’MUSIC – OUR WORLD’

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CONTENT

WHAT IS MUSICAL DIVERSITY?

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In this short contribution, I will not give evidence of an irrefutable definition of musical diversity. Richard Letts, in a UNESCO study, provides a statement which could serve as a basis for discussion:

1. “Musical diversity exists if there is freedom of musical expression…,
2. “Musical diversity exists if there is a pluralism of musical structures (musical repertoires, musical forms, a wealth of traditions, hybrid forms etc.). …
3. “Musical diversity exists if there are different groups of people making music separately or together. …[1]

However, this is not a definition but a listing of pre-conditions to achieve musical diversity. Defining musical diversity seems to be a difficult task because Letts even does not undertake an attempt in his 400-page long report.

Marilena Vecco explores the topic of cultural heritage and provides a review of attempts at a definition and goes back more than two centuries. In France, at the end of the 18th century, terms such as *patrimoine* and *monument* were

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[1] Richard Letts, *The Protection and Promotion of Musical Diversity*, 2006, downloaded from the Internet <http://www.imc-cim.org/programmes/imc_diversity_report.pdf> (7/2015), p. 8.

first used.[2] At the end of the 20th century, the conviction strengthened that not only sites and monuments could be rated as worthy of being preserved, but

> “It must be founded on our ability to recognise its aesthetic, historic, scientific, social values etc., or rather, it is society, the community that must recognise these values, upon which its own cultural identity can be built.”[3]

This quote not only proposes a definition but also stresses that cultural/musical heritage has a twofold orientation. Besides physical, i.e. tangible objects, heritage can also be intangible, existing only in the heads of people.

Interviews

Instead of a definition and to find out, how musical diversity is seen, I will provide in the following lines some exemplary aspects drawn out of interviews conducted with students, music students, some professional musicians and community musicians (choristers and musicians in amateur wind bands). All interviews were conducted with partners in Luxembourg, a country with a significant cultural diversity, due to a native population small in number, but multilingual and to an impressive amount of immigration from various origins and during a long-lasting period that extends one century.

Musical diversity in the view of students[4]

Some students see musical diversity closely related to freedom of expression (cf. above), but they consider mainly modern mainstream music, e.g. Rock, Pop, Jazz, Rap. Two students provide a quite concise definition in referring to the text of the UNESCO: “Given that every human being is different, he

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[2] Cf. Marilena Vecco, “A definition of cultural heritage: From the tangible to the intangible” in: *Journal of Cultural Heritage* 11 (2010), p. 321.

[3] Ibid., p. 323.

[4] Interviews conducted by teacher students of the University of Luxembourg in fulfilment of their studies.

expresses himself in a different musical way. This is the origin of musical diversity.” Globalisation of music uses tools such as comprehensive streaming services which facilitate the access to music of every part of the world to a smartphone. One of the results is that different genres merge. However, an amalgamation to an almost unrecognisable condition would be most deplorable. On the other hand, Jazz is a good example; from a historical point of view, it gave rise to a new genre with both, African and North American influences.

A further aspect deals with the economic perspective: The most successful musicians strike it rich, while the other perish and with them their cultural local, regional or national rooting.

Musical diversity in the view of the members of wind band[5]

Band members in Luxembourg habitually include three generations. Therefore, it is hardly surprising that the interviewed musicians often answered unexpectedly such as “Musical diversity is today more essential than in the past.” On the other hand, their view of musical diversity is influenced by their band membership and within this narrow frame, manifold and diverse. While an older musician establishes a connection with the choice of the repertoire, highlighting that nowadays concert programmes include multiple genres in contrast to earlier, when the focus was on more classical pieces, a younger member emphasises the usefulness of YouTube as a treasure trove and a source for inspiration for the design of an appealing repertoire covering band music from all over the world.

Musical diversity in the view of the members of a male choir[6]

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[5] Cf. Damien Sagrillo, „Music Education and Musical Diversity Presented by the Example of Wind Bands in Luxembourg”, in: Bernhard Habla (Ed.), *Alta Musica 33*, Margraf, Weikersheim 2016, p. 360.

[6] Cf. Damien Sagrillo, „Aus dem Blickwinkel der Sänger: Die CMS, ‘wie sie leibt und lebt’. Ein Luxemburger Männerchor im Jahr 2016”, in: Gilbert Gliedner / Damien Sagrillo (Ed.), Festschrift *100 Joer Chorale Municipale*, p. 301-302.

The author of these lines is the conductor of a male choir in Luxembourg for more than 20 years. The mean age of the singers is about 70 years. Choir singing is a perishing tradition in Luxembourg. This cultural heritage, which flourished after the Second World War until the late sixties, will disappear within a short time. It is not surprising that the singers of the male choir consider musical heritage more traditionally and differently, namely from two angles, e.g. a general one and the second about their practicing of choral music. Their broad definition is unexpectedly rather precise: Musical heritage concerning musical practices and behaviours includes different music genres (one singer coins the term ‘tendencies’) and music of different times. (The statement about the music of different regions and countries, nevertheless, is missing!).

Musical diversity in the view of music students and professionals[7]

The interviews with music students and mostly young professionals uncover no new aspects, but associate musical diversity with (their own) music education. For one music student, musical diversity was experienced during his studies abroad, the music university being a melting pot of students of different origins. The fusion of genres enables the creation of new music styles. One should dare to experience with music. Most interviewees disapprove a one-sided musical training focussing too much on the classical perception of music and on old-fashioned educational practices. Some statements: Music is fundamentally human; where war and weapons separate cultures and religions, music connects them. Musical diversity is experienced rather unconsciously. For a composer, musical diversity keeps him/her open-minded for the new. Musicians should be willing to expand their horizons and to localise sources of inspiration. Nowadays, the Internet and global networking favour musical diversity.

A young percussion teacher provides an astounding multitude of aspects which go far beyond the mentioning of different genres and which, on the other

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[7] Interviews conducted by teacher students of the University of Luxembourg in fulfilment of their studies.

hand, seem most apparent: Music can be performed everywhere; music can be experienced and practiced; music and musical instruments have classical/Western or ethnic origins; music has different parameters, music has various functions, music can cause emotions; "everything is music".

A brass player highlights that globalisation specifies the example of the 16th-century Venetian polychoral model. While today, we have direct access to it, barely two decades ago, one had to buy a CD and again three decades earlier one has to go to Venice to hear it, in this case however in close contemplation.

Discussion

According to the interviews, musical diversity is a matter of opinion which depends on multiple aspects, such as age groups, social environment, e.g. the membership in community groups, and not so much the general education, but on the level of their musical education. While pupils in Hungary are taught their rich heritage of popular song culture and together with this, the handling of their voice, music pedagogues in several other European countries bemoan that neither pupils nor teachers are acquainted with their local, regional or national song heritage. However, with an early confrontation with the latter comes not only the training of vocal skills but also the awareness of musical diversity.

Musical diversity and musical heritage are both related. Where musical diversity exists, musical heritage can build on it. On the other hand, both seem to be antipodes to (musical) globalisation. Nevertheless, globalisation is being amplified by the digitisation of communication technologies, and digitisation can help to transfer the awareness of musical diversity and heritage. This said, one could distinguish two dimensions of musical diversity and cultural heritage. The latter is vertical in the transmission of music. Values, culture, music, folk songs and –tunes are transmitted from generation to generation. The former represents the horizontal aspect and has perhaps less to do with transmission, but more with mutual influence and interference on a local, regional, national, continental or global level. "Diversity is nothing more than a difference from the majority. In any culture there is a majority and many minorities."[8] This short definition of Michael D. Lee is about cultural diversity. Although somewhat simplistic and reductionist, it reveals the horizontal character of cultural/musical diversity. In that sense, it can also be considered, according to a David-versus-Goliath scenario, as a veiled criticism against global tendencies blighting musical diversity. The *International Music Council* (IMC) runs the *Many Musics Action Programme* (MMAP) which aims to preserve musical diversity against the dangers of globalisation. The IMC criticises that:

> "Standardisation and the demand for uniformity in the practice and consumption of musics in different social environments pose grave danger to the rich diversity of musical traditions of the world."[9]

However, the awareness of heritage should be strengthened because…

> "…at the same time strong forces – political and commercial – counteract the growth of cultural diversity, and thus contribute to imposing uniformity. IMC is well aware of the dangers of cultural uniformity: uniformity across cultures threatens local identity, just as absolute uniformity within a culture threatens individual identity."[10]

The omnipresence of the mass media could serve for educational purposes. Instead, in many cases, they become an obstacle to learning, a toy that keeps people from active music practice and degrades them to passivity. Music is consumed in the same way as a cola, a hamburger or an ice cream. The access to music is even easier. It is supported by ever-new initiatives and innovations

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[8] Michael D. Lee, *What is Cultural Diversity?*, at the Internet page <https://www.ethnoconnect.com/articles/1-what-is-cultural-diversity> (10/2017).

[9] International Music Council, *Many Musics. An IMC Action Programme Promoting Musical Diversity*, <at the Internet page http://www.imc-cim.org/mmap/pdf/mmap312frame-e.pdf> (11/2017), p. 4

[10] Ibid., p. 2.

from the business world. Alexandre Lunsquis comment on this imbalance turns out unusually drastic:

> “However, it is well known that with education come social awareness, cultural consciousness, and critical judgment, which are forbidden resources to populations controlled by all kinds of economic, social and political oppressive matrixes.”[11]

Although correct in substance, it is more likely to be based on a creeping process, without the active participation of the actors involved. It occurs with no ill intent but as an insidious development. Without further action and financial expenditure of the commercial mainstream music industry, musical diversity is crushed.

Globalisation is unstoppable, also in the musical and cultural domain. It appears that a critical discussion about globalisation is not the top priority of Western education curricula, but the emphasis lies on the more positive aspects which undoubtedly exist, but these approaches constitute only a unilateral view of a multi-faceted phenomenon. Globalisation should and could with the help of its powerful tools enhance and favour the preservation of musical and cultural diversity.

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[11] Alexandre Lunsqui, „Music and Globalization: Diversity, Banalization and Culturalization”, in*: Musique et globalisation (Filigrane Nr. 5),* Makis Solomos (Hrsg.), 1/2007, p. 12.

HOW DOES PLAYING A MUSICAL INSTRUMENT AFFECTS THE BRAIN?

Lilla Papp, Zsuzsa Buzás, Damien Francois Sagrillo

Summary

It is well known that musical training since infancy results in changes in brain connectivity, volume, and functioning, in particular in motor performance (basal ganglia, cerebellum, motor and premotor cortices), visuomotor transformation (the superior parietal cortex), inter-hemispheric callosal exchanges, auditory analysis and the notation reading (Visual Word Form Area, VWFA). In addition, neural plasticity seems to be very sensitive to the conditions during which multisensory learning occurs. For example, it was found that violinists have a greater cortical representation of the left compared to the right hand, trumpeters exhibit a stronger interaction between the auditory and somatosensory inputs relative to the lip area, and professional pianists show a greater activation in the supplementary motor area (SMA) of the cortex and the dorsolateral premotor cortex compared to controls.

These neuroplastic changes concern not only the gray matter but also the white fibers and their myelination.

Introduction

1. Neurobiology of the musical score reading

Music reading involves decoding a vertical dimension (pitch), single elements (notes), elements in combination (chords) and processing timbral features (Fullness, Brightness, Timbral Complexity and Activity), rythm and tonal features (pulse, key clarity) trough motor-, coordination-, memory- and recognition functions in the brain. Figure 1

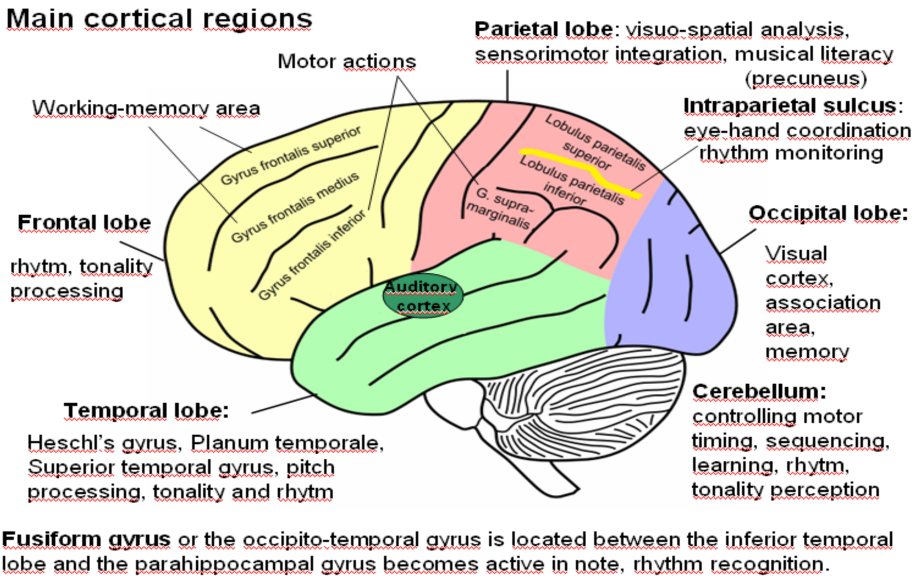


Figure1. Neural localization of musical score reading (Lieke Dekker, Mongelli 2014)

2. Musicians compared to nonmusicians brain

Musicians showed higher connectivity between **the precuneus and the insula**, a cortical region that links external and internal information processing (Lamm and Singer, 2010; Couto et al., 2013). **Precuneus** is a part of the superior parietal lobule forward of the occipital lobe (cuneus). It is involved with episodic memory, visuospatial processing, reflections upon self, and aspects of consciousness. The precuneus is located on the inside between the two cerebral hemisphere in the rear region between the somatosensory cortex and forward of the cuneus (which contains the visual cortex). It is above the posterior cingulate. Subdivisions: A, Sensorimotor anterior region: The mental imagery concerning the self has been located. B, Cognitive, associative central region: The areas with which it links are involved inexecutive functions, working memory and motor planning. C, Visual posterior region: This connects with visual areas in the cuneus and primary visual cortex, involved in episodic memory and visuospatial imagery. **The insula** is involved in the processing of emotional, sensorimotor, visceral, and interoceptive information (Craig, 2009). In particular, the insula is critically involved in evaluating the emotional salience of both external and interoceptive stimuli (Craig, 2009; Menon and Uddin, 2010; Straube and Miltner, 2011). Together with **the dorsal cingulate cortex**, the insula constitutes the core part of a salience network that integrates cognitive and emotional information to make appropriate responses, which is highly relevant to musical performance. **The operculum** (activated in opera singers during actual and imagined singing of an Italian aria and in subjects listening to pleasant music (Koelsch et al., 2006) and insula are continuous and interconnected structures and appear to work cooperatively. The operculum and insula have been suggested to be involved in music-related emotional processing (Gebauer et al., 2014), suggesting that this region is involved in the integration of multimodal sensory information and may form a connection between auditory and somatosensory areas (Sepulcre et al., 2012). Further, the operculum is connected to both the auditory and motor cortices and may therefore play a critical role in audiomotor integration. Therefore, a neural network connecting the precuneus with the operculum and insula may integrate mental imagery with interoceptive and emotional information to influence musical performance. **Heschl's Gyrus and the Planum Temporale** Functional connectivity between the precuneus and the HG/PT region was also higher in musicians compared to nonmusicians. The HG/PT region processes music-related pitch information (Hall and Plack, 2009; Puschmann et al., 2010; Angulo-Perkins et al., 2014). The connectivity between the precuneus and the HG/PT region may allow the integration of mental imagery with analysis of complex sounds; the higher connectivity between these regions in musicians may reflect the fact that musicians are trained to integrate imagery and sound information. Moreover, the HG/PT region has been demonstrated to have strong connections with the operculum (Sepulcre et al., 2012; Sepulcre, 2015), suggesting further integration of sounds with emotional, interoceptive, and sensorimotor information. **Music changes activity in core emotion networks in response to music,** including the superficial and laterobasal nuclei groups of the amygdala, the hippocampal formation, the right ventral striatum (including the nucleus accumbens) extending into the ventral pallidum, the head of the left caudate nucleus, the auditory cortex, the pre-supplementary motor area (SMA), the cingulate cortex and the orbitofrontal cortex. Functional connections between the superficial amygdala and the nucleus accumbens, as well as between the superficial amygdala and mediodorsal thalamus, are stronger during joy-evoking music than during fear-evoking music (Koelsch, S et al., 2013). This suggests that the **superficial amygdala, nucleus accumbens and mediodorsal thalamus** constitute a network that modulates approach–withdrawal behaviour in response to socio-affective cues such as music. Activity changes in the (right) **laterobasal amygdala** were observed in response to joyful music in some studies (Mueller, K. et al., 2011, Koelsch, S. et al., 2013). and in response to unpleasant or sad music in other studies (Koelsch, S. et al., 2006, Mitterschiffthaler, M. T. et al., 2007). Thus, activation of the laterobasal amygdala in these studies was probably due to coding of the positive or negative reward value of music. Notably, the laterobasal amygdala receives direct projections from the auditory cortex (in addition to projections from the auditory thalamus) (LeDoux, J. E. 2000), and by virtue of such **projections the auditory cortex modulates laterobasal amygdala activity** in response to complex sounds with emotional valence (Kumar, S. et al., 2012). **Nucleus accumbens:** Several studies have shown signal changes in the ventral striatum (including the nucleus accumbens) in response to pleasant music. Two studies showed activity in the nucleus accumbens during intense feelings of music-evoked pleasure and reward — socalled ‘chills’ or ‘musical frissons’ (Blood, A. J. et Zatorre E. J. 2001, Salimpoor V. N. et al., 2011), often involving experiences of shivers or goose-bumps. Importantly, the nucleus accumbens is not only active during frissons but is also activated as soon as music is experienced as pleasurable. During rewarding experiences of music, this network seems to be functionally connected with the auditory cortex: while listening to music, the functional connectivity between the nucleus accumbens and the auditory cortex (as well as between the nucleus accumbens and orbitofrontal cortex) predicts whether individuals will decide to buy a song. Together with evidence showing activity changes in the ventral tegmaental area (**VTA)** during musical frissons, this indicates that music-evoked pleasure is associated with activation of the mesolimbic dopaminergic reward pathway. Moreover, dopamine availability has been shown to increase in the dorsal striatum during the anticipation of a musical frisson and in the ventral striatum during the experience of the frisson. **Hippocampal activity** was associated in some studies with music-evoked tenderness, peacefulness, joy, music-evoked frissons or sadness. In other studies hippocampal activity changes were associated with both positive (joy) and negative (unpleasantness and fear) emotions. Emotion-related activity changes in the hippocampal formation are consistent with mounting evidence indicating that the hippocampal formation is substantially involved in emotion, owing to its role in the regulation of the hypothalamus–pituitary–adrenal (HPA) axis-mediated stress response (O'Mara, S. 2005). Functional connectivity between the hypothalamus and the hippocampal formation has been shown in response to music-evoked joy (Koelsch, S. & Skouras, S. 2013), which supports the notion that the hippocampus is involved in music-evoked positive emotions that have endocrine effects associated with a reduction of emotional stress, such as lower cortisol levels. Consistent with the observation that the hippocampus hosts oxytocin receptors and that it is involved in the regulation of oxytocin release into the bloodstream by the pituitary gland, suggesting that another emotional function of the hippocampus in humans, beyond stress regulation, is the formation and maintenance of social attachments. Attachment-related emotions (such as love) and emotions that can arise owing to the experience of social attachments (such as joy and happiness) have positive valence, and are hence probably associated with neural activity in the ventral striatum (which receives a large number of direct projections from the hippocampal formation. Signal changes in the hippocampus in response to strongly unpleasant or fear-evoking music are perhaps due to automatic inhibitory processes, which might prevent hippocampal damage in response to acoustic stressors. For example, the laterobasal amygdala is involved in the regulation of neural input into the hippocampal formation in the inhibition of fear responses to faces and in the downregulation of hippocampal neural activity in response to loud or unpleasant sounds. **Cingulate cortex:** receives inputs from the thalamus and the neocortex, and projects to the entorhinal cortex via the cingulum. It is an integral part of the limbic system, which is involved with emotion formation and processing, learning and memory. The combination of these three functions makes the cingulate gyrus highly influential in linking behavioral outcomes to motivation (e.g. a certain action induced a positive emotional response, which results in learning). **Orbitofrontal cortex (OFC)**: involved in the control of emotional behaviour and automatic (non-conscious) appraisal and is activated by breaches of expectancy. Figure 2.

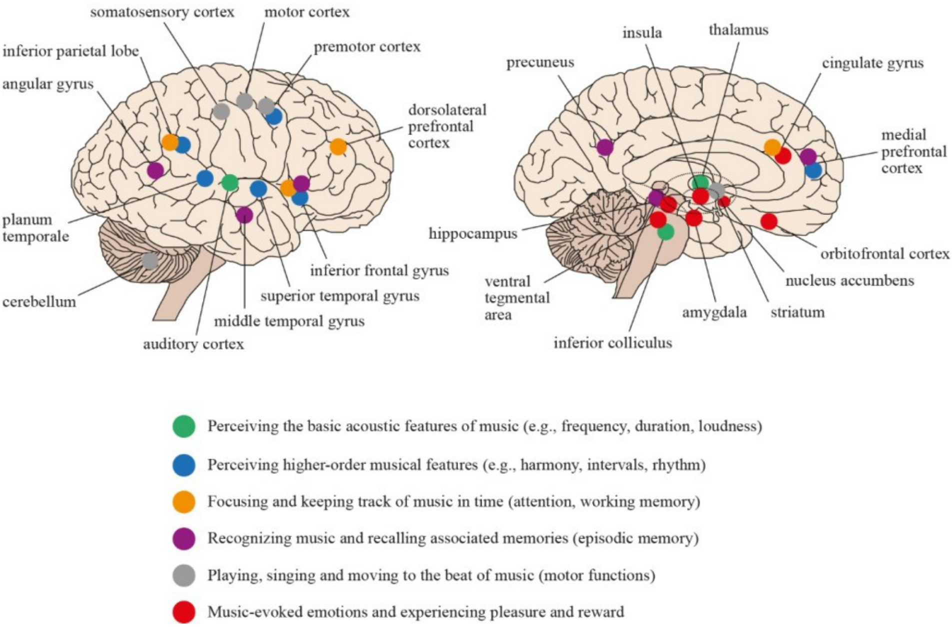


Figure 2. Key brain area associated with music processing J. O. Kelly 2016.

Methods: Neuroimaging techniques

Results:

It has been reported that **musicians have greater cortical thickness** in the superior temporal and dorsolateral frontal regions as a result of their training (Bermudez et al., 2009). Musicians who were trained at a younger age showed greater cortical thickness in the ventral premotor cortex (vPMC) compared with those who were trained at an older age.

Among the other brain areas that showed different cortical thickness, Heschl’s gyrus and bilateral intraparietal sulci strongly correlated with musical performances in relative pitch tasks (Foster and Zatorre, 2010). Musicians have been shown to have a significant increase in the volume of gray matter in the right fusiform, right posterior and middle cingulate, right and left superior temporal (Schneider et al., 2002; Bermudez and Zatorre, 2005), and right inferior orbitofrontal gyri as well as in the Broca’s area in the left inferior frontal gyrus (IFG) that is associated with music-related abilities (Sluming et al., 2002; Fauvel et al., 2014), premotor cortex (Gaser and Schlaug, 2003), cerebellum (Hutchinson et al., 2003), and hippocampus (Groussard et al., 2010). Figure 3.

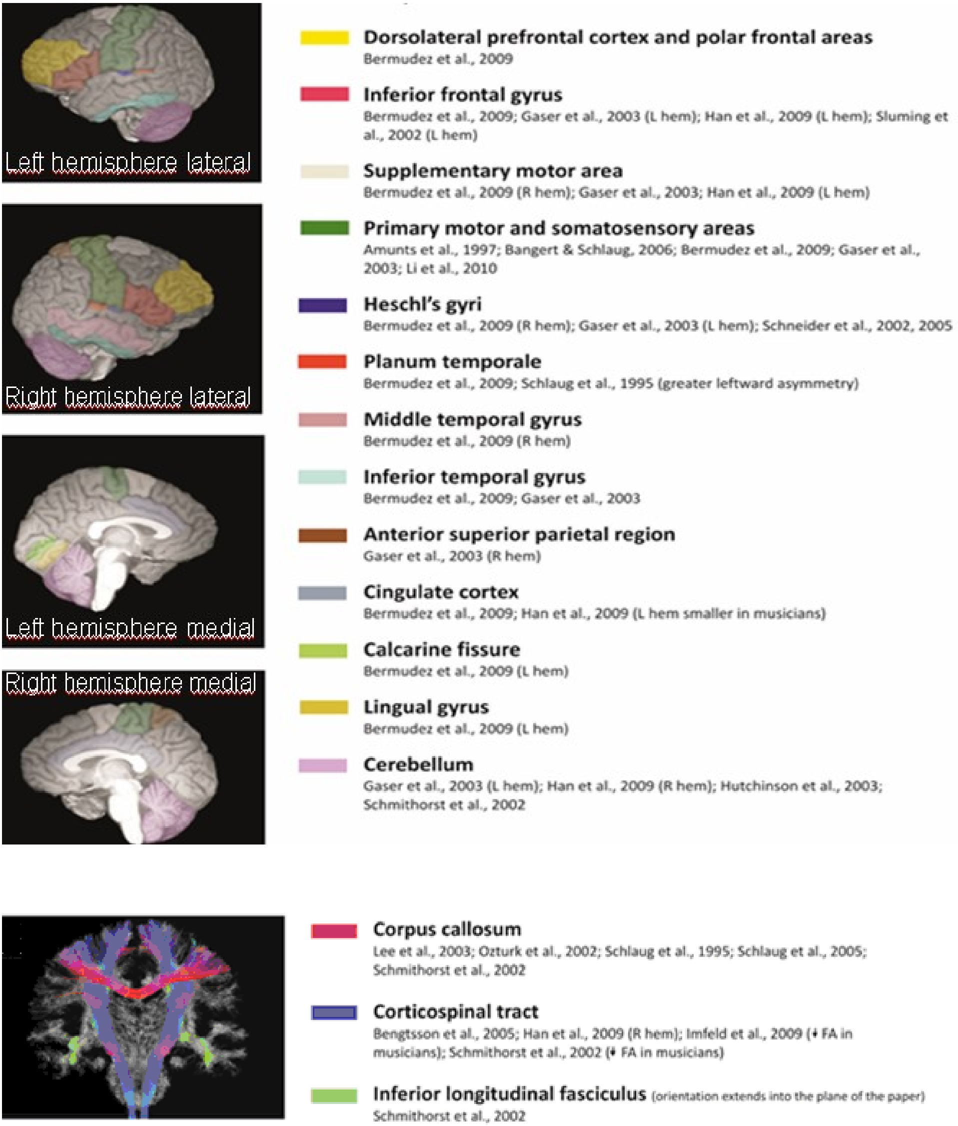
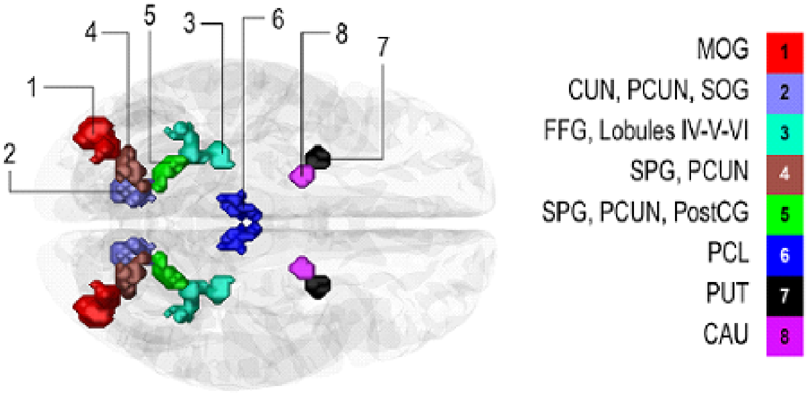


Figure 3. Stuctural brain differences musicians compared to non-musicians. Adapted from Merrett and Wilson 2011.

As for score reading, the prominent symmetry largely focalized in the visual areas in keyboardists compared to string players may arise from the need to acquire visual information (i.e., score reading) for both right and left hands, while simultaneously monitoring the synchronized movements of both hands. Piano playing from a score is a complex transcription task with high-visual-load activity that involves active, continuous, multiple-part reading of parallel sequences of events. In contrast, score reading for string players is for the most part a serial process, that is, the reading of one melody line at a time. Furthermore, the different symmetry in keyboard and string players reflects specific competences required for mastering each instrument: a midline, symmetrically bimanual instrument like the piano where exact motor timing for synchronization of both hands is required, as opposed to a mediolateral, asymmetrically bimanual instrument like the violin, in which arms, hands and fingers play a different role when performing, namely, the right hand controls the movement of the bow while the left hand is concerned with fingering the strings, and where the coordination between fingering and bowing is not synchronous. (Burunat et al., 2015). Fig. 4.



Occipital and parietal lobes (middle and superior occipital gyrus MOG, SOG), cuneus CUN, **precuneus PCUN**, **superior parietal gyrus (SPG)**, somatosensory cortex (postcentral gyrus PostCG), temporal areas (fusiform gyrus, FFG), cerebellum (lobules IV-V-VI), and a small subcortical area within the **dorsal striatum (caudate nucleus CAU** and **putamen PUT**). For the string players, **however, only one small cluster** in the middle and superior frontal gyrus MFG and SFG **displayed** more prominent over the keyboardists.

I. Burunat et al., 2015

Figure 4. Structural brain differences keyboard versus string players

Discussion:

Musicians have been shown to have a significant increase in the volume of gray matter in the right fusiform, right posterior and middle cingulate, right and left superior temporal, and right inferior orbitofrontal gyri as well as in the Broca's area in the left inferior frontal gyrus (IFG) that is associated with music-related abilities, premotor cortex, cerebellum, and hippocampus. Comparing with non-musicians, **pianists** showed:

more grey matter in regions associated with learning (hippocampus), with sensory and motor control and processing (putamen and thalamus), with emotional processing and the reward system (amygdala), as well as with auditory and language processing (left superior temporal cortex); but they also showed less grey matter in regions involved in sensory and motor control (postcentral gyrus), in processing of musical stimuli (right superior temporal cortex), and structures that have been related to music-score reading (supramarginal gyrus). Moreover, among the pianists it was observed that the right putamen correlated significantly with the age of start of music training (the later they started to play the piano, the greater was the volume of grey matter in the right putamen). The putamen is a deep subcortical structure which main function is motor control and automatization of movements. The volume of grey matter in this structure has been previously related with piano-playing skills: the higher the pianistic skills (the automaticity), the smaller the volume of grey matter. (Vaquero L. et al., 2016.) It was investigated how pianists are able to encode the association between the visual display of a sequence of key pressing in a silent movie and the corresponding sounds, thus enabling them to recognize which piece was being played. In this study, the temporal planum was found to be heavily involved in multimodal coding. The most experienced pianists exhibited a bilateral activation of the premotor cortex, the inferior frontal cortex, the parietal cortex and the supplementary motor area (SMA). It was found that the cortical representations for notes of different timbre (violin and trumpet) were enhanced in **violinists and trumpeters**, preferentially for the timbre of the instrument on which the musician was trained, and especially when both parts used to play the instruments were stimulated (cross-modal plasticity). For example, when the lips of trumpet players were stimulated touching the mouthpiece of their instrument at the same time as a trumpet tone, activation in the somatosensory cortex increased more than the sum of the somatosensory activation increases for lip touch and trumpet audio stimulation administered separately. (Proverbio et al., 2014).

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’MUSIC IS MEDICINE’
(Music from a biomedical perspective)

Lilla Papp, Zsuzsa Buzás, Damien Francois Sagrillo

Abstract: The notion is based on neurobiological evidences that music improves health and well-being through emotional regulation and cognitive processes. Clinicians are now turning to neuroscience to understand and measure therapeutic interventions from a biomedical perspective. The potential of music to modulate activity in the brain structures has important implications for the use of music in the treatment of psychiatric and neurological disorders. Starting from this point of view, we summerized briefly 1. the neuroanatomy of music processing (perceptual: auditary nerve, brainstem, cochlea, auditory thalamus, auditory cortex and emotional: the amygdala, nucleus accumbens, hypothalamus, hippocampus, insula, cingulate cortex and orbitofrontal cortex) 2. the neurochemistry of music (a, reward, motivation and pleasure: dopamine and opioids, b, stress and arousal: cortisol, c, immunity: serotonin), d, social affiliation: oxytocin, vasopressin) 3. and how music effects on the mental illnesses (neurobiology, physiology and music therapy)

Keywords: emotional regulation, music processing, neurochemistry of music, brain disorders

1. Neuroanatomy of music processing

a, Auditory perception

The auditory pathway begins in the cochlea and then travels via cranial nerve VIII (i.e., cochlear nerve) to the brainstem, where it passes through relay nuclei including the ventral and dorsal cochlear nuclei, superior olivary nuclei, inferior colliculi, and medial geniculate bodies, before terminating in the primary auditory cortex, which is located in the superior temporal gyrus. The cochlea, a small spiral liquid-filled chamber, lined with the basilar membrane and overlaid with sound-sensitive hair cells, manages this process. In response to vibrations, the cochlea hair cells oscillate within the enclosed fluid. This oscillating motion opens pores in the cell walls to release electrically charged metal atoms. The change in electric state produces neural signals that surge through the cochlear nerve fibres to the brain. These cells are tonotopically mapped (spatial organisation based on frequency); that is, different hair cells respond to different frequencies. Perception of sound depends on the decoding processes of the brain. To interpret the pitch of a sound instantly, each pitch-selective neuron in the primary auditory cortex directly connected to and dedicated exclusively for a segment of the basilar membrane to interpret the pitch of a sound instantly. Part of preliminary pitch and speech processing occurs in the brainstem. Electrochemical signals travel from the cochlea to the primary auditory cortex via the brainstem (inferior colliculus) and the primitive, subcortical brain is triggered immediately with stimulus detection. The cerebellum decodes the rhythm, and the thalamus assesses the signal, ready to trigger a subconscious survival reflex. The thalamus (medial geniculate bodies) then signals the amygdala to generate an emotional response. The prefrontal cortex manages high-level processes such as awareness and expectations, which are the result of associations that the hippocampus creates by correlating the received signal to retained memories. Overall, tinnitus is accompanied by structural and functional alterations in the prefrontal cortex, parietal cortex, cingulate cortex, amygdala, hippocampus, nucleus accumbens, insula, thalamus and cerebellum. Thus auditory cognition occurs when an audio signal changes its mechanical nature, progresses through mechanical and hydrodynamic states, and ends as an electrochemical signal at the auditory cortex. Auditory cortex is placed in both hemispheres, in the upper side of temporal lobes. It is divided into the Primary Auditory Cortex (A1), the Secondary Auditory Cortex (A2), and the Associative Auditory Cortex. Different hemispheres are specialized in different auditory processing: Left hemisphere: temporal structure, speech, fast changes, Right hemisphere: pitch, frequency, timbre, slow changes. As we can see in the image below, there is a tonotopic organization. That means that, as in the case of the Cochlea, information from different frequencies is placed separately also in A1. Due to cortical plasticity, it is possible to rearrange the organization after training. Figure 1,2

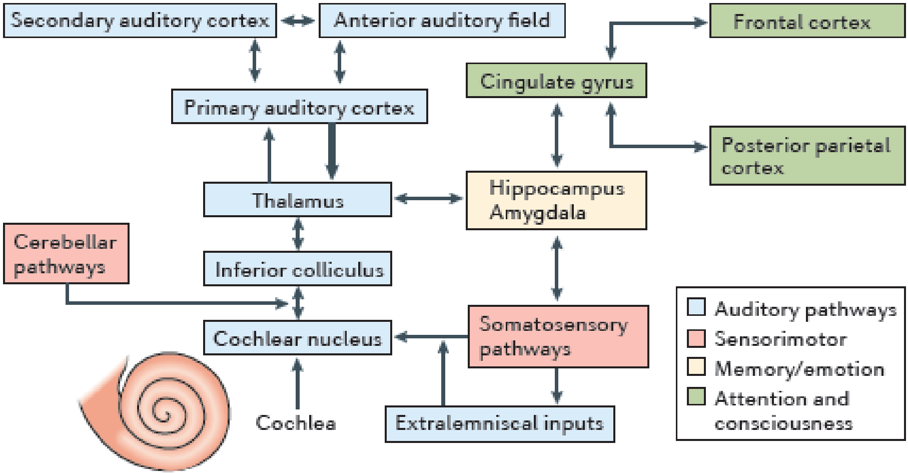
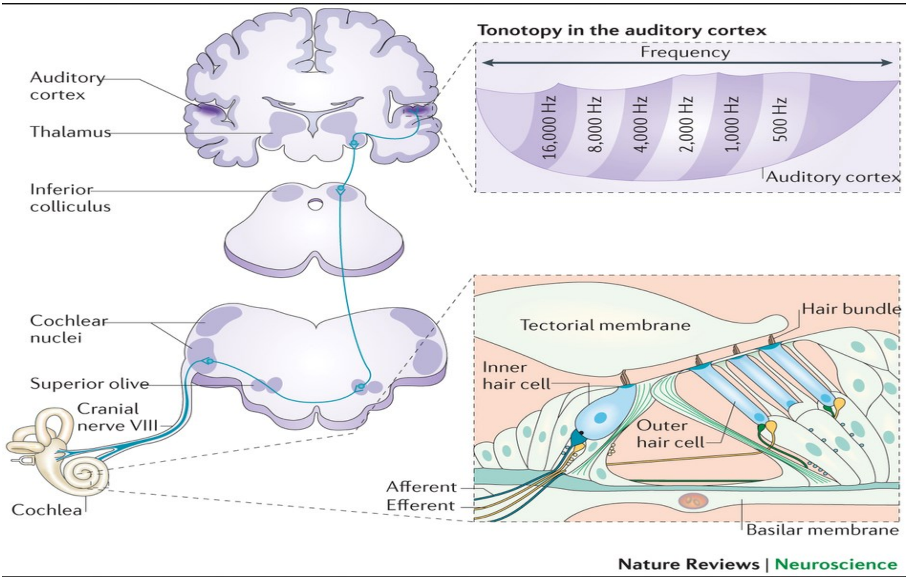


Figure1. The human auditory pathway. Adapted from Ana Belén



Elgoyhen et al., 2015

Figure 2. Simplified representation of auditory and nonauditory pathways in tinnitus. Adapted from Susan E Shore et al., 2016

a, Emotional responses

Several neuroanatomical structures and neurotransmitters have been implicated in specific aspects of emotion. *The prefrontal cortex (PFC)* plays key roles in emotional processing and emotion perception. The PFC is part of the frontal lobe and can be divided into different substructures: the medial PFC (mPFC) and the dorsolateral PFC (dlPFC). The mPFC appears to be particularly active during emotion processing. The mPFC is also part of a larger “default mode network,” which includes parts of the temporal, parietal, and cingulate cortices. The default mode network is important for introspective emotional processes. The dorsolateral part of the PFC (dlPFC) has been implicated in cognitive tasks related to emotional perception, such as moral decision-making. Note the distinction between the dlPFC (more active during cognitive- emotional perception in response to external stimuli) and the mPFC (more active during internal emotional processing). *The amygdala* (AMYG), a bilateral structure of the **limbic system** located within the temporal lobes, is strongly associated with fear and processing of unpleasant emotional stimuli. The amygdala is activated in response to unpleasant music listening and deactivated in response to pleasant music listening. Damage to the amygdala can also lead to impaired recognition of fearful music. Nearby structures are also related, further underlining the central role of the amygdala; in particular, connections to the subgenual and pregenual anterior cingulate cortex have been implicated in both regulation and intensification of negative emotional responses, although their exact roles are unclear. The superficial amygdala and the medial nucleus of the amygdala sensitive to socio-affective information and modulate approach–-withdrawal behaviour in response to such information. The laterobasal amygdala codes the positive or negative reward value of music and regulates neural input into the hippocampus (Hip). The central nuclei of the amygdala involved in autonomic, endocrine and behavioural responses, and expression of emotion. Hippocampus (Hip) regulates hypothalamus–pituitary–adrenal axis activity, is vulnerable to emotional stressors and generates attachment-related emotions. The nucleus accumbens (NAc) sensitive to rewards and motivates, initiates and invigorates behaviours to obtain and consume rewards. The projection from the nucleus accumbens (NAc) to the mediodorsal thalamus (modulates corticocortical communication, movement control and approach–withdrawal behaviour) is relayed via the ventral pallidum, which is the main efferent target of the NAc. This striatal–pallidal–thalamic pathway forms part of the limbic loop, which also includes the orbitofrontal cortex (OFC), involved in the control of emotional behaviour and automatic (non-conscious) appraisal and is activated by breaches of expectancy. The cingulate cortex receives inputs from the thalamus and the neocortex, and projects to the entorhinal cortex via the cingulum. It is an integral part of the limbic system, which is involved with emotion formation and processing, learning and memory. The combination of these three functions makes the cingulate gyrus highly influential in linking behavioral outcomes to motivation (e.g. a certain action induced a positive emotional response, which results in learning). This role makes the cingulate cortex highly important in disorders such as depression and schizophrenia. It also plays a role in executive function and respiratory control.The anterior cingulate cortex (ACC) the frontal part of the cingulate cortex; regulates autonomic functions (blood pressure and heart rate), as well as attention, reward anticipation, decision-making, empathy, and emotion. The rostral cingulate zone (RCZ) convergence zone for interoceptive awareness, internal selection of movements and autonomic regulation. The substantia nigra (SN) is a nucleus in the midbrain that is considered part of the basal ganglia and plays a role in eye movement, motor planning, reward-seeking, learning and addiction. It made up of two anatomically and functionally distinct portions: the substantia nigra pars compacta and the substantia nigra pars reticulata. The GABAergic neurons in the pars reticulata convey the final processed signals of the basal ganglia to the thalamus and superior colliculus. In addition, the pars reticulata also inhibits dopaminergic activity in the pars compacta via axon collaterals, although the functional organization of these connections remains unclear. The auditory cortex computational hub in an affective–attentional network with limbic, paralimbic and neocortical connections. Figure 3.

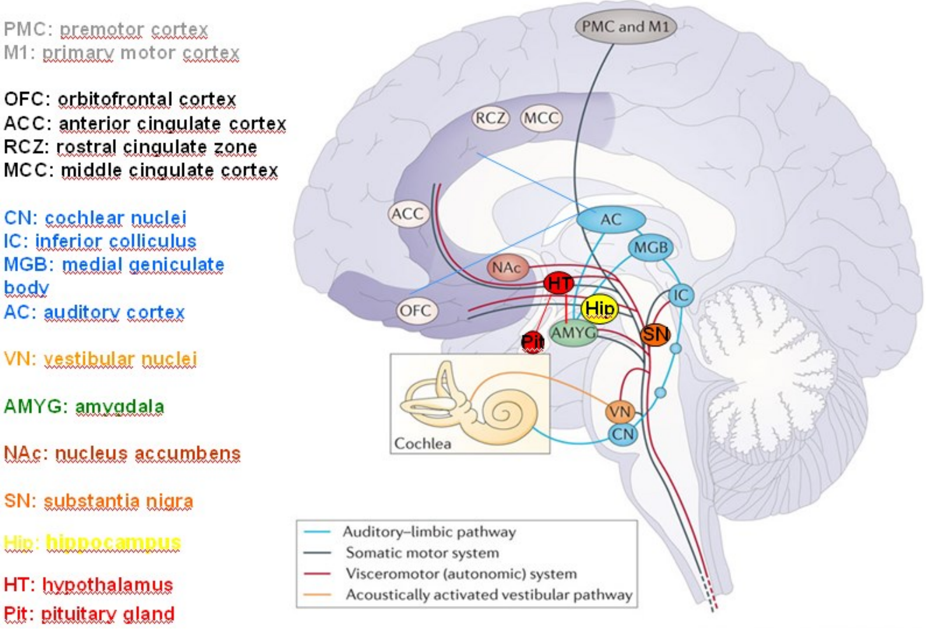


Figure 3. The main pathways underlying responses to music. Adapted from S. Koelsch, 2015.

2. Neurochemistry of music

a, Reward, motivation and pleasure

The reward system represents another well-studied neural circuit involving specific structures and neurotransmitters. The neurotransmitter dopamine is believed to mediate reward-seeking behaviors. In the **nucleus accumbens (NAc)**, a substructure of the **ventral striatum** of the basal ganglia, the neurotransmitter **dopamine** leads to the release of **endogenous opioids**. The release of these opioids results in the sensation of pleasure. Dysfunction of this reward circuitry has been repeatedly implicated in addiction. Low levels of **serotonin**—another neurotransmitter associated with the sensation of pleasure—may be a predictor of addiction. Listening to pleasurable music was found to be associated with NAc activation, as well as ventral tegmental area (VTA)-mediated interactions between the NAc and brain structures known to regulate autonomic, emotional, and cognitive functions. Dopaminergic neurons originating in the VTA with major projections to the NAc and forebrain regions are necessary for the efficacy of rewarding stimuli. A strong link between emotional and cognitive subsystems during musical pleasure was uncovered, linking orbitofrontal cortex with the mesocorticolimbic dopaminergic circuitry (NAc and VTA). Pleasant (consonant) and unpleasant (dissonant) music were contrasted, and the results confirmed activation of the ventral striatum during pleasurable music listening. Ventral striatum activation was also found in response to music that was pleasant due to its familiarity. Strong deactivations were observed in the amygdala, hippocampus, parahippocampal gyrus, and the temporal poles in response to pleasant music. As the hippocampus is known to facilitate and inhibit defensive behaviors in response to stress, the deactivation may be related to modulation of the stress hormone cortisol in response to pleasant vs unpleasant music. Activation of the insula in response to pleasant music has also been observed – a significant finding because of the insula’s connectivity to the NAc and its role in the appetitive phase of reward, particularly in addictive behaviors. Current evidence suggests that endogenous opioid peptides are essential for both ‘wanting’ and the hedonic perception or ‘liking’ of a rewarding stimulus. Imaging of central opioid receptors (using opioid receptor ligands) would clarify the role of these endogenous peptides in musical reward – specifically within regions previously implicated in opioid-mediated reward, including the VTA, NAc, amygdala and dorsomedial midbrain.

b, Stress and arousal

Several key neurochemicals mediate the stress response. These include the glucocorticoids (e.g., cortisol), a product of the HPA stress axis, which regulate metabolism and immune function. Cardiovascular changes are induced by the catecholamines, norepinephrine and epinephrine, which are, in turn, regulated by the brainstem locus ceruleus and central and peripheral autonomic nervous system. Other important mediators of the stress response include the hypothalamic hormones, corticotrophin-releasing hormone (CRH), adrenocorticotropic hormone (ACTH), serotonin, and the peptide derivatives of proopiomelanocortin (POMC), including a-melanocyte stimulating hormone and b-endorphin. It is important to note that these stress mediators act not only in peripheral tissue, but act on target receptors within brain regions mediating cognitive function, emotion, reward and the sleep-wake centers of the brain. The amygdala, for example, is rich in cortisol receptors and interacts with norepinephrine input and hippocampal connections. As for music research, the techno music increased plasma cortisol, ACTH, prolactin, growth hormone and norepinephrine levels, consistent with heightened HPA axis and sympathetic nervous system activity. Additionally, the relaxing classical music did not cause the expected reduction in HPA and sympathetic activation (highlighting the need for a more standardized approach to musical selection). Moreover, the changes in norepinephrine, b-endorphin and growth hormone during techno music listening were negatively correlated with harmavoidance and positively correlated with novelty seeking traits. Furthermore, it has been selected three pieces of music that putatively ‘differed in their rhythmic characteristics’, including a Strauss waltz (regular rhythm), a ‘modern classic’ by H.W. Henze (irregular rhythm) and a ‘meditative piece’ by Ravi Shankar (non-rhythmic). The neurochemical effects of music were compared to a silent baseline. The meditative piece significantly reduced plasma levels of cortisol and norepinephrine, whereas the other two pieces had no effect.

c, Immunity

Stress and aging have detrimental effects on both immune system responses, leading to a weakening of defenses against new pathogens and increases in systemic inflammation. Positive emotions, such as optimism, and stimuli eliciting those emotions, such as humor and laughter, may mitigate the negative effects of age and stress. Given that music enhances mood and reduces stress, it stands to reason that it may also improve immune function. Interestingly, a trend toward increased NK cell activity was found in the group drumming condition, along with an increased 5-DHA-to-cortisol ratio, which suggests enhanced immune functioning and a buffering of the stress response (DHA is an endogenous neurosteroid secreted by the adrenal gland and is a precursor to androgen production). Moreover, group drumming was associated with a decrease in gene expression of the stress-induced cytokine interleukin-10 (IL-10), and interferon- g and bi-directional changes in NK cell activity. Furthermore, NK cell activity was reduced in individuals with high pre-intervention levels, whereas the opposite was found for individuals with low pre-intervention levels. Additionally, group drumming counteracted age-related declines in immune functioning. Older adults (>60 years) displayed significant increases in total number of lymphocytes (including NK cells), T cells, CD4+ T cells, memory T cells, and production of interferon-g and interleukin-6 (IL-6, a cytokine with both pro- and antiinflammatory properties), relative to a pre-intervention baseline. There were no significant changes observed in younger adults. Otherwise, the growth hormone releasing-factor (GHRF) is expressed in neurosecretory cells of the hypothalamus and lymphocytes, which suggests a modulatory role for music in immune regulation; there is further evidence of an interaction between GHRF and IL-6 in human lymphocytes. Several studies have investigated the effects of music on salivary immunoglobulin A (s-IgA), a principal immunoglobulin secreted externally in body fluids, including saliva and mucus of the bronchial, genitourinary and digestive tracts. Notably, salivary IgA is a first line of defense against bacterial and viral infections, and a reliable marker of the functional status of the entire mucosal immune system. Increased s-IgA concentrations from baseline have been reported following experimenter-chosen music that was relaxing. Both studies, however, used only silence as a control, thus the effects could be due to attentional engagement or mood modulation rather than music per se. A third study used appropriate control conditions and also accounted for salivary flow rate (which has been shown to modulate s-IgA concentrations). In this study, the authors investigated the effects of emotional valence (e.g., happy vs sad) on s-IgA levels using experimenter-selected music vs visualization (a control for mood). Music was associated with increased s-IgA levels compared to resting levels and the visualization condition, regardless of the emotional valence of the music. This suggests that mood manipulation through music has beneficial effects on immunity beyond other mood-induction methods. Further research is needed to confirm this. Furthermore, blood plasma levels of IgA (as opposed to s-IgA) were measured in surgery patients who listened to experimenter- selected 'calming music' vs silence. There was no significant difference in blood plasma IgA levels among patients in the music condition compared to the control condition, even though the stress marker cortisol was significantly decreased with music. An important consideration in this study – and others involving surgery patients – is that the effects of local anesthetic infiltration may interfere with the effects of musical intervention on biological measures. Three studies found that group singing elicits a greater increase in s-IgA concentrations than passive listening. Saliva samples were taken from members of a professional chorale during rehearsals and performance of a classical music piece. After controlling for salivary flow rate, s-IgA concentrations increased 150% during rehearsals and 240% during the performance. Selfreported positive affect and relaxation among professional singers showed a significant positive correlation with s-IgA levels during performance, but not rehearsal. In a multiple regression model, self-reported stress did not show a significant correlation with s-IgA, although this factor still contributed to a proportion of the variance in s-IgA. Thus, active performance may have a particularly strong impact on mucosal immunity, and this effect is related to the mood-enhancing effects of the musical activity.

Review

d, Social affiliation

*Oxytocin and vasopressin are i*mplicated two neuroendocrine hormones in social affiliation and trust. Both hormones are synthesized in the hypothalamus, released into the bloodstream from the posterior pituitary gland, and serve other important roles as well; vasopressin is an antidiuretic and increases blood pressure, while oxytocin causes uterine dilation during birth and milk ejection during nursing. In non-human studies, oxytocin and vasopressin have been shown to act as neuromodulators that link social affiliation to reward pathways. In human research, variations in a vasopressin receptor gene have been associated with interpersonal skills, pair-bonding, and empathy. Oxytocin, meanwhile, has been shown to facilitate empathy, eye contact, generosity, and face memory; it is also associated with reduced amygdala activation after a threatening stimulus. Additionally, studies in neuroeconomics have demonstrated increases in financial trust toward investors and generosity toward peers following intranasal administration of oxytocin. Oxytocin and vasopressin also have important implications in mental health disorders and treatment. For instance, higher oxytocin levels are associated with treatment response in social anxiety disorder. Individuals with Williams syndrome, often characterized by unusually trusting behaviors toward strangers, have higher levels of both oxytocin and vasopressin compared to controls. study revealed larger variability in oxytocin levels among a group of depressed women. Low oxytocin and/or reduced sensitivity to oxytocin may also be involved in symptoms of social isolation common in schizophrenia and PTSD. Interestingly, a single 30-minute singing lesson was associated with an increase in serum oxytocin levels relative to a pre-lesson baseline in both professional and amateur singers, with no reported differences between groups. Open-heart surgery patients who listened passively to experimenter-selected ‘soothing’ music (i.e., soft, relaxing, of 60 to 80 beats per minute, with a volume of 50–60 dB) for 30 minutes one day after surgery had higher levels of serum oxytocin compared to bed-rest alone.

3. How music effects on the mental illnesses

Each mental illness has uniquely dysregulated circuitry. Commonly implicated neurocircuits in psychiatric illness are the **prefrontal cortical-striatal-pallidal-thalamic pathways (Fig. 4), the prefrontal cortical-limbic pathways (Fig. 5), the prefrontal cortical-aminergic feedback pathways (Fig. 6), the paralimbic/limbic circuits (Fig. 7).**

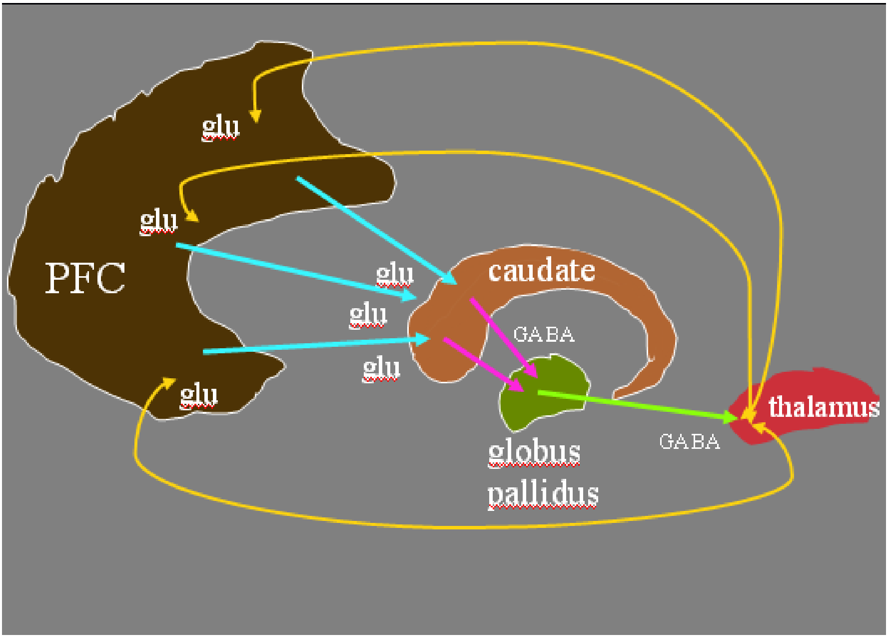


Figure 4. Prefrontal cortical-striatal-pallidal-thalamic pathways: From the prefrontal cortex (PFC), the glutamatergic neurons project to the striatum. The thalamus is the final place prefrontal output is processed before it returns to back to the prefrontal cortex; it is glutamatergic. Pallidal projections are GABAergic and go to the thalamus.

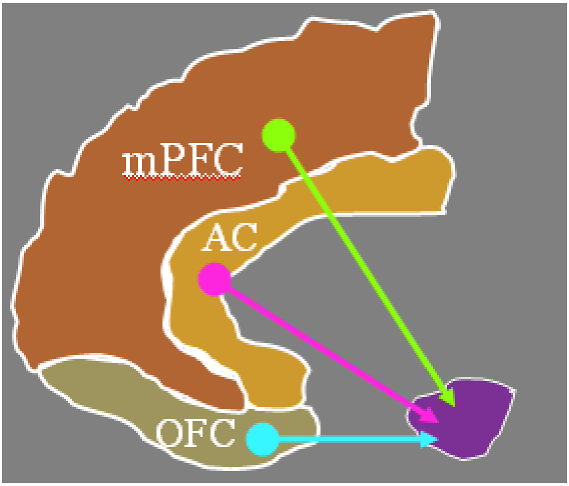


Figure 5. Prefrontal cortical-limbic pathways: The striatum is made up of GABAergic neurons There are separate striatal structures: the dorsal striatum (caudate, putamen), and the ventral striatum (nucleus accumbens). The medial prefrontal cortex (mPFC), the orbitofrontal cortex (OFC), and anterior cingulate cortex (AC) all inhibit amygdalar activity (purple). When these structures are dysregulated, amygdalar activity is less modulated by the prefrontal cortex: anxiety and emotional responses are less controlled; fear may be more easily aroused.

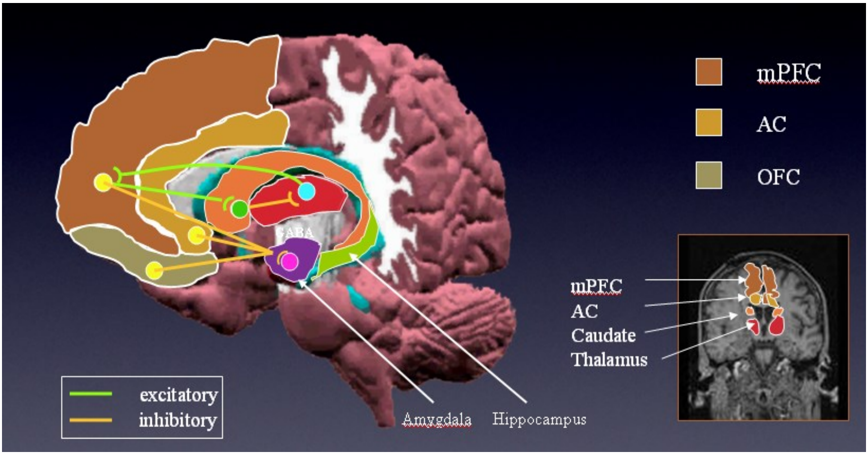
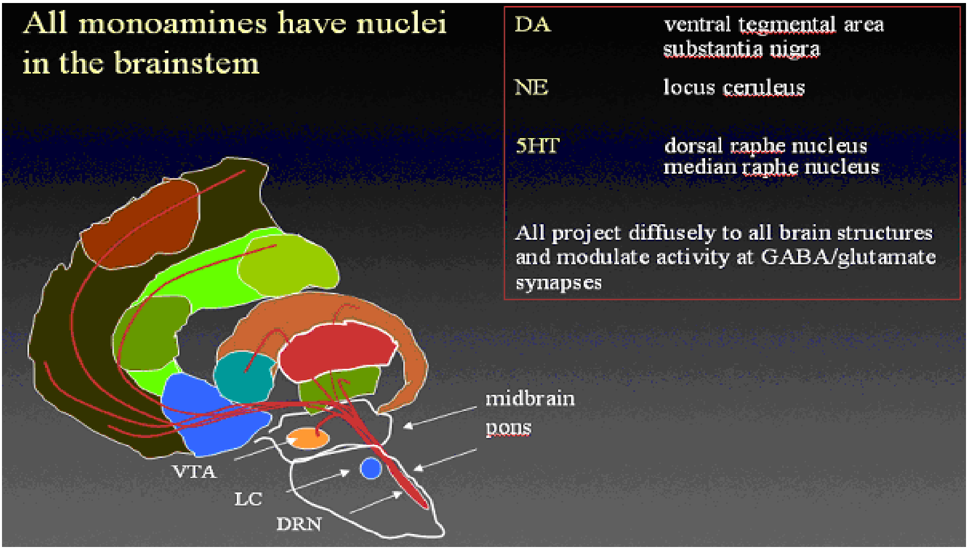


Figure 6. Prefrontal cortical-aminergic feedback pathways: When prefrontal-striatal-thalamic processing is dysregulated, prefrontal function inhibition of hippocampus/amygdala will be disconnected resulting in: abnormal function in the medial prefrontal cortex (mPFC), anterior cingulate cortex (AC), and the orbitofrontal cortex (OFC) anxiety, autonomic arousal, hypothalamic pituitary axis (HPA) activation.



All monoamines have nuclei in the brainstem

DA	ventral tegmental area substantia nigra
NE	locus ceruleus
5HT	dorsal raphe nucleus median raphe nucleus

All project diffusely to all brain structures and modulate activity at GABA/glutamate synapses

Figure 7. Paralimbic/limbic circuits: Abbrev. Dorsal raphe nucleus (DRN), locus coeruleus (LC), ventral tegmental area (VTA), Dopamine (DA), Norepinephrine (NE), Serotonin 5HT

The one type of mental illnesses is the **schizophrenia**, described inefficient cortical processing due to prefrontal cortical dysfunction, dopamine neurotransmission abnormalities

the neurodegenerative process, serotonergic and dopaminergic abnormalities, dopaminergic hypothesis: Mesolimbic hyperdopaminergic: Mesolimbic structures: Ventral striatum (Nucleus accumbens, olfactory tubercle), bed nucleus of stria terminalis, amygdala, lateral septal nucleus, dorsal striatum (caudate). Mesocortical: hypodopaminergic: Mesocortical structures: Entorhinal cortex, Prefrontal cortex (PFC) including dorsolateral pfc, orbitofrontal pfc, and anterior cingulate. Results in overactive limbic areas, poor prefrontal/executive function. Hypoglutamatergic hypothesis: Consequence of hypofunctional glutamatergic neurons in the prefrontal cortex: abnormal cortical feedback to ventral tegmental area (VTA) disinhibits the VTA causing increased dopamine release in limbic areas, disinhibits substantia nigra, causing increased dopamine release in dorsal striatum, which results in abnormal regulation of both cortical glutamate and GABA. Hypoglutamatergic hypothesis: During neurodevelopment, this hypoglutamergic state results in abnormal connectivity and function of prefrontal cortex and limbic areas resulting in inefficient cortical processing. Furthermore, multiple structures of the brain are reduced in volume in schizophrenia: prefrontal cortex, temporal cortex, entorhinal cortex, parahippocampal cortex, hippocampus, cortical and limbic structural abnormalities.

Bipolar illness is characterized by a progressive illness course with greater time spent in the depressive phase of the illness, mixed episodes and rapid cycling overtime. Decreased gray matter in prefrontal, temporal cortex and limbic structures. Decreased temporal cortical thickness that correlates with the number of recent mood episodes, and cognitive impairment.

A BDNF polymorphism exaggerates these gray matter decrements.

Major depression is primarily due to abnormal function in the noradrenergic and serotonergic neurotransmitter systems. The result of a systems level dysregulation of multiple cortical, subcortical, and limbic neurociruits. Not associated with volumetric abnormalities in any cortical or limbic structures. The result of clear abnormal structure and functio of the mamillary bodies.

Obsessive Compulsive Disorder: Abnormalities in the noradrenergic system. Hypermetabolism in the orbitofrontal cortex. Decreased volume of the orbitofrontal cortex.

Prominent hypothalamic pituitary axis dysregulation.

Post-traumatic stress disorder (PTSD): Elevated CRF levels in CSF, reduction in volume of the medial prefrontal cortex. Abnormal connectivity between prefrontal cortical and limbic structures resulting in dysregulation of the hypothalamic pituitary axis and autonomic nervous system. Reduced volume of limbic structures such as the hippocampus and amygdala. Fig.8.

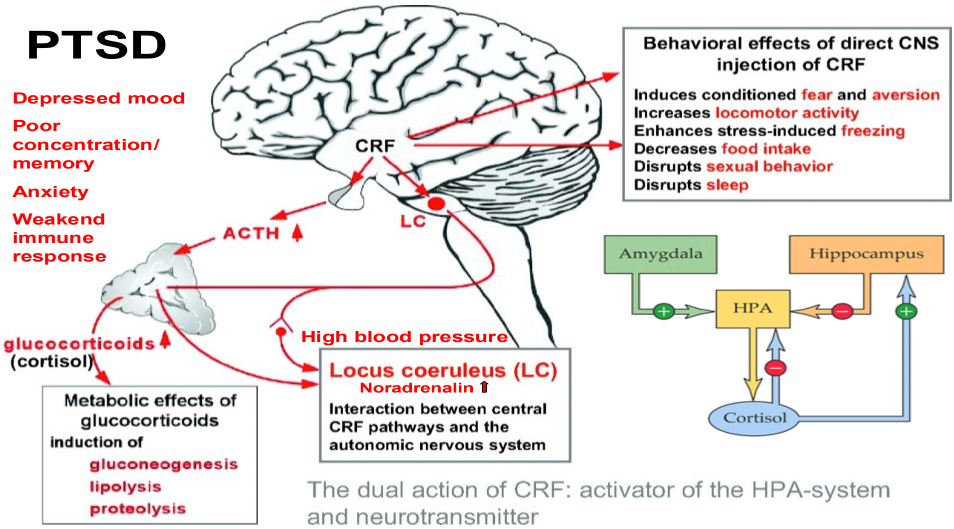
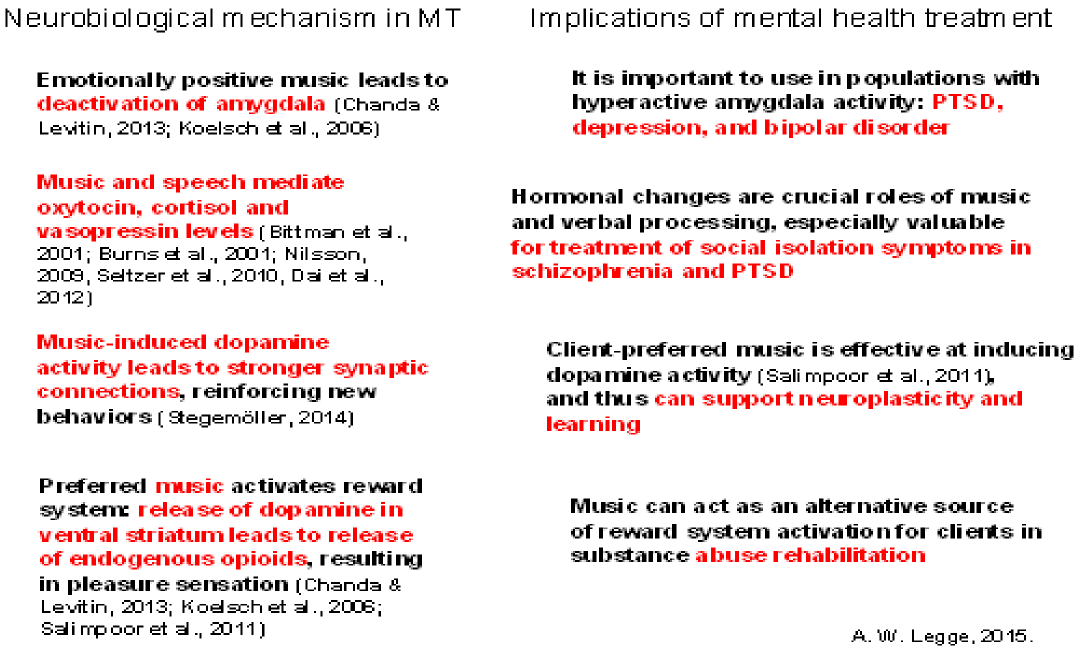


Figure 8. Neurobiology and physiology of post-traumatic stress disorder (PTSD)



Neurobiological mechanism in MT

Emotionally positive music leads to deactivation of amygdala (Chanda & Levitin, 2013; Koelsch et al., 2006)

Music and speech mediate oxytocin, cortisol and vasopressin levels (Bittman et al., 2001; Burns et al., 2001; Nilsson, 2009, Seltzer et al., 2010, Dai et al., 2012)

Music-induced dopamine activity leads to stronger synaptic connections, reinforcing new behaviors (Stegemöller, 2014)

Preferred music activates reward system: release of dopamine in ventral striatum leads to release of endogenous opioids, resulting in pleasure sensation (Chanda & Levitin, 2013; Koelsch et al., 2006; Salimpoor et al., 2011)

Implications of mental health treatment

It is important to use in populations with hyperactive amygdala activity: PTSD, depression, and bipolar disorder

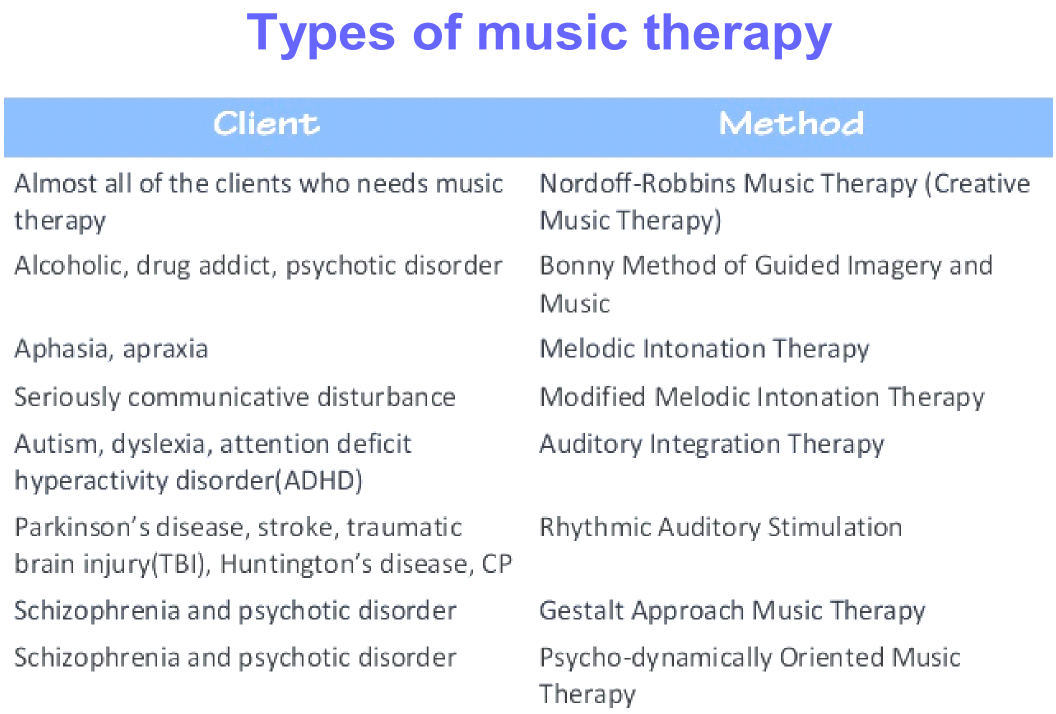
Hormonal changes are crucial roles of music and verbal processing, especially valuable for treatment of social isolation symptoms in schizophrenia and PTSD

Client-preferred music is effective at inducing dopamine activity (Salimpoor et al., 2011), and thus can support neuroplasticity and learning

Music can act as an alternative source of reward system activation for clients in substance abuse rehabilitation

A. W. Legge, 2015.

Abbrev. MT-music therapy



Types of music therapy

Client	Method
Almost all of the clients who needs music therapy	Nordoff-Robbins Music Therapy (Creative Music Therapy)
Alcoholic, drug addict, psychotic disorder	Bonny Method of Guided Imagery and Music
Aphasia, apraxia	Melodic Intonation Therapy
Seriously communicative disturbance	Modified Melodic Intonation Therapy
Autism, dyslexia, attention deficit hyperactivity disorder(ADHD)	Auditory Integration Therapy
Parkinson's disease, stroke, traumatic brain injury(TBI), Huntington's disease, CP	Rhythmic Auditory Stimulation
Schizophrenia and psychotic disorder	Gestalt Approach Music Therapy
Schizophrenia and psychotic disorder	Psycho-dynamically Oriented Music Therapy

Neuroanatomy of music processing

aCC: anterior cingulate cortex
mPFC: medial prefrontal cortex
OFC: orbitofrontal cortex

iFG: inferior frontal gyrus

TP: temporal lobe

PL: parietal lobe

TPJ: temporoparietal junction

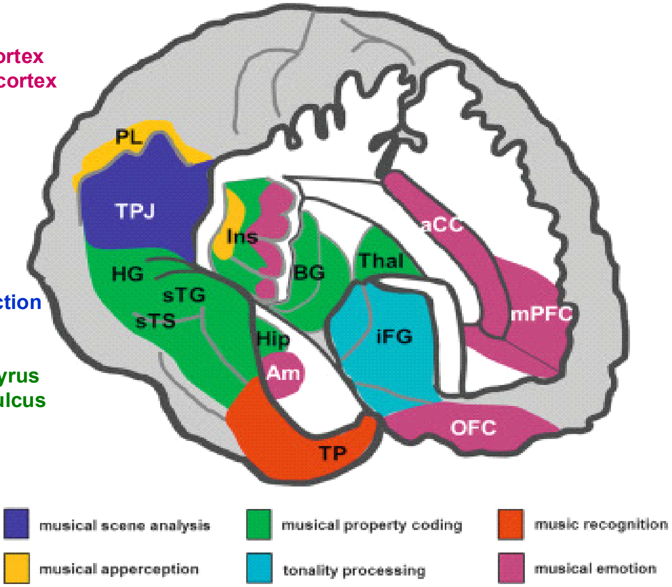
HG: Heschl's gyrus
sTG: superior temporal gyrus
sTS: superior temporal sulcus

HiP: hippocampus

BG: basal ganglia

Thal: thalamus

Ins: Insula



C.N.Clark et al., 2015.

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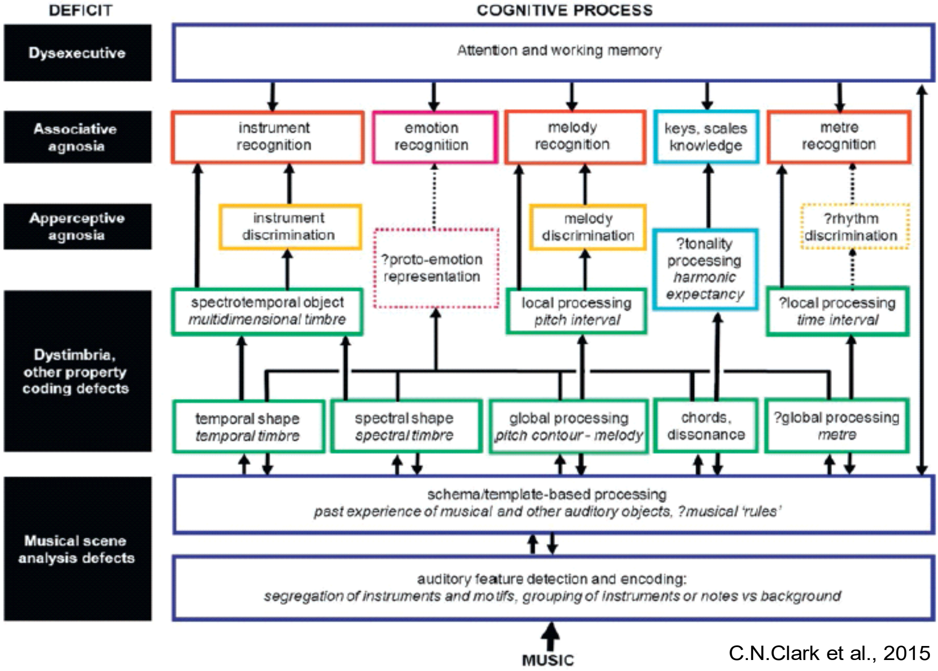

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NEUROBIOLOGY OF THE MUSIC COMPONENTS PERCEPTION

Lilla Papp, Zsuzsa Buzás, Damien Francois Sagrillo

Summary

Once a musical composition is complete, it will have numerous features that can be broken down into basic components that are all processed simultaneously in the brain during the listening process. These features of music include basic pitch, pitch contour, melody, harmony, timbre, form, dynamics, duration, articulation, temporal structure (rhythm, meter, beat, tempo), consonance and dissonance, loudness, and emotional responses. The details regarding neural correlates of music perception are still largely unclear as music perception is a complex cognitive task involving the perception and integration of various structural components of music. Comparing the studies using high-cost neuroimaging techniques (such as fMRI, PET, and MEG), assessing the musical structure-related brain dynamics, electroencephalography EEG modality has gained increasing attention in the past few years.

Introduction

Musical structures

Pitch is the perceived sensation of the frequency of a given note in a piece of music, with different notes being relatively higher or lower in pitch to one another. Pitch contour refers to the relative change in pitch over time of a primary sequence of notes in a piece of music (i.e., the “ups” and “downs” in the song). **The melody** of a piece of music consists of the linear succession of pitches or notes (i.e., the “horizontal” aspect of music) that the listener perceives as a single musical phrase or entity that is the centerpiece of the song. **Harmony** within a musical piece refers to the use of simultaneous pitches or notes that can be provided by the use of chords, multiple instruments, multiple voices, or a mixture thereof. Furthermore, harmony is considered the “vertical” aspect of music and involves chords, chord construction, and chord progressions. In Western music, most harmonies are tertian, with the pitch intervals based on thirds (e.g., root, third, fifth, seventh), giving a consonant or pleasing sound. In some forms of music (e.g., jazz), the harmonic structures may be different, using chords and chord progressions that have more dissonant qualities. The temporal structure of a musical piece has several components, including **the rhythm, meter, beat, and tempo**. (Fig.1)

Figure 1. A depiction of rhythm, beat and metre. A **rhythm** is a sequence of auditory events, the onsets of which are separated by time intervals. The **beat** is the sequence of regular, salient time positions that are perceived in the rhythm. **Metre** is the hierarchical organization of beats into strong and weak (strong beats in the metrical structure are indicated in the top line). D. J. Cameron and J. A. Grahn, 2015.

Thus, **the rhythm** of a song consists of the arrangement or pattern of sounds (i.e., pitches, notes) and silences over time and is often consistent throughout a given melody. The tempo of a song is the speed or frequency of the beat and is usually measured in “beats per minute” or bpm. The tempo can differ significantly between various styles of music, ranging from 40 bpm to over 200 bpm. **Timbre**, also known as tone color or tone quality, refers to the unique characteristics of a given note or sound and allows us to perceive the differences between different voices, as well as between various musical instruments, such as string instruments, wind instruments, horns, and percussion instruments. **Musical consonance and dissonance** generally refer to the quality of chord and harmonic structures, and whether they are complementary and pleasing to the ear or not. Consonant chords and harmonies have pitch intervals that are complementary (e.g., octaves, thirds, fifths) and increase each other's resonance, and are generally considered to be pleasant to the listener. In contrast, dissonant chords and harmonics have intervals that are considered "unstable," with an aural need (i.e., musical tension) to resolve to a more stable musical consonance.

Methods: Neuroimaging techniques (such as fMRI, PET, MEG, EEG)

Results

1. Pitch processing in the brain

These studies and others have suggested the possibility of a "pitch center" in the lateral Heschl's gyrus (HG) region, responsible for primary pitch processing of complex auditory inputs (Griffiths 2003; Bendor and Wang 2006; Puschmann et al. 2010, Lee et al. 2011). They also identified the right superior temporal sulcus region as being highly activated in this setting. In addition, there was also significant activation within the left inferior parietal lobule and the anterior cingulate cortex. Thus, pitch contour and melody processing are predominantly mediated in the posterior part of the right superior temporal gyrus (STG), while processing of pitch intervals and direction involves the posterior and anterior regions of the supratemporal cortex bilaterally. Furthermore, the planum temporale (PT) is also involved in the processing of pitch intervals, pitch direction, and sound sequences (Gutschalk et al. 2002, Metherate et al. 2005; Nelken 2008). Further research into the functional anatomy and neurobiology of primary pitch processing will be necessary before any final conclusions.

2. Temporal components processing in the brain

A, Rhytm, beat, tempo

The neural processing of the temporal organization of music (i.e., rhythm, meter, beat, tempo) has not been as clearly delineated as the processing of pitch perception. Herholz and Zatorre (2012); Herholz et al. (2012); have described two distinct neural timing mechanisms and subsystems: one involving the olivo-cerebellar pathways that acts as a precision clock to mediate duration-based timing, and another that involves a striato-thalamo-cortical network that mediates relative, beat-based timing. High levels of Pulse Clarity were linked with increased activation in the bilateral superior tempral gyrus STG, as well as the right primary auditory cortex. Interestingly, the presence of unclear key (i.e., low levels of Key Clarity) was found to be associated with increased activation in cortical and subcortical areas such as parts of the bilateral precentral gyrus, the right mid-cingulate gyrus in the vicinity of the supplementary motor area and right postcentral gyrus, and the left hemispheric superior frontal gyrus, the left insula and the bilateral rolandic operculum (Alluri et al., 2012). A recent fMRI study had subjects find and tap to the beat of rhythms that were varied from metrically simple to metrically complex (i.e., from a strong to a weak beat) (Kung et al. 2013). Moreover, the beat finding and beat tapping activity activated overlapping brain regions that included the superior temporal gyrus, premotor cortex, and ventrolateral prefrontal cortex (VLPFC). In addition beat tapping activity in the superior temporal gyrus and VLPFC was correlated with both perception and performance, suggesting that they were important for retrieving, selecting, and maintaining the musical beat. Furthermore, basal ganglia activation was noted as well, but was similar in all conditions and did not correlate with either perception or production of the beat. Compared to rhythms without a beat, listening to beat-based rhythms elicits more activity in the SMA (supplementary motor area) and the basal ganglia. The basal ganglia (eg. substantia nigra) not only respond during beat perception, but are crucial for normal beat perception to occur. (J.A. Grahn and M. Brett, 2007). In contrast to the basal ganglia, the cerebellum appears to play a different role in timing. Whereas the basal ganglia is important for beat perception and beat-based timing (i.e., timing of events relative to a regular and predictable beat), the cerebellum has been implicated in the perception of absolute time intervals (i.e., timing of events not relative to a beat). As for absolute and beat-based timing: cerebellar regions and the inferior olive were more active for absolute timing, and regions of the basal ganglia, SMA, PMC (premotor cortex), and other frontal cortical regions were more active for beat-based timing (S. Teki et al., 2011). Furthermore, basal ganglia activity was low during the initial presentation of a beat-based rhythm, during which participants were engaged in beat-finding. In addition, activity was high when beat-based rhythms followed one after the other, during which participants had a strong and continuing sense of the beat, suggesting that the basal ganglia are more involved in beat continuation than beat-finding (J.A. Grahn and J.B. Rowe, 2013). (Figure 2).

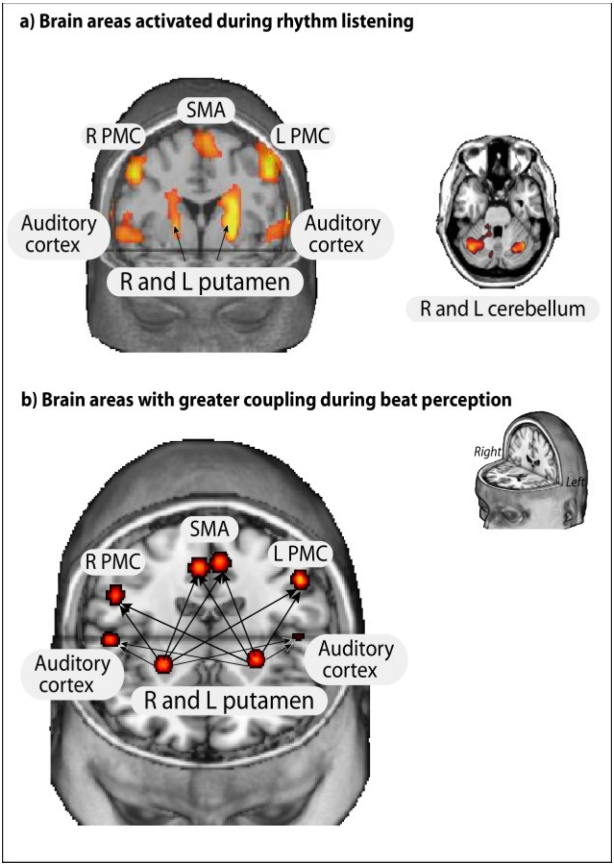


Figure 2. **Functional connectivity analysis revealed a cortico-subcortical network including the putamen, SMA, and PMC under conditions that may require internal generation of the pulse** Neural regions that are a) active while listening to rhythms, and b) coupled (show greater correlation in activity) during beat perception (adapted from J.A. Grahn and M. Brett, 2007, J.A. Grahn and J.B. Rowe, 2009.)

PMC = premotor cortex, SMA = supplementary motor area, R = right, L = Left.

B, Timbral feature processing in the brain

In the auditory cortex all the timbral features namely Fullness, Brightness, Timbral Complexity and Activity, was associated with increased neuronal activation in the bilateral superior temporal gyrus STG. The right hemisphere displayed positive correlations with timbral components in the Heschl's gyrus HG, rolandic operculum, supramarginal gyrus, and superior temporal pole than the left hemisphere. In contrast, the left hemispheric middle temporal gyrus had a larger proportion displaying such a correlation than its right hemispheric counterpart.

In the cerebellum high values of Fullness and Activity in the stimulus were associated with increased activation in the declive, uvula, and pyramis (lobule VI, Crus I and II). Increase in the timbral components of Brightness and Timbral Complexity was associated with increased activation in the declive only.

In the cerebrocortical areas decreased Fullness and Activity was found to be associated with increased activations in the bilateral postcentral gyrus, and the left precuneus. In addition, low levels of Fullness were associated with increased activations in the bilateral inferior parietal gyrus, and those of

Activity were associated with increased activations in the left superior frontal gyrus and left medial frontal gyrus. Increased activations in the right medial frontal gyrus were found to be associated with increasing Activity. Furthermore, increase in Brightness recruited the bilateral precentral gyrus, and the right putamen. Reduced levels of Brightness in the stimulus, on the other hand were associated with increased activations in two left hemispheric clusters of the medial frontal gyrus and the posterior cingulate cortex. No negative correlations were found for Timbral Complexity. Negative correlations between timbral features of Activity and Fullness and brain activity were observed in cerebrocortical regions are known to be part of the default mode network **(DMN)**, whose core is composed of the medial prefrontal cortex (mPFC), posterior cingulate cortex (PCC), precuneus/PCC, and bilateral AG. The DMN is a neural circuit constantly monitoring the sensory environment and displaying high activity during lack of focused attention on external events (Fox et al., 2009; McAvoy et al., 2008) and it has been hypothesized to generate spontaneous thoughts during mind- wandering and is believed to play an essential role in creativity (Buckner et al., 2008; Vessel et al., 2012, 2013; Utevsky et al., 2014). In the visual modality, a network comprising several parietal areas such as the precuneus and the supramarginal gyrus highly activated with reduced visual attention or load. Similarly, the left posterior cingulate, one of the central structures of the DMN, deactivated during moments in the stimulus with high Brightness, which were associated with the presence of several instruments playing simultaneously. (V. Alluri et al., 2012). Figure 3.

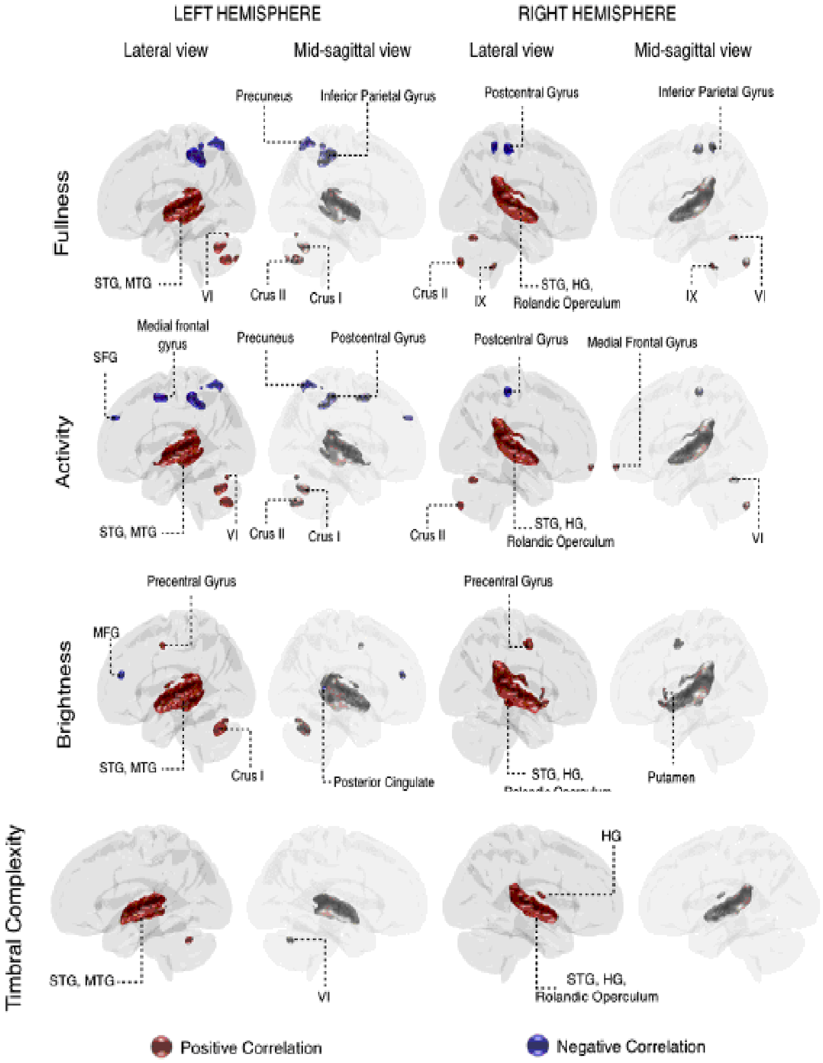


Figure 3. Lateral and mid-sagittal views of the left and right hemispheres of the brain showing regions correlating significantly with timbral components.

There is a process of structure building, in which the musical signal goes through final processing for harmony, meter, rhythm, timbre, and temporal features. This is the process of **musical syntax**, where chords and harmonies are analyzed in terms of the preceding harmonic and musical context. Musical syntactic processing occurs predominantly in the pars opercularis of the inferior frontolateral cortex bilaterally, as well as in the anterior portion of the superior terminal gyrus (STG) and the ventrolateral premotor cortex.

3. EEG studies

Neural resonance theory (Large and Snyder, 2009) hypothesizes that pulse and meter correspond to neural rhythms that synchronize with acoustic rhythms, influencing temporal expectancy, attention, and movement coordination. Thalamocortical oscillations exhibit 1/f frequency spectra with peaks in specific frequency bands, including delta (~ 1–4Hz), theta (~ 4–8Hz), beta (~ 13–30Hz), and gamma (~ 30–70Hz) (Buzsáki, 2006). Pulse frequencies overlap with cortical oscillations in the delta range, while other metrical frequencies extend into theta and sub-delta ranges. Frequency relationships among metrical levels include harmonics, subharmonics, and other integerratios. (Musacchia et al., 2014). Figure 4.

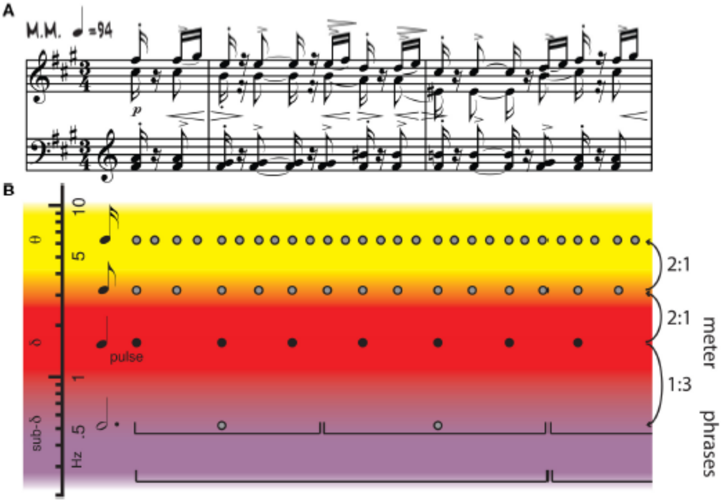


Figure 4. A Piano score of Isaac Albeniz’s Iberia II,Triana. B Annotation showing pulse (blackdots), metrical structure (all dots), and phrasing (brackets). Adapted from Large (2014)

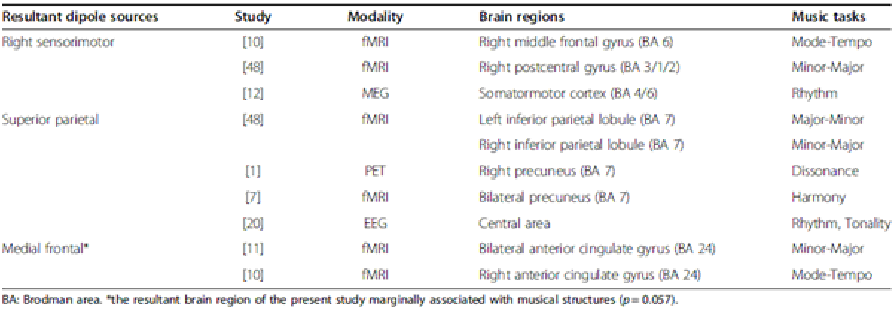
Compared to other neuroimaging studies, using electroencephalography (EEG) techniques it has been reported that music composed in major mode and played at a fast tempo primarily activated the left frontal regions, which were known to be related to positive-valence emotion, whereas music played at a slow tempo and minor mode activated the right frontal regions, which were associated with negative-valence emotion (Tsang et al. 2001). Moreover, the frontal midline theta has been shown to activate during musical emotion perception (Sammler D. et al., 2007, Lin YP, 2010). Furthermore, it has been described that the frontal midline theta decreased with increased arousal level of musical tempo (Tian et al. 2013). To avoid volume conduction in EEG recording, Cong et al. (2013) applied independent component analysis (ICA) to isolate the activations of the brain sources associated with musical tonal and rhythmic waveforms. They reported two brain regions whose theta and alpha activities sparsely and distinctly associated with the musical attributes. Interestingly, one study found that when listening to a tone sequence of isochronous, alternating strong and weak beats, neural activity in the gamma band of oscillatory frequencies (in this case defined as 20-60 Hz) was greater for strong beats than weak beats (J.S. Snyder and E.W. Large, 2005). In addition, when a tone in the sequence was occasionally omitted, anticipatory gamma responses occurred in the gaps where tones were expected. These findings suggest that gamma responses may index the perception and expectation of beats. In a similar study, participants heard a simple, repeating pattern: two identical tones followed by a silent gap. Participants imagined one of the two tones to be accented (emphasized), and oscillatory activity in the beta band (20-

30 Hz; note that this overlaps with the gamma range as defined in the study discussed immediately above) was greater for the tone with imaginary accents than for the other tone (Wang Y, et al., 2012). Moreover, beta activity therefore shows a similar pattern to gamma activity in the study described above, but for imagined accents, rather than physical accents (greater intensity). Thus, beta activity also appears to be sensitive to the expectation of when a tone will occur. When listening to isochronous sequences with varying rates, beta activity decreases following the onset of tones, but rebounds with a time course that is specific to the rate of the isochronous stimulus tones. The relationship between the timing of the beta rebound and the rate of the stimulus tones suggests that beta activity indexes anticipation of the timing of the next tone (T. Fujioka, L.J. Et al., 2012). Overall, both beta and gamma have been implicated in anticipation of the beat, but future research may elucidate whether they have distinct roles. Regarding the musical mode-related activations, it has been reported that music with major mode augmented delta-band activity over the right sensorimotor cortex, suppressed theta activity over the superior parietal cortex, and moderately suppressed beta activity over the medial frontal cortex, compared to minor-mode music, whereas fast-tempo music engaged significant alpha suppression over the right sensorimotor cortex (Yuan-Pin Lin et al., 2014). In other EEG study, it has been presented

simultaneous high-pitched and low-pitched tones in an isochronous stream and occasionally found either the higher or the lower tone 50 ms earlier than expected, while leaving the other tone at the expected time. Furthermore, EEG recordings revealed that mismatch negativity responses were larger for timing deviants of the lower tones, indicating better timing encoding for lower pitched compared with higher-pitch tones at the level of auditory cortex. The low-voice superiority effect for encoding timing explains the widespread musical practice of carrying rhythm in bass-ranged instruments and complements previously established high-voice superiority effects for pitch and melody. (Michael J. Hove et al., 2014). In addition, in one study it has been trained piano naive subjects with a learn-to play by- ear paradigm, to play a simple melodic sequence over five days. After training, it has been recorded EEG of subjects listening to the song they learned to play, a transposed version of that song, and a control song with different notes and sequence from the learned song. Interestingly, beta band power over sensorimotor scalp showed increased suppression for the learned song, a moderate level of suppression for the transposed song, and no suppression for the control song. As beta power is associated with attention and motor processing, they interpret this as support of the motor system's activity during covert perception of music one can play and similar musical sequences. (Matt D. Schalles and Jaime A. Pineda 2015).

4. Musical structures and brain regions

The previously reported findings in musical structure related brain regions are able to validate the brain regions revealed by ICA (independent cluster analysis). Firstly, the involvement of superior parietal region or precuneus has been reported to be associated with harmonic/consonant melodies and may reflect the music-related mental state during music listening, such as memory retrieval or visual imagery. The degree of consonant harmonics are commonly considered simpler and more often in major keys, whereas dissonance is usually associated with minor mode. (Table 1)



Resultant dipole sources	Study	Modality	Brain regions	Music tasks
Right sensorimotor	[10]	fMRI	Right middle frontal gyrus (BA 6)	Mode-Tempo
	[48]	fMRI	Right postcentral gyrus (BA 3/1/2)	Minor-Major
	[12]	MEG	Somatormotor cortex (BA 4/6)	Rhythm
Superior parietal	[48]	fMRI	Left inferior parietal lobule (BA 7)	Major-Minor
			Right inferior parietal lobule (BA 7)	Minor-Major
	[1]	PET	Right precuneus (BA 7)	Dissonance
	[7]	fMRI	Bilateral precuneus (BA 7)	Harmony
	[20]	EEG	Central area	Rhythm, Tonality
Medial frontal*	[11]	fMRI	Bilateral anterior cingulate gyrus (BA 24)	Minor-Major
	[10]	fMRI	Right anterior cingulate gyrus (BA 24)	Mode-Tempo

BA: Brodman area. *the resultant brain region of the present study marginally associated with musical structures ($p = 0.057$).

Table 1: Summary of estimated dipole sources supported by previous music-related evidences Yuan-Pin Lin et al., 2014

Discussion:

The core of the modulatory music processing model (Figure 5) contains compartments for pitch analysis and temporal analysis, along with other aspects of musical processing. However, the model is somewhat simplistic and does not take into account many other aspects of the musical acoustic signal and music processing (e.g., timbre, harmony, beat) that have been studied in patients and normal subjects.

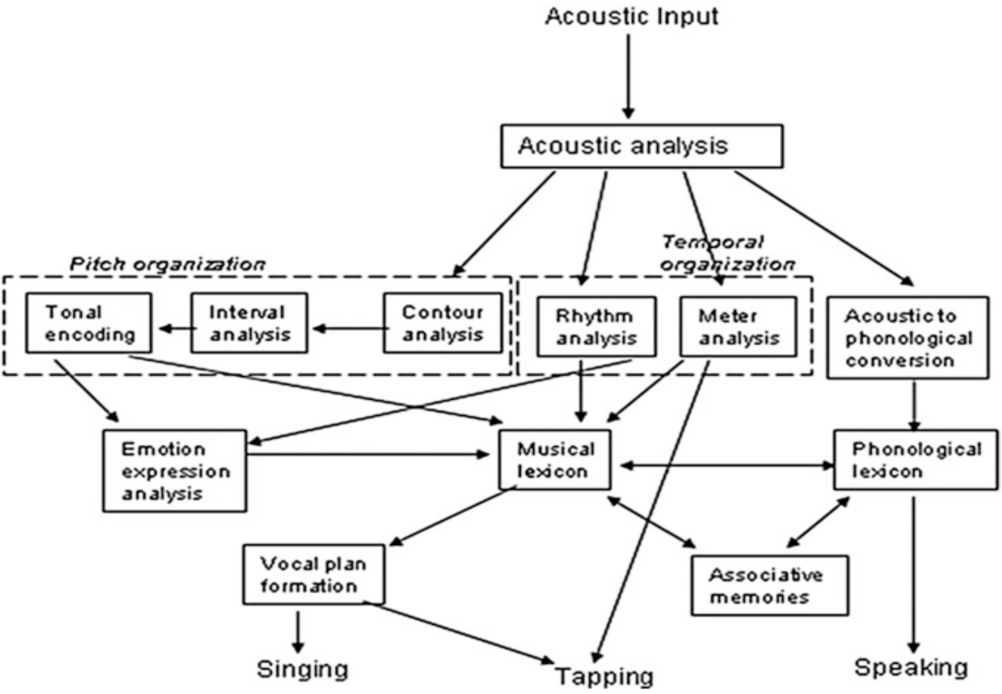


Figure 5. Model of music processing as proposed by Peretz and colleagues. The musical acoustic signal is initially analyzed in parallel in the “pitch organization” and “temporal organization” compartments, followed by further processing for emotional expression, comparisons with the musical lexicon and phonological lexicon, and evaluations for associative memories. Adapted from Herdener et al. (2014).

Music perception begins with the decoding of acoustic information. Acoustic information is translated into neural activity in the cochlea, and progressively transformed in the auditory brainstem, as indicated by different neural response properties for the periodicity of sounds, timber (including roughness, or consonance/dissonance), sound intensity, and interaural disparities in the superior olivary complex and the inferior colliculus. The auditory information is projected mainly via the subdivisions of the medial geniculate body into the **primary auditory cortex (PAC, corresponding to Brodmann’s area (BAs) 41)** and **adjacent secondary auditory fields (corresponding to BAs 42 and 52)**. Moreover, the (primary) AC is involved in the transformation of acoustic features (such as frequency information) into percepts (such as pitch height and pitch chroma). While auditory features are extracted, the acoustic information enters the auditory sensory memory (or “echoic memory”), and representations of auditory Gestalten are formed. Operations of the auditory sensory memory are at least partly reflected electrically in the mismatch negativity (MMN). The MMN has a peak latency of about 100–200 ms9, and most presumably receives its main contributions from neural sources located in the PAC and adjacent auditory (belt) fields, with additional (but smaller) contributions from frontal cortical areas These frontal areas appear to include **(ventral) premotor cortex (BA 6)**, dorsolateral prefrontal cortex near and within the inferior frontal sulcus, and **the posterior part of the inferior frontal gyrus (BAs 45 and 44).** The frontal areas are possibly involved due to their role in attentional processes, sequencing, and working memory (WM) processes. (Figure 6)

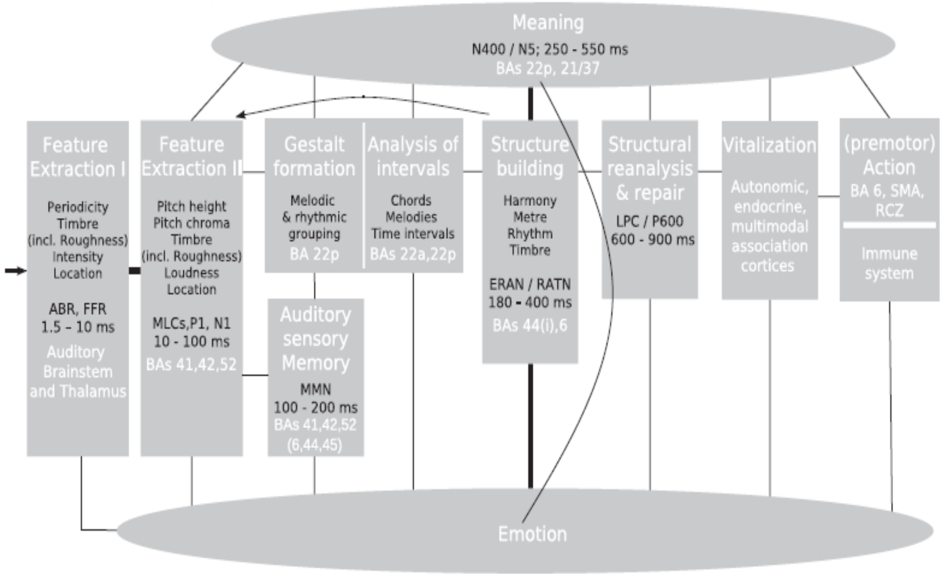


Figure 6. Neurocognitive model of music perception. ABR, auditory brainstem response; BA, Brodmann area; ERAN, early right anterior negativity; FFR, frequency-following response; LPC, late positive component; MLC, mid-latency component; MMN, mismatch negativity; RATN, right anterior-temporal

negativity; RCZ, rostral cingulate zone; SMA, supplementary motor area. Italic font indicates peak latencies of scalp-recorded evoked potentials. Adapted from S. Koelsch 2011.

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