Interplay between music, emotion and cognitive function in health and disease

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Music is one of the oldest and most powerful means to afford communication and convey emotion. Here I review recent research on the inter-relations between music, emotion and cognitive function both in healthy individuals and neurological patients with brain damage. This topic is timely given the increasing amount of evidence on the cognitive enhancing effects triggered by music exposure. The focus of this paper will be on how the brain can be stimulated by music and how music, through the emotional reaction, can in turn modify brain function. There are clear associations between music listening, musical training and general cognitive performance. However, future studies are needed to enhance understanding of the precise nature of the cognitive and neural mechanisms by which music influences cognition.

Music processing stems from the initial coding of sound waves in the ears, followed by tonotopic sound processing in the cochlear system and subsequent processing by a network of subcortical structures including medial geniculate thalamic nuclei before reaching the primary auditory cortex. Music perception is a complex process that involves the coordination of different brain regions. There are interactions between auditory cortical systems coding sound pitch and pitch relations across time, pre-motor and motor areas for tempo and rhythm and pre-frontal cortex for tonality (reviewed in ref. 3). The specific feature relations between the different musical components such as pitch, tempo and tonality may determine the emotional component of the music; however, since music preference is highly idiosyncratic, the emotional power of a given musical piece will be greatly influenced by the individual’s musical tastes and preferences.

Emotional responses to music have been categorized according to valence and arousal dimensions. Pleasant music listening activates brain areas involved in emotion and reward such as the dorsal and orbital parts of the prefrontal cortex and trigger enhanced neuronal responding and increased connectivity in mesolimbic brain areas (i.e., nucleus accumbens and ventral tegmental area) that also respond to rewards. The fact that these emotional and reward-related regions are part of a dopaminergic system points out to the suggestion that pleasurable music listening may lead to dopamine neurotransmitter release — although to the best of my knowledge this has not been tested directly and awaits future confirmation.

The effects of music listening on arousal have been demonstrated by recording the heart rate and the galvanic skin responses. Overall, the picture emerging from these studies suggests that music selected by the individual may be a powerful way of enhancing autonomic arousal (i.e., increasing the strength of the galvanic skin response). Sad music, in contrast with happy music, can reduce the level of arousal (i.e., decreasing skin conductance and slowing the heart rate). To the extent that arousal can facilitate the speed of our reactions to relevant behavioral targets and improve the orienting of attention, music-induced alertness can be a powerful tool to modulate general cognitive performance. It is likely, however, that music effects on alertness are modulated by individual preferences for particular musical genres.

Music Influences Cognition in Health

This topic has not received much investigation to date, however, there is evidence that music listening can enhance several aspects of cognitive processing such as attention and creativity. A well-known effect of music listening on cognitive performance is the so-called ‘Mozart effect’. This is an improvement in spatial reasoning skills when participants are exposed to Mozart relative to other control conditions. Further research is consonant with the suggestion that the ‘Mozart effect’ may be due to the emotional reaction induced by the interaction between music exposure and the observer’s musical preferences. In this regard, it should be noted there is a clear link between emotional state and general cognitive functioning. Positive affect can lead to a more flexible and creative way of approaching problem solving, it can improve the scope of memory recall in word association tasks and it can enhance the scope of visual spatial attention processes as well as improve the selection of visual targets across time. From this follows that pleasant music listening, through general positive affect induction, ought to trigger a similar facilitation of cognitive processing.

There is evidence for correlations between musical training and other human skills such as math and verbal abilities such as memory for words and reading processes. Musical training also appears to be associated with a more rapid linguistic development in healthy child and with improved spelling skills in children with dyslexia. It is difficult, however, to establish a causal relationship between music training and general cognitive benefits.
role of musical training from these investigations alone since these associations between musical training and cognitive performance may arise due to other factors. For example, individuals that undergo musical training may possess general enhanced cognitive capacities to start with. Also musical training effects may lead to an improvement of general cognitive capacities related to attention and memory function which can in turn influence performance on a wide range of cognitive tasks. In fact, musical training may lead to brain plasticity changes in a wide range of brain networks related to skilled motor processing, auditory and verbal processing, memory and attention, which in turn may transfer to benefit performance in many cognitive domains. It is also possible that individuals that undergo musical training may also benefit from the emotional enhancing influence of the music experience and through this impact on emotion, general cognitive processing can be enhanced.

**Music-Based Restoration of Cognition in Disease**

Nowadays, music is being used to improve brain function after brain insult in a wide range of neurological patient populations. The benefits of music-based therapy on cognitive recovery expand emotion, attention, memory and motor processes. There is even data suggesting that joint musical and kinetic stimulation can help to improve the clinical condition in cases of vegetative states after brain injury. Motor training paired with exposure to auditory rhythms appears to be an effective mean of activating the motor system in stroke survivors and this can lead to improvements of motor function in the paretic arm. There is also interesting evidence that musical-based training (i.e., learning to play a musical instrument) can be a powerful way of improving recovery of motor skills after stroke. Auditory-motor feedback through music exposure can also lead to motor task improvements in the precision of arm and finger movements in patients with Parkinson disease.

In the memory and verbal domains, there is evidence that music exposure can influence verbal and autobiographical recall in patients with Alzheimer disease and dementia. There are also case reports of patients with aphasia that show improved speech when the patients sing familiar music lyrics relative to when the patients merely speak excerpts of familiar lyrics. Thus, the musical component related to ‘singing’ the lyrics influenced speech production in these patients. In line with this, there is evidence that music therapy of speech based on melodic intonation (i.e., the incorporation of musical components such as melody and rhythm in the speech produced by the patient) can be effective to rehabilitate speech in aphasic patients. Functional neuroimaging of the brain provided evidence of reactivation of Broca’s area and the left prefrontal cortex when patients repeated words with melodic intonation relative to production without melodic intonation.

Two recent studies demonstrated the power of music to enhance awareness in stroke patients. There is evidence that one hour of music listening a day over a period of two months can lead to a higher cognitive recovery in a general stroke population compared to patients groups on standard therapy care or other auditory-stimulation control conditions. Significant improvements though music listening can be observed in verbal memory and the control of attentional focusing. Moreover, music listening is also associated with significant mood improvements in the post-stroke stage. There is also striking evidence of pleasant music effects on the degree of awareness of chronic stroke patients that suffer from visual neglect. Visual neglect is a debilitating condition that follows brain lesions usually in the right hemisphere, where patients appear unaware of visual stimuli presented in the side of space contralateral to the brain lesion, despite having intact perceptual pathways. Interestingly, the visual neglect syndrome can be overcome by having patients to listen to their pleasant music listening. A recent study showed that awareness of neglect patients for stimuli in their impaired visual field can be markedly improved when neglect patients listen to pleasant music relative to silence or unpreferred music. This recovery induced by pleasant music correlated with enhanced functional activation in emotional regions of the orbitofrontal cortex and attentional brain regions in spared areas of the parietal cortex and early visual regions. These findings are consistent with the suggestion that music influences visual cognition through positive affect.

The specific neural mechanism of the music effect remains to be established. Musically induced arousal and positive mood are likely moderators of the influence of music in cognition. Music may lead to enhanced or optimal neurotransmitter release either by activating noradrenergic transmission which is critical for alertness and attention or by supporting dopaminergic activity in fronto-striatal networks that support working memory processing. Neurotransmitter release induced by music may boost the transmission of neural signals and the cognitive resources available for cognitive processing. It is early days however to describe precisely the nature of the neural mechanisms by which music influences cognition. Pleasant music listening and musical training may engage neuroplastic mechanisms both in the healthy and the injured brain. However, the nature of mechanisms supporting the interplay between music exposure, neuroplasticity and cognitive enhancement remains to be established.

Music is universally enjoyed by all cultures across the world and it is a rather rich source of sensory stimulation. The use of music for the treatment of cognitive disorders after brain insult is a benign, simple and non-expensive way of influencing brain function compared to other invasive treatments and pharmacological interventions. This resource should be exploited at its maximum level.

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