MUSICAL TRAINING-INDUCED NEUROPLASTICITY

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Introduction

The **brain** has a remarkable capacity to modify its structural and functional organization throughout the entire life. Its connectivity is only partially determined by genetics and it may be substantially modified through sensory experiences.

Music is a highly complex sensory stimulus that involves several cognitive processes and it is an ideal tool to investigate how sensory-motor systems interact with cognition.

At the early 20th century Ramon y Cajal already proposed that **musical training** (MT) could be a strong **multimodal stimulator** for **brain plasticity**.

Over the last decades, it has been amply demonstrated that MT has pronounced effects both on the structure and function of the human brain, leading to improved higher-order cognitive skills.

Professional musicians represent an ideal **model** to study human training-related plasticity since they typically started playing music early in life and continue throughout life.

Objectives

- To examine how the brain responds to music
- To study what changes are experienced by the brain after a musical training period
- To describe the effects of musical training to other cognitive skills
- To describe the mechanisms by which neuroplastic changes occurs
- To discuss the existence of sensitive periods for such neuroplastic changes

Methods

The methodology consisted on a bibliographic research using PubMed database. Key words used for database research were: 'musical training', 'brain plasticity', 'musicians brain', 'music and neuroplasticity', 'sensitive period', etc. Then, abstracts were read and those which contained relevant information for this review were selected.

Music processing

Both the perception and production of music involve both the auditory and the motor system. While playing a musical instrument, every tone is associated with a particular movement, also while listening to music motor areas associated with the production of those sounds are activated. Is therefore obvious that there exists a closely interaction between motor and auditory systems. It has been described a model for **auditory-motor transformations** in which planum temporale (PT) transforms complex sound into a motor representation in prefrontal, premotor and motor cortices. The arcuate fasciculus (AF) connects the PT with inferior frontal regions, such as Broca's area (BA), which is related to the activation of the **mirror-neuron system**. Mirror neurons are sensitive to multimodal inputs and are found in ventral premotor cortex (vPMC) and in BA region. Neural activity in those areas is tightly correlated suggesting a functional connection and supporting evidence for possible substrates mediating these auditory-motor interactions.

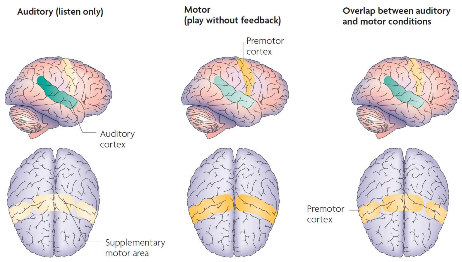


Figure 1. Coupling between auditory and premotor cortices. Comparison of brain activity while listening to a piece learned (auditory group), or playing it but without auditory feedback (motor group), it is observed a significant overlap both in auditory and premotor regions (right column). *From (1).*

Musicians vs. non-musicians

Structural differences

Musicians show:

- Larger anterior portion of **corpus callosum (ACC)**
- Higher volume and enhanced fiber integrity of **arcuate fasciculus**
- Higher average relative volume in the **cerebellum**
- Increased grey-matter volume of the **auditory cortex**
- Increased leftward assymetry of **planum temporale** (only in 'absolute pitch' possessors)
- Larger **somatosensory cortical representation of the left hand fingers**

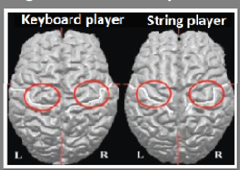


Figure 2. A prominent inverted **omega sign** (indicative of a larger hand finger cortical representation) is seen more on the left than the right hemisphere in the keyboard player and only on the right in the string player. *From (2).*

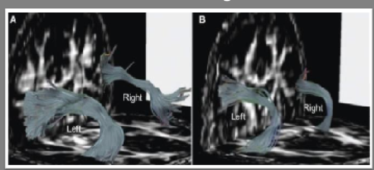


Figure 3. Arcuate fasciculus, an auditory-motor tract, enhanced by musical training. Musicians (A) differed from non-musicians (B) in having larger tract volume and higher fiber integrity of the right and left AF, reflecting enhanced auditory-motor integration in musicians. *From (2).*

Functional differences

Musicians show:

- Enlarged **auditory cortical representations** for specific tones and instrumental timbres
- **Earlier auditory MMN response** to subtle changes in pitch and temporal patterns
- Enhanced responses to temporal novelty in the anterior left **hippocampus**
- Earlier and larger auditory and audiovisual **brainstem** responses to complex sounds
- Enhanced activation of **sensorimotor integration areas**

Improved detection of rhythmic irregularities and pitch fine-grained manipulations

Figure 4. Cerebral activation pattern of a rhythm discrimination task. Both groups show an extended pattern of activation involving the superior temporal lobe as well as the parietal lobe (green circles). Musicians differ from non-musicians by having less activation of the primary auditory cortex but more activation of frontal regions bilaterally, particularly in the inferior frontal gyrus (blue circles). *From (2).*

Cross-modal interactions

Music is a **multimodal stimulator** that modulates the crosstalk between brain regions. Cortical areas thought to respond to one sensory modality, begin to process information from other sensory modalities in musicians. It is because musical training enhances **auditory-sensorimotor synchrony** and **cross-modal integration** in **multisensory brain areas**, which integrate information from auditory, visual and somatosensorial modalities, inducing **cross-modal plasticity**.

This reorganization may lead to an enhancement of non-musical skills, besides of improving musical expertise, which is commonly referred as a **transfer effect.** Skill transfer occurs when the novel and trained tasks recruit **overlapping processing networks** and engage shared brain areas. The close relationship between language and music processing mechanisms leads to an improvement in **linguistic skills** in musicians. Also, musical training improves **executive function**, benefiting many cognitive tasks, such as attention, memory and intelligence in general.

Sensitive periods for musical training

A sensitive period (SP) is an age window during which the neural systems are more susceptible to change when stimulated. First evidence for the existence of a SP for MT came from differences observed in ACC, since it was larger in those musicians who began MT before the age of 7 years. Several studies provide evidence that musicians who begin training early in childhood possess greater reorganization in auditory and motor brain regions. The acquisition of 'absolute pitch' is one of the main evidence for the existence of a SP, because it is highly dependent on the age at which MT has begun. Thus, early MT may lead to long-lasting positive effects on the adult brain, even though MT in adulthood could also induce neuroplasticity.

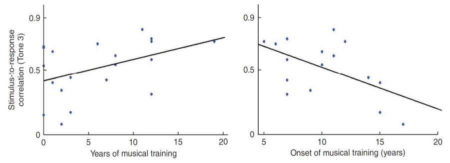
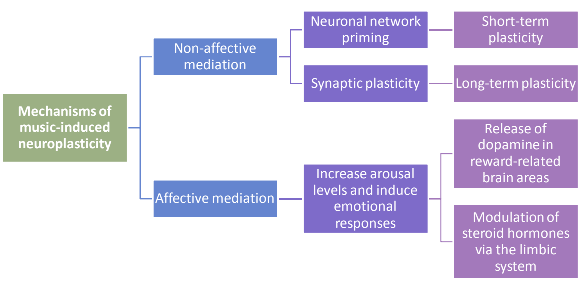


Figure 5. Stimulus-to-response correlates positively with musical expertise and correlates negatively with the age of onset of musical training. *Adapted from Wong et al., Nat Neurosci. 2007 Apr;10(4):420-2.*

Mechanisms of neuroplasticity



Conclusion

It has been accumulated considerable evidence of training-induced plasticity in the human brain. Brain differences found in musicians may reflect neuroanatomical adaptations in order to improve cognitive and motor functions, influencing musical aptitude. The sooner the training is initiated, the highest the changes observed, although neuroplasticity is also possible in the adult brain. Observable morphological alterations are the consequence of cellular and molecular changes that music induces through an affective or a non-affective mediation. Thanks to its properties, MT could be used in the education and health care fields.

Selected references

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