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Music medicine. A neurobiological approach

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Abstract Music medicine is a relatively new medical specialty for most countries in the world and a rediscovery of a discipline for some countries in Europe. In the scope of music medicine are health problems of musicians like stage fright and psychic stress, pain syndromes and motor disturbances. Specific demands of musicianship like performing before the public, performing under the constant critical scrutiny of conductors, being expected to perform perfectly, and the physical demands of performing on a musical instrument were seen as the determinants of the complaints, and treatment does usually not differ between musicians and non-musicians with comparable diseases. In the present article, growing neurobiological evidence will be summarized showing that musicians differ from non-musicians on brain structure and function and on some hormonal and immunological parameters. Musicians tend to have atypical brain organization for verbal and non-verbal materials, their auditory system tracks sound levels more accurately, musicians attend pre-consciously to musical material and they react to music as if it is a stressor, i.e. with increased activity of the autonomic nervous system and with an increase in stress hormone production. A musician is more likely than a non-musician to be non-right-handed and to be vulnerable to atopic diseases. Testosterone levels are assumed to be lower (male) and higher (female) than controls. Melatonin was found to be elevated, and ACTH was related to musical talent. His/her brain reflects early music practice by enlarged structures, like the anterior part of the corpus callosum and the representation for piano tones and for the left thumb and little finger in string players. In addition, the left planum temporale was found to be larger in musicians with absolute pitch. These differences between musicians and non-musicians may have implications for music medicine in theory and practice, and further research should help to improve treatment of musicians.

"In response to the increasing incidence and awareness of the health problems of professional musicians, music medicine, a new medical specialty, has come into being," Sternbach wrote in 1993 [27]. This statement is true for many countries in the world; however, music medicine of today is also, for some Europeaen countries, a rediscovery of a discipline known at least in the 19th and 20th centuries. This is documented by books on music medicine for instance by Karl Sundelin: Ärztlicher Rathgeber für Musiktreibende (medical adviser for musicians) from 1832 and by Kurt Singer: "Die Berufskrankheiten der Musiker" (occupational diseases of musicians) from 1926.

Sterbach [27] and Potter & Jones [24] have recently summarized the most often reported health problems of musicians, and these are comparable to those mentioned, for example, by Singer in 1926: stage fright and psychic stress, pain-syndromes and motor disturbances are at the top of the list. To answer the question why musicians suffer from emotional problems, the specific demands of musicianship like performing before the public, performing under the constant critical scrutiny of conductors, being expected to perform perfectly are discussed [27]; and pain, sensory loss, and lack of coordination are seen in the context of the physical demands of performing on musical instruments [24].

In theory and practice, musicians are viewed as patients like non-musicians who have special problems linked to their profession. There is, however, growing evidence that musicians differ from non-musicians in brain structure and function. It seems possible that, in addition to the challenge of their profession, reactions of musicians to this challenge may be specific and different from the reaction of non-musicians to the same demands.

The central assumption of modern neuroscience is that all behavior is a reflection of brain function. The action of the brain underlies not only relatively simple motor behaviors such as walking or grasping or playing an instrument, but also elaborate affective and cognitive behaviors such as feeling, learning, thinking, and composing a symphony [15]. With respect to the subject who behaves, Fedor-Freybergh [4] has recently stated that the human life has to be considered as an indivisible continuum where each of the developmental stages is equally important, all stages interdependent and not separable from the whole individual life's continuum. In this continuum, the individual represents an indivisible entity of all functions on both physiological or physical, psychological and social levels. The physical, biochemical, endocrinological and psychological processes represent the whole which cannot be divided. Thus, if differences exist between musicians and non-musicians in this system it seems likely that the theoretical basis of music medicine should be broadened and neurobiological findings should be included.

Whether the brain of a musician is the same or different from the brain of a non-musician in structure and function was investigated in case studies even in the past centuries. For instance, Auerbach's search for a morphological substrate in the brains of eminent musicians between 1906 and 1913 included the brains of the conductors Felix Mottl and Hans von Bülow, the teacher of music Naret Koning, the singer Julius Stockhausen, and the violoncellist Bernhard Cossmann. Auerbach concluded that in all cases so far investigated, the middle and posterior thirds of the superior temporal gyrus were strongly developed and showed great width; they were intimately connected with the equally well developed gyrus supramarginalis [20]. Auerbach has also described and illustrated what he thought to be an abnormally large anterior Henschl convolution in the brain of the cellist Cossmann and the conductor Mottl. Klose added in 1920 one more example in the brain of the prodigy pianist Sökeland. He found that, "in the left hemisphere, the auditory convolution of Flechsig is enormously developed and vaulted..." [20]. With respect to lower auditory pathways, His reported in 1895 an observation in the skull of Johann Sebastian Bach. An abnormally large fossa cochlearis was found which would point to an enlarged cochlear ganglion [20].

The first attempts of modern neuroscience to investigate musicians' brain structure and function began in the 1970s and was concerned with questions about brain functions in a very general way like this: which of the two cerebral hemispheres of musicians is more than the other involved in music processing or in processing speech? Using dichotic listening technique, tachistoscopic or EEG measures, musicians showed atypical processing for both musical and verbal materials. While, in non-musicians, music was processed predominantly with right hemisphere functions, musicians showed a relative superiority of left hemisphere functions for the respective processes. Speech, on the other hand, which is, in non-musicians, predominantly processed by functions of the left cerebral hemisphere showed tendencies for bilateral or even right lateral dominance in musicians [1, 6, 8]. Atypical processing was accompanied by enhanced occurrence of non-righhandedness [10, 12].

In the 1990s, new imaging techniques allowed study of the working brain and measurement of brain structure in healthy subjects, among them musicians. As a consequence of the above-mentioned studies, two structures were of special interest because they were expected to explain the findings of atypical processing of verbal and musical material in musicians. The first structure was the corpus callosum which is the most prominent fiber bundle connecting the right and left cerebral hemispheres. The second one was the planum temporale, a brain area containing auditory association cortex, which is usually larger on the left side. Using MRI technique, Schlaug et al. [26] found that the anterior part of the corpus callosum was larger in musicians than in non-musicians, and the left planum temporale was larger in those musicians who possessed absolute pitch compared to musicians without absolute pitch and to non-musicians.

The corpus callosum data were interpreted as indicating a difference between musicians and non-musicians in interhemispheric communication of sensorimotor areas. It was assumed that playing an instrument with daily practice would result in enlargement of the respective part, i.e. training changes brain structure. The difference between musicians and non-musicians in this area of the corpus callosum was due to musicians who had started music practice before the age of 7, i.e., music practice has changed brain structure only when it was started before the age of 7.

With respect to the planum temporale results, Schlaug et al. [26] have argued that outstanding musical ability is associated with increased leftward asymmetry of cortex subserving music-related functions. Since the planum temporale develops between week 29 and 31 of gestation [5], Schlaug et al. have argued that the increased leftward asymmetry occurs prenatally and seems to be stimulated postnatally by special experiences made by musicians. Zatorre et al. [30] have also reported a greater left planum temporale in musicians with absolute pitch. They used MRI measures like Schlaug and coworkers did.

MRI techniques have also served Elbert et al. [2] to investigate the primary somatosensory cortices of string players in comparison to non-musicians. They found enlarged representation of the left thumb and little finger in string players. Results were due to those musicians who had started playing musical instruments before the age of 7. A study from Pantev et al. [23] has investigated the representation of tones in the cortex. Using functional magnetic source imaging technique, they measured cortical representations in highly skilled musicians. Dipole moments for piano tones, but not for pure tones of similar fundamental frequency (matched in loudness) were found to be enlarged by about 25% in musicians compared with control subjects who had never played an instrument. Enlargement was correlated with the age at which musicians began to practice and did not differ between musicians with absolute or relative pitch.

Micheyl and coworkers [21] were interested in lower auditory pathways and in cortical processing. They found that musicians' auditory system track sound levels more accurately than non-musicians. The activity of the MOBC (medial olivocochlear bundle), an auditory efferent subsystem, was measured in musicians and non-musicians and a significant difference between the two groups was found. Musicians had greater ability to maintain the perceived loudness of a sound, that is, to hear more closely the actual real levels of sound. While it seems likely that this is learned unconsciously, the authors also discuss the possibility that if innate, this ability predisposes people to become musicians.

There is also evidence for pre-attentively superior auditory processing in musicians. This was revealed by the brain's automatic change-detection response, which is reflected electrically as the mismatch negativity (MMN) and generated by the operation of sensoric memory, the earliest cognitive memory system [16]. Major chords and single tones were presented to both professional violinists and non-musicians. Slightly impure chords, presented among perfect major chords, elicited a distinct MMN in professional musicians, but not in non-musicians. According to Koelsch et al. [16], the outcome demonstrates that compared to non-musicians, musicians are superior in pre-attentively extracting more information out of musically relevant stimuli. Data are in line with earlier results [28]. Using the same method, these authors instructed musicians and non-musicians to read a book and ignore sounds while subjects were presented with a repetitive sound pattern with occasional changes in its temporal structure. The MMN component of ERPs was larger in amplitude in musicians than in non-musicians, indicating more accurate sensory memory function in musicians.

Is it because musicians have a finer auditory system that they react to music more sensitively than non-musicians? In the 1970 studies with musicians, among them the famous conductor Herbert von Karajan, and non-musicians have shown that there is a greater sensitivity of the autonomic nervous system of musicians to music [7]. New studies have confirmed early findings [3]. If musicians are exposed to music—the pieces may be vivid or calm—they react with an increase of heart rate and of other indicators of the autonomic nervous system. If one measures cortisol, a stress hormone, an increase is found in musicians even when they hear peaceful music. In non-musicians, on the other hand, peaceful music tends to initiate a decrease in heart rate and other indicators of the autonomic nervous system, or in stress hormones, if it does anything [29].

The relationship between the auditory system and emotions has been investigated mostly with rodents. In 1984, LeDoux and coworkers [17] found that, in rats, lesions to the medial geniculate nucleus (MG) and lower auditory centers, but not lesions to the auditory cortex, block autonomic and behavioral responses coupled to acoustic stimuli. The result was interpreted as indicating subcortical rather than cortical efferents of MG sustain these responses. In 1993, LeDoux found that the neural system underlying the conditioning of autonomic and behavioral fear responses to auditory stimuli involves projections through the auditory system to the medial geniculate body and from there directly to the amygdala [18]. In 1997, LeDoux and Muller [19] added some more details. The found that the amygdala's lateral nucleus receives and integrates the sensory inputs from the thalamic and cortical areas, and the central nucleus provides the interface with motor systems controlling specific fear responses in various modalities (behavioral, autonomic, endocrine). Internal connections within the amygdala allow the lateral and central nuclei to communicate.

Recent research with healthy human subjects also documented the intimate connection of the auditory system to emotions. To determine how vocally expressed emotion is processed in the brain, Morris et al. [22] measured neural activity in healthy volunteers listening to fearful, sad, happy and neutral non-verbal vocalizations. According to Morris et al., their data have demonstrated that processing vocal emotion involves a bilaterally distributed network of brain regions and that processing fear-related auditory stimuli involves context-specific interactions between the amygdala and other cortical and brainstem regions implicated in fear processing.

The above-mentioned studies [29] had included hormone measurement to test music in the context of stress. Another approach to study hormones in musicians was applied by the present author. Based on studies from psychology indicating that musicians tend to be psychologically androgynous—i.e. male and female personality characteristics coexist in a person irrespectively of the biological sex—we tested the hypothesis that psychological androgyny has a physiological basis. As an indicator of physiological androgyny the gonadal steroid testosterone (T) was measured in saliva. We found creative musicians (composers) had testosterone values that differed from non-musicians. Males' T levels were significantly lower and female's T levels were significantly higher than those of controls [11]. We have interpreted our data as indicating physiological androgyny in creative musicians. In a second group of creative male and female musicians, we found the pineal hormone melatonin was significantly higher in musicians than in non-musicians [13], and ACTH was significantly positive related to results of a music test [14]. One might suspect these results to indicate that a complex hormone system could differ between musicians and non-musicians.

We have also measured immune parameters in musicians and non-musicians. Our research [10, 12] was guided by theoretical considerations of Norman Geschwind and Albert Galaburda [5] who have summarized experimental findings on cerebral lateralization from various fields in neuroscience and have discussed biological mechanisms, associations and pathology, offering, i.e. a hypothesis about how experimental findings would suggest how musical talent develops.

Briefly summarized, it was argued that in about 1/3 of human development, the two cerebral hemispheres are somewhat different from that of the majority because the steroid hormone testosterone has, at a certain point of development, too strong effects on the developing brain. Whether the strong T impact is due to enhanced amount or enhanced effect, consequences for brain development are far reaching. After week 20 of gestation, testosterone can slow the development of the left cerebral hemisphere or parts of it and, as a compensatory effect, adjacent areas in the left and/or parts of the right cerebral hemisphere develop especially well. As a result, a slighly atypical brain anatomy is likely to occur. Atypical brain anatomy results in atypical processing of verbal and non-verbal materials and may be accompanied by atypical handedness, i.e. non-righthandedness, and may favor the occurrence of special talents like musicality.

Since immune structures are assumed to develop together with the left cerebral hemisphere, Geschwind and Galaburda have argued, the above-mentioned retardation of left hemisphere development also affects immune structures. They develop slower and influence postnatal functioning. As a consequence, in people with atypical brain anatomy, among them musicians, one can expect vulnerability towards autoimmune diseases, towards atopic diseases, i.e. they will be vulnerable towards allergies, asthma, eczemas, and towards other disorders for which the immune system is important.

We tested predictions from the hypothesis three times in 120 male and female adolescents whom we followed for 8 years throughout puberty and whom we retested 5 years after the 8-year longitudinal study had ended. To assess immunological parameters, we gave questionnaires to our subjects and, when they were about 19 years old, we measured immunglobulin E, the total amount of immunoglobulins, and β-endorphin in blood serum. According to Geschwind and Galaburda [5], we expected musicians would suffer more often than non-musicians from atopic diseases and would be more vulnerable towards atopic diseases as reflected by enhanced immunoglobulin E values. Our data were in line with the expectations; however, males and lefthanders suffered more often from atopic diseases than females and righthanders, and those who had right-hemisphere dominance for verbal processing were the most vulnerable as reflected by elevated immunoglobulin E values [10, 12, 9].

In spite of the diversity of approaches to study brain structure and function in musicians and to measure hormones and immune parameters, an idea begins to develop about how a musician may differ from a non-musician from a neurobiological point of view. We can imagine a person who has, in addition to musical talent, atypical brain organization for verbal and non-verbal materials and who possesses a very fine ear for music. He/she attends pre-consciously to musical materials and reacts to music as if music is a stressor, i.e., with increased activity of the autonomic nervous system and with increased stress hormone production. This person is very likely to be non-righthanded and to be vulnerable to atopic diseases, especially when the person is male. At the same time he/she is physiologically androgynous, i.e. testosterone levels are lower (males) or higher (females) than those of non-musicians, and at least one more hormone, the pineal hormone melatonin, is higher in both sexes compared to non-musicians. His/her brain reflects early music training by enlarged structures, like the anterior part of the corpus callosum and the representations for piano tones and for the left thumb and little finger in string players. If he/she posesses absolute pitch, the left planum temporale is larger than in controls.

For music medicine, the neurobiological findings seem to indicate that musicians are not patients like non-musicians even if they suffer from the same diseases as non-musicians do. Musicians differ from non-musicians in many aspects of brain structure and function, and in some hormones, neurotransmitters, and immune parameters. As Fedor-Freybergh put it in 1999 [4], the brain is the central nervous controller and neurotransmitters, systemic hormones and hormone-like mediators of immune cells are chemical messengers in this complex system. Though future research will have to clarify what kind of consequences these findings may have for the theory and practice of music medicine, the sensitivity of the autonomic nervous and the stress hormone systems of musicians towards music gives first ideas about the implications of neurobiological findings for treatment. Stage fright and psychic stress are among the most often reported complaints of musicians. Do musicians require a somewhat different therapeutic approach? There are only some reports about treatment of musicians and non-musicians with divergent outcome. Ross et al. [25] have recently published results of treatment of occupational cramp with botulinum toxin A. Their patients were writers and musicians. Moderate to complete improvement in dystonia occured in 70% after the first injection and in 85% after the second injection, with better outcome in non-musicians than in musicians. Möller* (personal communication) who practices at the two conservatories in Berlin, uses what he calls "baby doses" of amitritylin (25–50 mg) to treat pain syndromes in musicians but not in non-musicians. Whether these two examples are more than pure chance should be investigated in future research.

The above quoted studies give some evidence of new aspects which should be added to the above cited well known diseases of musicians. There seems to be a vulnerability of musicians towards atopic diseases. This was found in our experimental studies but is also confirmed by biographies of famous musicians in the past. Alban Berg, for example, suffered from eczemas his entire life, and Leonard Bernstein suffered from asthma from his early childhood—to name just two out of several other musicians. Since prevention is one of the most important goals of music medicine, it seems most welcome to take note of such vulnerabilities.

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