SMA for tonal working memory processes. In addition to the inferior frontal gyrus, the dorsolateral prefrontal cortex also coordinates with pre-SMA to support cognitive control in cases of great uncertainty. Pre-SMA and RCZ are responsible for error detection and frequently work in tandem with the dorsolateral prefrontal cortex in situations that cannot be predicted. For example, when one listens to chromatic music, the increasing activity in pre-SMA and RCZ may reflect their role in the detection of out-of-key notes, whereas the increasing activity in the dorsolateral prefrontal cortex may reflect its role in providing and updating tonal context.

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During musical improvisation, the executive control functions of SMA are closely integrated with volition, allowing musicians to become “agents,” who can express their personal intentions with highly creative and well-organized music. Improvisation is full of uncertainty, which can prompt and stimulate the exercise of SMA/RCZ. A brain-imaging study of professional pianists points out that the functional connectivity between the dorsolateral prefrontal cortex and SMA is positively related to the time span of improvisation training. Moreover, college students majoring in classical piano also demonstrate more activity the inferior frontal gyrus and RCZ during improvisation. Similarly, when rappers improvises lyrics in performances, the functional connection between the medial prefrontal cortex and the inferior frontal gyrus as well as SMA/RCZ increased. Another study suggests that when musicians perform rhythm improvisation, activity in SMA/RCZ, dorsolateral prefrontal cortex, and insula is higher than that of non-musicians. In these creative and uncertain performative acts, one’s cognitive flexibility can be exercised. This view is consistent with a recent finding which prescribes improvisation training for those who want to improve cognitive control through learning music.

For patients with Tourette syndrome and Alzheimer’s disease, the roles of SMA/RCZ in volition, sensorimotor processing, and sequence processing during music activities can also be observed. Tourette syndrome is a movement disorder that involves repetitive movements (tics) that cannot be voluntarily controlled. Dr. Oliver Sacks, a neurologist and a forerunner in music therapy, points out that percussion instruments are suitable for Tourette syndrome patients because many of them have special musical talents, which are most manifest in music with strong rhythm and spontaneous improvisation. People with Tourette syndrome may be able give exorbitant improvisation when playing drums. Their performance is often accompanied by obvious impulse and drive, which are closely related to the physical action of tics. A brain-imaging study finds that SMA/RCZ activation, which may reflect their desire and impulse, increases in participants with Tourette syndrome before they have a tic. From this point of view, the music talents of people with Tourette syndrome may also be related to

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the generation of desires and intentions in SMA/RCZ. Dr. Sacks believes that Tourette syndrome allows us to rethink the question of will—when this creative beast (Tourette syndrome) is transformed into music, people with Tourette syndrome can successfully combine the original impulse with the controllable self, thus enjoying a convoluted double life.

Alzheimer's disease is the most common type of dementia. Because of the gradual accumulation of amyloid in the brain, the cognitive function in patients with Alzheimer's disease degrades, the ability to recognize people and things declines, and the memory fades. Prior studies suggest that the intervention of music can improve the emotional and cognitive functions of patients with Alzheimer's disease. Even with patients with memory impairment, they tend to be more capable of recalling the past events when they listen to music they learned from the age of 10 to 30. Therefore, Dr. Sacks points out that listening to familiar songs for patients with Alzheimer's disease is a way to retrieve the connection between emotion and memory or to evoke the memory via bodily movements or dance. Why do people with Alzheimer's disease tend to respond to familiar songs which they used to know years ago? The key may be hidden in the pre-SMA and RCZ of the brain. A brain imaging study demonstrates that pre-SMA and RCZ, which are responsive to familiar music, are atrophied relatively late in Alzheimer patients. Although there is also accumulation of amyloid proteins in the pre-SMA and RCZ, their function degenerates more slowly. This explains why people with Alzheimer's disease are more likely to retain musical memories. I suggest that this finding also reveals that patients with Alzheimer's disease may be able to hum along with familiar music, and even recall related physical movements. Perhaps with proper stimulation of SMA and RCZ, music can reactivate the impaired mechanism for memory and allow them to enjoy life anew.

Keywords: cognitive science, music and the brain, improvisation, volition, motor control

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