A Neuroscientific Perspective on Music Therapy

Stefan Koelsch

Department of Psychology, University of Sussex, Falmer, Brighton, United Kingdom

During the last years, a number of studies demonstrated that music listening (and even more so music production) activates a multitude of brain structures involved in cognitive, sensorimotor, and emotional processing. For example, music engages sensory processes, attention, memory-related processes, perception-action mediation ("mirror neuron system" activity), multisensory integration, activity changes in core areas of emotional processing, processing of musical syntax and musical meaning, and social cognition. It is likely that the engagement of these processes by music can have beneficial effects on the psychological and physiological health of individuals, although the mechanisms underlying such effects are currently not well understood. This article gives a brief overview of factors contributing to the effects of music-therapeutic work. Then, neuroscientific studies using music to investigate emotion, perception-action mediation ("mirror function"), and social cognition are reviewed, including illustrations of the relevance of these domains for music therapy.

Key words: **music therapy; neuroscience; emotion; mirror function; social cognition**

Introduction

Music therapy can have effects that improve the psychological and physiological health of individuals. In the conference volume originating from the "Neurosciences and Music II" conference, Thomas Hillecke and colleagues[1] presented a "heuristic working factor model for music therapy" (p. 271) that assumes five factors which contribute to the effects of music therapy. These modulating factors are attention, emotion, cognition, behavior, and communication. In the following, I will briefly describe, discuss, and elaborate on these factors.

(1) *Attention modulation:* Music can automatically capture attention[2,3] and thus distract attention from stimuli prone to evoke negative experiences (such as pain, anxiety, worry, sadness, etc.). This factor appears to account, at least partly, for anxiety-, and pain-reducing effects of music listening during medical procedures,[4,5] as well as for beneficial effects of music therapy in the treatment of tinnitus or attention-deficit disorders.[1]

(2) *Emotion modulation:* As will be reviewed in the second section of this article, studies using functional neuroimaging have shown that music can modulate activity of all major limbic- and paralimbic brain structures, that is, of structures crucially involved in the initiation, generation, maintenance, termination, and modulation of emotions. These findings have implications for music-therapeutic approaches for the treatment of affective disorders, such as depression, pathologic anxiety, and post-traumatic stress disorder (PTSD) because these disorders are partly related to dysfunction of limbic structures, such as the amygdala, and paralimbic structures, such as the orbitofrontal cortex. This factor is also closely linked to *peripheral physiological effects*: Emotions always have

Address for correspondence: Stefan Koelsch, Ph.D., Senior Research Fellow and Lecturer in Psychology, Department of Psychology, Pevensey Building, University of Sussex, Falmer, Brighton, BN1 9QH, UK. koelsch@cbs.mpg.de

The Neurosciences and Music III—Disorders and Plasticity: Ann. N.Y. Acad. Sci. 1169: 374–384 (2009).
doi: 10.1111/j.1749-6632.2009.04592.x

effects on the vegetative (or autonomic) nervous system, the hormonal (endocrine) system, and the immune system. Systematic knowledge of the effects that music listening and music making have on these systems is still lacking, but because of the power of music to evoke and modulate emotions, it is conceivable that music therapy can be used for the treatment of disorders related to dysfunctions and dysbalances within these systems (see also the article by Michael H. Thaut *et al.*[5a] in this volume).

(3) *Cognition modulation:* This factor includes memory processes related to music (such as encoding, storage, and decoding of musical information, and of events associated with musical experiences), as well as processes related to the analysis of musical syntax and musical meaning. This factor might contribute to the effects of music therapy on the facilitation of Alzheimer's patients' adaptation to residing in a long-term care facility.[6]

(4) *Behavior modulation:* This factors accounts for the evocation and conditioning of behavior (such as movement patterns involved in walking, speaking, grasping, etc.) with music. Detailed descriptions of the music-therapeutic effects of this factor are provided in the articles by Gottfried Schlaug *et al.*[6a] and Eckart Altenmüller *et al.*[6b] in this volume. Note that the distinction between cognition (factor 3) and action (factor 4) should be understood conceptually, rather than physiologically, or even functionally: Mounting evidence indicates that cognition and action considerably overlap in the sense that they often share a common neural code. For example, mirror neurons are active during both perception and action (see the Perception-Action Mediation section of this article for details), auditory working memory (WM) relies on sensorimotor codes that encode and maintain information,[7,8] syntactic processing of music involves brain structures also involved in speech production,[9,10] and the premotor cortex also serves a variety of cognitive tasks, such as WM, sequencing, and serial prediction. Thus, because modulation of behaviors and actions is likely to affect cognitive processes, cognitive processes can be modulated by the learning of different or new behavioral and action patterns. A similar relation presumably exists between actions and emotions.

(5) *Communication modulation:* Because music is a means of communication, particularly active music therapy (in which patients make music) can be used to train skills of (nonverbal) communication. Music therapy has been applied for the treatment of communication disorders, such as selective mutism,[11] and for the training of interpersonal competencies.[1] Notably, this factor is also related to *social cognition*: As will be described in detail in the Social Cognition section of this article, listening to music produced by other humans engages cognitive processes attempting to understand the intentions, desires, and perhaps even beliefs of those who produced the music. This effect could be used by music therapy for the treatment, for example, of individuals with autism or conduct disorders.

Another factor that contributes to the effects of music therapy is *perception modulation*: Musical training shapes the decoding of acoustic features, such as pitch height, and frequency modulations already at the level of the brain stem,[12] as well as on the level of the auditory cortex.[13] A study by Wong *et al.*[12] showed that adults with musical training have a more accurate tracking of the pitch contour of Chinese tones (that is, of pitch variations that distinguish words and inflections in Chinese). This suggests that musical training has effects on basic perceptual processes during language comprehension. This is relevant because children with language impairment often suffer not only from productive, but also from perceptual difficulties,[14,15] and it is therefore conceivable that music-therapeutic treatment of such perceptual difficulties can also help in the treatment of language impairment. An early treatment of language impairment is important to decrease the risk for the development of learning and reading disorders after entering school.

The numerous effects of music (as summarized in the different factors) on activity in a large variety of brain structures accounts for what has previously referred to as *cognitization*: At the conference "Neuroscience and Music III," Teppö Särkämö presented evidence for the notion that such "cognitization" induced by music listening could be responsible for the effects of music on the recovery of stroke patients (see the article by A. Forsblom *et al.*[15a] in this volume). In the following, I will review some effects that are usually evoked when listening to music, and which play important roles in the emergence of beneficial effects during music therapy. These effects originate from three domains: emotion, perception-action mediation, and social cognition.

Emotion

With regards to emotional processing, previous functional neuroimaging studies have shown that listening to music can have effects on the activity of all limbic and paralimbic structures (that is, of core structures of emotional processing) in both musicians and in so-called nonmusicians. Using PET, Anne Blood and colleagues[16] investigated brain responses related to the valence of musical stimuli. The stimuli varied in their degree of (permanent) dissonance, and were perceived as less or more unpleasant (stimuli with the highest degree of permanent dissonance were rated as the most unpleasant). Variations in pleasantness/unpleasantness affected activity in the posterior subcallosal cingulate cortex, as well as in a number of paralimbic structures: increasing unpleasantness correlated with activations of the (right) parahippocampal gyrus, while decreasing unpleasantness of the stimuli correlated with activations of frontopolar and orbitofrontal cortex.

No activations of central limbic structures, such as the amygdala, were observed in that study, presumably because the stimuli were presented under computerized control without musical expression. However, in another PET experiment, Blood and Zatorre[17] used naturalistic music to induce extremely pleasurable experiences during music listening, such as "chills" or "shivers down the spine." Participants were presented with a piece of their own favorite music (using normal CD recordings; as a control condition, participants listened to the favorite piece of another subject). Increasing chills intensity correlated with increases in regional cerebral blood flow (rCBF) in brain regions thought to be involved in reward and emotion, including the insula, orbitofrontal cortex, the ventral medial prefrontal cortex, and the ventral striatum. Also correlated with increasing chills intensity were decreases in rCBF in the amygdala and the hippocampus. Thus, activity changes were observed in central structures of the limbic system (amygdala and hippocampus). This was the first study showing modulation of amygdala activity with music, which was important for two reasons: First, it provided evidence for the assumption that music can induce "real" emotions (because the activity of core structures of emotion processing was modulated by music). Second, it strengthened the empirical basis for music-therapeutic approaches for the treatment of affective disorders, such as depression and pathologic anxiety, because these disorders are partly related to dysfunction of the amygdala.[18,19]

Activity changes in limbic and paralimbic structures in response to music were also shown with fMRI: A study by Koelsch *et al.*[20] investigated brain responses to joyful instrumental dance tunes (played by professional musicians), and to permanently dissonant counterparts of these dance tunes (for other studies using consonant and dissonant music, see Sammler *et al.*[21] and Ball *et al.*[22]). Unpleasant music elicited increases in blood-oxygen-level-dependent (BOLD) signals in the amygdala, the hippocampus, the parahippocampal gyrus, and the temporal poles (and decreases of BOLD signals were observed in these structures in response to the pleasant music). During the presentation of the pleasant music, increases of BOLD signals were observed in the ventral striatum (presumably nucleus accumbens [NAc]) and the insula (in addition to some cortical structures not belonging to limbic- or paralimbic circuits, which will not be further reported here). The results of this study thus showed that listening to joyful, pleasant music can lead to activity changes in the amygdala, the ventral striatum, and the hippocampus (that is, in core areas of the limbic system), even if individuals do not have intense "chill" experiences.

Activity changes in the amygdala in response to music were also reported in another recent fMRI study[22] which used original (mainly consonant) piano pieces as pleasant stimuli, and electronically manipulated, permanently dissonant versions of these stimuli as unpleasant stimuli. Interestingly, signal changes in the amygdala in response to both consonant and dissonant music were positive in a central aspect of the amygdala (also referred to as laterobasal group by the authors), and negative in a dorsal aspect of the amygdala (also referred to as centromedial group by the authors). This shows that different subregions of the amygdala show different response properties to auditory stimulation. No signal difference was found in the amygdala between the consonant and the dissonant music conditions (although participants clearly rated the consonant pieces as more pleasant), perhaps because the consonant pieces were not all happy dance tunes (as in the study by Koelsch *et al.*[20]), or perhaps due to the selection of subjects.[23] Eldar *et al.*[24] reported results of an fMRI study that showed activity changes within the amygdala and the hippocampus in response to the simultaneous presentation of (positive and negative) music and film clips (film clips were neutral scenes from commercials, positive music was also taken from commercials, and negative music mainly from soundtracks of horror movies). Interestingly, the combined conditions (positive music with neutral film, as well as negative music with neutral film) were rated as more positive or negative than when music was presented alone (note that film clips played without music were rated as neutral). Correspondingly, activity changes in the amygdala were considerably larger during the combined (film and music) presentation than for the presentation of film clips alone, or music alone (analogue response properties were observed in the areas of the ventrolateral frontal cortex for both positive and negative, and in the hippocampus for negative, music combined with the film clips).

Notably, the activity changes evoked by music alone (without film clips) were too weak to become statistically significant. The combination of emotional music with neutral film clips possibly stimulated fantasies about positive or negative things that might happen next, increasing the overall emotional activity. However, if merely neutral film clips have such a strong influence on limbic brain activity, one can imagine how much stronger this influence would be if the visual information had strong positive or negative emotional content. Similarly, an fMRI study reported by Baumgartner *et al.*[25] showed that emotional responses to negative (fearful and sad) pictures were considerably stronger when pictures were presented together with fearful or sad music. Correspondingly, brain activations were stronger during the combined presentation of pictures and music compared with the presentation of pictures alone: For example, activation of the amygdala was only observed in the combined condition, but not in the condition where only pictures were presented. The combined presentation also elicited stronger activation in the hippocampus, the parahippocampal gyrus, and the temporal poles. The network comprising amygdala, hippocampus, parahippocampal gyrus, and temporal poles has also been observed in other studies investigating emotions induced by music.[20,26] This suggests that these structures play a consistent role in the emotional processing of music, perhaps along with the pregenual cingulate cortex (which is, like the hippocampus, parahippocampal gyrus, and temporal pole, also monosynaptically connected with the amygdala).

A recent fMRI study also showed that the amygdala can even be activated by unexpected (music-syntactically irregular) chord functions,[27] indicating that activity of the amygdala can be modulated even by fairly abstract musical features. Notably, involvement of the amygdala in the emotional processing of music has been reported not only in functional neuroimaging studies, but also in a lesion study from Gosselin *et al.*,[28] in which patients with medial temporal lobe resections (including the amygdala) showed impaired recognition of fearful music. With regard to the generation of emotion, Griffiths *et al.*[29] reported that a patient with a lesion of the left amygdala and the left insula showed a selective loss of intensely pleasurable experiences, and of vegetative responses, during music listening (the patient had lost the capability to experience chills in response to musical pieces that had elicited chills in him before the brain lesion).

The activity changes in the (anterior) hippocampal formation evoked by listening to music are relevant for music therapy because patients with depression or PTSD show a volume reduction of the hippocampal formation (associated with a loss of hippocampal neurons, and blockage of neurogenesis in the hippocampus), and individuals with reduced tender, positive emotionality show reduced activity changes in the hippocampus in response to music.[23] It is plausible that music therapy can help to reanimate activity in the hippocampus, prevent the death of hippocampal neurons, and lift the blockage of hippocampal neurogenesis. However, there is a lack of methodologically sound studies on beneficial effects of music therapy on individuals suffering from depression (details have been reviewed elsewhere[30]), and studies fulfilling the standards of evidence-based medicine (controlled, randomized, blinded trials with experimental and control groups) are required to provide convincing evidence for beneficial effects of music therapy on depression. The same holds for the effects of music therapy on individuals with PTSD, or anxiety disorders.

We[31] have previously argued that the hippocampus (perhaps particularly the anterior hippocampal formation) plays an important role for the generation of tender, positive emotions and happiness, and, in our view, one of the great powers of music is to evoke hippocampal activity related to happiness.

Another limbic structure that a number of functional neuroimaging studies reported to be activated during listening to pleasant, or positive, music is the NAc, which is part of the ventral striatum: NAc activity was reported in the study from Blood and Zatorre[17] during intensely pleasurable episodes of music listening, in studies from Koelsch *et al.*[20] and Brown *et al.*[32] during listening to pleasant music, and in a study from Menon and Levitin[33] in response to normal musical pieces contrasted with unpleasant (scrambled) counterparts of those pieces.

The NAc is innervated by dopaminergic brain stem neurons (located mainly in the ventral tegmental area of the midbrain) and appears to play a role in invigorating, and perhaps even selecting and directing, behavior in response to incentive stimuli, as well as in motivating and rewarding such behavior.[34] Activity in the NAc correlates with experiences of pleasure,[35] for example, during the process of obtaining a goal, or when an unexpected reachable incentive is encountered, during sexual activity, ingestion of chocolate, or consumption of drugs. Moreover, activity in the NAc has been shown to correlate with self-reported positive emotion elicited by a reward cue.[36] It has previously been suggested that, in humans, NAc activity corresponds to experiences of "fun" (which should be differentiated from experiences of "happiness"[31]). Music therapy can make use of such experiences, for example to elevate the mood in individuals with mood disorders.

It is important to add that emotional processes always have effects on the vegetative nervous system, as well as on the hormonal system, which, in turn, modulates immune system activity. All these effects are potentially relevant for music-therapeutic applications because they open the possibility for using music to achieve beneficial effect in patients with autonomic, endocrine, or (auto)immune disorders. However, systematic research on such possibilities is lacking thus far.

Perception-Action Mediation

Musical activity, even simply listening to music, always automatically engages action-related processes (see the articles by Jessica A. Grahn[36a] and Joyce L. Chen[36b] and their colleagues in this volume). The neuroscientific investigation of perception-action mediation (or the "mirror neuron system") has two major benefits: First, it provides us with information about the neural correlates of action-related mechanisms as effects of auditory perception, which are an important aspect human cognition (for example, on account of its relevance for the understanding and learning of the production of both vocal and nonvocal sounds). Second, it might help to understand the neural correlates of a number of music-therapeutic effects (see also below, and the articles by Schlaug,[6a] Altenmüller,[6b] and Thaut[5a] and their co-workers in this volume), thus opening perspectives for the further development of these therapeutic applications.

In his *common coding approach* to perception and action, Wolfgang Prinz[37] described that the late stages of perception overlap with the early stages of action in the sense that they share a common representational format. Such a common format can, for example, be a common neuronal code. Similarly, Liberman and Mattingly[38] proposed in their *motor theory of speech perception* that, during speech perception, speech is decoded by the same processes that are involved in speech production. Several years later, Giacomo Rizzolatti and his colleagues found neurons located in the area F5 of the monkey premotor cortex, which were not only active when the monkey performed a movement, but also when the monkey simply observed that movement.[39] For example, when the monkey observed an experimenter grasping a piece of food with his hand, neural responses in neurons located in area F5 are evoked. These neurons cease to fire when the experimenter moves the food toward the monkey, and they fire again when the monkey grasps the food. That is, these neurons discharge during observation of the grip, cease to fire when the food is given to the monkey, and discharge again when the monkey grasps it (see also the article by Luciano Fadiga *et al.*[39a] in this volume).

In the following, I will review studies on mirror activity, or perception-action mediation, during listening to auditory information (see Haslinger *et al.*[40] for an fMRI study on pianists and nonmusicians observing piano playing finger/hand movements). To my knowledge, the first published study on music-related perception-action mediation (or "mirror function") was published in an MEG study by Jens Haueisen and Thomas Knösche in 2001.[41] In that study, both nonmusicians and pianists were presented with piano melodies, and compared to nonmusicians, musicians showed neuronal activity in premotor areas that was induced simply by listening to music (the task was to detect wrong notes, and those trials were excluded from the data evaluation). Interestingly, the center of neuronal activity for notes that would usually be played with the little finger was located more superiorly than activity for notes that would usually be played with the thumb, supporting the notion that the observed neural activity was actually (pre)motor-related activity.

One year later, Evelyne Kohler reported neurons (again in the area F5 of the monkey premotor cortex) that discharge not only when a monkey performs a hand action (such as tearing a piece of paper), but also when the monkey saw and simultaneously heard the sound of this tearing action.[42] Importantly, simply hearing the sound of the same action (performed out of the monkey's sight) was equally effective in evoking a neuronal response. Control sounds that were nonaction-related (such as white noise or monkey calls) did not evoke any excitatory response in that neuron.

As mentioned above, the study by Haueisen and Knösche[41] showed perception-action mediation in musicians (pianists). Music-related perception-action mediation in nonmusicians was shown by a study from Dan Callan and colleagues.[43] In that study, activation of premotor cortex was observed not only when subjects were singing covertly, but also when they were simply listening to singing. Interestingly, premotor activity in the same area was also observed during both covert speech production and listening to speech. This showed that mirror mechanisms cannot only be observed in musicians, but also in nonmusicians.

In a study on the effects of musical training on mirror mechanisms (or perception-action mediation) in nonmusicians,[44] nonmusicians were trained over the course of 5 days to play a piano melody with their right hand. After this training period, simply listening to the trained melody activated premotor activity. Listening to an untrained melody did not activate premotor cortex, suggesting that in the early stages of learning, perception-action mediation relies on fairly specific learned patterns. Bangert *et al.*[45] measured BOLD responses during both listening to melodies and producing simple melodies with the right hand on a keyboard (without auditory feedback) For pianists, they reported activation during both perception and production of melodies in the premotor cortex, the pars opercularis (corresponding to BA 44 in the inferior frontal gyrus), the planum temporale, and the supramarginal gyrus. Activations in the premotor cortex (and BA 44) during both perception and production of melodies were clearly left lateralized.

Interestingly, perception-action mediation appears to be modulated by emotional processes: In our fMRI experiment on music and emotion (in which pleasant and unpleasant music was presented to the participants),[20] the contrast of listening to pleasant versus listening to unpleasant music showed an increase in BOLD signal in premotor areas (as well as in the rolandic, or central, operculum) during listening to pleasant music. During listening to unpleasant music, a *decrease* in BOLD signal in these areas was found. That is, premotor activity during listening to music was clearly modulated by the emotional valence of the music, suggesting that perception-action mediation is modulated by emotional processes. We have previously suggested that the rolandic operculum contains, at least partly, the representation of the larynx, and therefore it seems that participants were quasi-automatically (that is, without being aware of this, and without intentional effort) "singing" subvocally along with the pleasant, but not with the unpleasant music. The activation of the rolandic operculum during singing is different from the one reported by Dan Callan in his study, perhaps because he used songs, whereas instrumental music was used in our study.[20] The notion that mirror mechanisms can be modulated by emotional factors is consistent with findings showing that auditory mirror mechanisms as elicited by emotional vocalizations can be modulated by emotional valence.[46]

This section has illustrated that music perception evokes a number of action-related processes (the details of the neural pathways underlying this phenomenon have been reviewed elsewhere[47]). Perception-action ("mirror") mechanisms are relevant for music therapy, because these mechanisms serve the learning of actions, the understanding of actions, and the prediction of actions of others (for details, see the article by Fadiga *et al.*[39a] in this volume). Moreover, several articles in this volume show how activation and training of perception-action mechanisms can be used in patients with neurologic disorders: For example, in this volume Gottfried Schlaug *et al.*[6a] describe how melodic intonation therapy can help patients with Broca's aphasia to regain language production, and Eckart Altenmüller and colleagues[6b] illustrate how music can be used for the recovery of fine and gross motor skills in stroke patients.

It should also be mentioned here that the premotor cortex (which is a critical structure for perception-action mediation) is also involved in a number of other cognitive functions. For example: premotor codes also serve WM. In experiments on WM for phonemes and for tones,[7,8] it was observed that the rehearsal of verbal information relies in part on premotor activity. Interestingly, it was also found that neural activity in practically identical areas also serves the rehearsal of tonal information (in nonmusicians; different results are presumably obtained with musicians). In both studies, activation was also observed in the planum temporale, presumably related to the transformation of auditory information into motor representations.[7,8,48]

Other cognitive functions in which the premotor cortex is involved comprise the analysis, recognition, and prediction of sequential auditory information,[49,50] and—perhaps related to this—the processing of musical structure (or musical syntax).[9,51] The automatic engagement of neural mechanisms mediating the processing of musical syntax has been reviewed elsewhere.[3]

Social Cognition

The last part of this article deals with a different topic, namely, social cognition and music. So far, I have listed a number of perceptual, cognitive, and affective processes that are automatically and effortlessly engaged as soon as we listen to music. However, there is another process that gets automatically engaged, of which many of us might not be aware, and that is the processes of mental state attribution ("mentalizing," or "adopting an intentional stance"), which is the attempt to figure out the intentions, desires, and beliefs of the individuals who actually created the music (also often referred to as establishing a "theory of mind" [TOM]). One of the questions of the following study was whether listening to music would automatically engage a TOM-network (typically comprising anterior frontomedian cortex, temporal poles, and the superior temporal sulcus).

In a recent study,[52] we wanted to make use of the listener‘s tendencies to believe that composers write *intentionally* and wish to *communicate* something through their music. We specifically wanted to test here whether attempts to figure out the composer‘s intentions activates the typical TOM network in the brain. Therefore, we conducted an fMRI study in which we presented nontonal music (from Arnold Schönberg and Anton Webern) to nonmusicians. The same pieces of music were played—counterbalanced across subjects—either with the cue that they were either written by a composer or with the cue that they were generated by a computer (a sound example can be found at http://www.stefan-koelsch.de/Social_Cognition).

We chose 12-tone music because for most nonmusicians (who are not very familiar with this kind of music) this music has a kind of random quality, thus making it plausible that the music was generated by a computer. Participants were told that this experiment was about emotion and music (that is, they were not informed about the real purpose of the study), and the task was to rate after each excerpt how pleasant or unpleasant they found each piece to be. Data of this behavioral task showed that valence ratings of participants did not differ between the two conditions (that is, whether participants were informed that the piece was from a composer or from a computer did not influence their perceived pleasantness of the piece). Interestingly, pieces were rated slightly above neutral, that is, the nontonal music was *not* rated as unpleasant, which is perhaps contrary to what one would expect, given that many people think that nontonal music is not pleasant music.

After the experiment, participants were presented with a postimaging questionnaire, in which they answered items, such as “imagining an agent” during the two conditions, “visual imagery,” “daydreaming,” and the like. However, the only item in which a difference between conditions was found was the item about how strongly participants felt that intentions were expressed by the music.

The fMRI data showed that when contrasting the brain activity of the Composer condition against the Computer condition there was an increase in precisely the neuroanatomic network dedicated to mental state attribution, namely, the anterior medial frontal cortex (aMFC), the left and right superior temporal sulcus, as well as left and right temporal poles. Notably, the brain activity in the aMFC correlated with the degree to which participants thought that an intention was expressed in the composed pieces of music. Thus, the data showed that listening to music automatically engages areas dedicated to mental state attribution (in the attempt to understand the composer’s intentions). Moreover, they showed that the meaning of music may be derived in part from the understanding that every note reflects an intentional act, which signals personal relevance to the artist representing a communication between the creator and the perceiver of the music. The TOM network can thus also be engaged by a fairly abstract, and not directly social, stimulus.

Future studies are needed to investigate how this effect of music listening can be utilized for music therapy. It is conceivable that this effect could be used for the treatment of, for example, persons with autism, or conduct disorder. We have recently commenced a study on the therapeutic effects of music making for individuals with impulsive aggression or moderate intermittent explosive disorder.[53] In summary, from the perspective of neuroscience and biology, there are numerous reasons to assume that music and music therapy has beneficial effects on the psychological and physiological health of individuals. However, so far only few studies have actually tested, and systematically investigated, such effects, and it is our challenge for the next decade to change this.

Conflicts of Interest

The author declares no conflicts of interest.

References

1. Hillecke, T., A. Nickel & H.V. Bolay. 2005. Scientific perspectives on music therapy. *Ann. N. Y. Acad. Sci.* **1060:** 271–282.
2. Sussman, E.S. 2007. A new view on the MMN and attention debate: the role of context in processing auditory events. *J. Psychophysiol.* **21:** 164–170.
3. Koelsch, S. 2009. Music-syntactic processing and auditory memory: similarities and differences between ERAN and MMN. *Psychophysiology* **46:** 179–190.
4. Nelson, A., W. Hartl, K.-W. Jauch, *et al*. 2008. The impact of music on hypermetabolism in critical illness. *Curr. Opin. Clin. Nutr. Metab. Care* **11:** 790–794.
5. Klassen, J.A., Y. Liang, L. Tjosvold, *et al*. 2008. Music for pain and anxiety in children undergoing medical procedures: a systematic review of randomized controlled trials. *Ambul. Pediatr.* **8:** 117–128.

5a. Thaut, M.H., J.C. Gardiner, D. Holmberg, *et al.* 2009. Neurologic music therapy improves executive function and psychosocial function in traumatic brain injury rehabilitation. *Ann. N. Y. Acad. Sci.* Neurosciences and Music III–Disorders and Plasticity. **1169:** 406–416.

6. Gerdner, L.A. & E.A. Swanson. 1993. Effects of individualized music on confused and agitated elderly patients. *Arch. Psychiatr. Nurs.* **7:** 284–291.

6a. Schlaug, G., S. Marchina & A. Norton. 2009. Evidence for plasticity in white matter tracts of chronic aphasic patients undergoing intense intonation-based speech therapy. *Ann. N. Y. Acad. Sci.* Neurosciences and Music III–Disorders and Plasticity. **1169:** 385–394.

6b. Altenmüller, E., J. Marco-Pallares, T.F. Münte & S. Schneider. 2009. Neural reorganization underlies improvement of stroke-induced motor dysfunctions by music-supported therapy. *Ann. N. Y. Acad. Sci.* Neurosciences and Music III–Disorders and Plasticity. **1169:** 395–405.

7. Hickok, G., B. Buchsbaum, C. Humphries & T. Muftuler. 2003. Auditory-motor interaction revealed by fMRI: speech, music, and working memory in area Spt. *J. Cogn. Neurosci.* **15:** 673–682.

8. Koelsch, S., K. Schulze, D. Sammler, *et al*. 2009. Functional architecture of verbal and tonal working memory: an FMRI study. *Hum. Brain Mapp.* **30:** 859–873.
9. Koelsch, S. 2005. Neural substrates of processing syntax and semantics in music. *Curr. Opin. Neurobiol.* **15:** 1–6.
10. Meyer, M. & L. Jancke. 2006. Involvement of left and right frontal operculum in speech and nonspeech perception and production. In *Broca's Region*. Y. Grodzinsky & K. Amunts, Eds.: 218–241. Oxford University Press. New York.
11. Findeisen, B. 2007. Music therapy in the treatment of young children with selective mutism. Workshop at the Conference on Music, Language and Movement, Herstmonceux Castle, East Sussex, UK, August 2007.
12. Wong, P.C., E. Skoe, N.M. Russo, *et al*. 2007. Musical experience shapes human brainstem encoding of linguistic pitch patterns. *Nat. Neurosci.* **10:** 420–422.
13. Koelsch, S., E. Schröger & M. Tervaniemi. 1999. Superior pre-attentive auditory processing in musicians. *Neuroreport* **10:** 1309–1313.
14. Gaab, N., J.D. Gabrieli, G.K. Deutsch, *et al*. 2007. Neural correlates of rapid auditory processing are disrupted in children with developmental dyslexia and ameliorated with training: an fMRI study. *Restor. Neurol. Neurosci.* **25:** 295–310.
15. Tallal, P. & N. Gaab. 2006. Dynamic auditory processing, musical experience and language development. *Trends Neurosci.* **29:** 382–390.

15a. Forsblom, A., S. Laitinen, T. Särkämö & M. Tervaniemi. 2009. Therapeutic role of music listening in stroke rehabilitation. *Ann. N. Y. Acad. Sci.* Neurosciences and Music III–Disorders and Plasticity. **1169:** 426–430.

16. Blood, A.J., R.J. Zatorre, P. Bermudez & A.C. Evans. 1999. Emotional responses to pleasant and unpleasant music correlate with activity in paralimbic brain regions. *Nat. Neurosci.* **2:** 382–387.
17. Blood, A. & R.J. Zatorre. 2001. Intensely pleasurable responses to music correlate with activity in brain regions implicated in reward and emotion. *Proc. Natl. Acad. Sci. USA* **98:** 11818–11823.
18. Stein, M.B., A.N. Simmons, J.S. Feinstein & M.P. Paulus. 2007. Increased amygdala and insula activation during emotion processing in anxiety-prone subjects. *Am. J. Psychiatry* **164:** 318–27.
19. Drevets, W.C., J.L. Price, M.E. Bardgett, *et al*. 2002. Glucose metabolism in the amygdala in depression: relationship to diagnostic subtype and plasma cortisol levels. *Pharmacol. Biochem. Behav.* **71:** 431–447.
20. Koelsch, S., T. Fritz, D.Y. von Cramon, *et al*. 2006. Investigating emotion with music: an fMRI study. *Hum. Brain Mapp.* **27:** 239–250.
21. Sammler, D., M. Grigutsch, T. Fritz & S. Koelsch. 2007. Music and emotion: electrophysiological correlates of the processing of pleasant and unpleasant music. *Psychophysiology* **44:** 293–304.
22. Ball, T., B. Rahm, S.B. Eickhoff, *et al*. 2007. Response properties of human amygdala subregions: evidence based on functional MRI combined with probabilistic anatomical maps. *PLoS ONE* **2:** e307.
23. Koelsch, S., A. Remppis, D. Sammler, *et al*. 2007. A cardiac signature of emotionality. *Eur. J. Neurosci.* **26:** 3328–3338.
24. Eldar, E., O. Ganor, R. Admon, *et al*. 2007. Feeling the real world: limbic response to music depends on related content. *Cereb. Cortex* **17:** 2828–2840.
25. Baumgartner, T., K. Lutz, C.F. Schmidt & L. Jäncke. 2006. The emotional power of music: how music enhances the feeling of affective pictures. *Brain Res.* **1075:** 151–164.
26. Fritz, T. & S. Koelsch. 2005. Initial response to pleasant and unpleasant music: an fMRI study. [Poster presented at the 11th Annual Meeting of the Organization for Human Brain Mapping (HBM), Toronto, Ontario, Canada, June 12–16, 2005.] *NeuroImage* **26**(Suppl.): T-AM 271.
27. Koelsch, S., T. Fritz & G. Schlaug. 2008. Amygdala activity can be modulated by unexpected chord functions during music listening. *Neuroreport* **19:** 1815–1819.
28. Gosselin, N., I. Peretz, M. Noulhiane, *et al*. 2005. Impaired recognition of scary music following unilateral temporal lobe excision. *Brain* **128:** 628–640.
29. Griffiths, T.D., J.D. Warren, J.L. Dean & D. Howard. 2004. "When the feeling's gone": a selective loss of musical emotion. *J. Neurol. Neurosurg. Psychiatry* **75:** 344–345.
30. Maratos, A.S., C. Gold, X. Wang & M.J. Crawford. 2008. Music therapy for depression. Cochrane Database of Systematic Reviews 2008, Issue 1. Art. No.: CD004517. doi: 10.1002/14651858.CD004517.pub2.
31. Koelsch, S., W.A. Siebel & T. Fritz. 2009. Functional neuroimaging of emotion with music. In *Music & Emotion*, 2nd ed. P. Juslin & J.A. Sloboda, Eds. Oxford University Press. New York. In Press.
32. Brown, S., M. Martinez & L.M. Parsons. 2004. Passive music listening spontaneously engages limbic and paralimbic systems. *Neuroreport* **15:** 2033–2037.
33. Menon, V. & D.J. Levitin. 2005. The rewards of music listening: response and physiological connectivity of the mesolimbic system. *NeuroImage* **28:** 175–184.
34. Nicola, S.M. 2007. The nucleus accumbens as part of a basal ganglia action selection circuit. *Psychopharmacology* **191:** 521–550.
35. Kilpatrick, M.R., M.B. Rooney, D.J. Michael & R.M. Wightman. 2000. Extracellular dopamine dynamics

in rat caudate-putamen during experimenter-delivered and intracranial self-stimulation. *Neuroscience* **96:** 697–706.

36. Knutson, B., C.M. Adams, G.W. Fong & D. Hommer. 2001. Anticipation of increasing monetary reward selectively recruits nucleus accumbens. *J. Neurosci.* **21:** RC159.

36a. Grahn, J.A. 2009. The role of the basal ganglia in beat perception: neuroimaging and neuropsychological investigations. *Ann. N. Y. Acad. Sci.* Neurosciences and Music III–Disorders and Plasticity. **1169:** 35–45.

36b. Chen, J.L., V.B. Penhune & R.J. Zatorre. 2009. The role of auditory and premotor cortex in sensorimotor transformations. *Ann. N. Y. Acad. Sci.* Neurosciences and Music III–Disorders and Plasticity. **1169:** 15–34.

37. Prinz, W. 1990. A common coding approach to perception and action. In *Relationships between Perception and Action.* O. Neumann & W. Prinz, Eds.: 167–201. Springer-Verlag. Berlin, Germany.

38. Liberman, A.M. & I.G. Mattingly. 1985. The motor theory of speech perception revised. *Cognition* **21:** 1–36.

39. Rizzolatti, G. & L. Craighero. 2004. The mirror-neuron system. *Annu. Rev. Neurosci.* **27:** 169–192.

39a. Fadiga, L., L. Craighero & A. D'Ausilio. 2009. Broca's area in language, action and music. *Ann. N. Y. Acad. Sci.* Neurosciences and Music III–Disorders and Plasticity. **1169:** 448–458.

40. Haslinger, B., P. Erhard, E. Altenmüller, *et al*. 2005. Transmodal sensorimotor networks during action observation in professional pianists. *J. Cogn. Neurosci.* **17:** 282–293.

41. Haueisen, J. & T.R. Knösche. 2001. Involuntary motor activity in pianists evoked by music perception. *J. Cogn. Neurosci.* **13:** 786–792.

42. Kohler, E., C. Keysers, M.A. Umiltà, *et al*. 2002. Hearing sounds, understanding actions: action representation in mirror neurons. *Science* **297:** 846–848.

43. Callan, D.E., V. Tsytsarev, T. Hanakawa, *et al*. 2006. Song and speech: brain regions involved with perception and covert production. *NeuroImage* **31:** 1327–1342.

44. Lahav, A., E. Saltzman & G. Schlaug. 2007. Action representation of sound: audiomotor recognition network while listening to newly acquired actions. *J. Neurosci.* **27:** 308–314.

45. Bangert, M., T. Peschel, G. Schlaug, *et al*. 2006. Shared networks for auditory and motor processing in professional pianists: evidence from fMRI conjunction. *NeuroImage* **30:** 917–926.

46. Warren, J.E., D.A. Sauter, F. Eisner, *et al*. 2006. Positive emotions preferentially engage an auditory-motor "mirror" system. *J. Neurosci.* **26:** 13067–13075.

47. Zatorre, R.J., J.L. Chen & V.B. Penhune. 2007. When the brain plays music: auditory-motor interactions in music perception and production. *Nat. Rev. Neurosci.* **8:** 547–558.

48. Warren, J.E., R.J. Wise & J.D. Warren. 2005. Sounds do-able: auditory-motor transformations and the posterior temporal plane. *Trends Neurosci.* **28:** 636–643.

49. Schubotz, R.I. & D.Y. von Cramon. 2002. Predicting perceptual events activates corresponding motor schemes in lateral premotor cortex: an fMRI study. *NeuroImage* **15:** 787–796.

50. Huettel, S., P. Mack & G. McCarthy. 2002. Perceiving patterns in random series: dynamic processing of sequence in prefrontal cortex. *Nat. Neurosci.* **5:** 485–490.

51. Koelsch, S., T. Fritz, K. Schulze, *et al*. 2005. Adults and children processing music: an fMRI study. *NeuroImage* **25:** 1068–1076.

52. Steinbeis, N. & S. Koelsch. 2009. Understanding the intentions behind man-made products elicits neural activity in areas dedicated to mental state attribution. *Cereb. Cortex* **19**(3): 619–623.

53. Koelsch, S., D. Sammler, S. Jentschke & W.A. Siebel. 2008. EEG correlates of moderate Intermittent Explosive Disorder. *Clin. Neurophysiol.* **119:** 151–162.