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Electroencephalography and Music Therapy: On the Same Wavelength?

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Abstract

Particularly due to its temporal resolution, electroencephalography (EEG) has proved to be a feasible tool to study music perception and cognition. Consistent with the growing impact of neuroscientific research in music within the last two decades, the application of electrophysiological parameters has become more interesting for music therapy as well. This article offers an overview of electrophysiological basics and principles of EEG recording. Further, it reviews some electrophysiological studies on music perception. Eventually, it focuses on the results of EEG studies in participants with depression: clinically relevant reductions in depression and anxiety parameters are accompanied by lasting changes in resting EEG, that is, significant absolute power increases at left frontotemporal alpha and theta waves. The implications for future developments in research and clinical practice of music therapy are discussed.

Keywords

electroencephalography (EEG), music therapy, emotion, depression, lateralization

Introduction

In 2012, more than 28 000 participants gathered in New Orleans for the annual meeting of the Society for Neuroscience. This number may give a good impression of the popularity of neuroscience. Accordingly, the past two decades have witnessed a surge of brain imaging studies in the field of cognitive neurosciences of music.[1] Music therapy (MT) gained interest as an applied area of neuroscientific research.[2] Music therapists are attracted by brain research, as some principles applied in therapy seem to be confirmed in neuroscientific research, for example, social aspects of music making.[3] Further, outcome research looks for biomarkers and predictors of treatment response.[4,5] Why is the study of the brain important for MT, and why is MT important for the study of the brain? Brain imaging methods are becoming more sophisticated and provide insights into brain processes related to human functioning and pathologies. Studies of the brain aim to show how music plasticizes fibers,[6] sparks neurotransmitter cascades,[7] and synchronizes body movement[8] and biological rhythms.

But will brain imaging help to foster internal or external validity of MT[9]; that is, how much of the research employed will help music therapists and health care decision makers to explain how and why MT works? Music therapists may want to contextualize brain activity during important moments in MT sessions, as demonstrated for instance in research on guided imagery and music,[10,11] but attempts to locate active MT in a laboratory setting impair the authenticity of the situation. The documentation of significant moments in therapy on recording appliances in particular demands a sensitive approach; that is, the measuring instruments must be adjusted as close as possible to everyday practice in order to generate context-sensitive data. However, technical limitations of brain imaging may restrict naturalistic settings of sessions. So far, in contrast to active music making,[12] receptive MT settings involving less body movement, for example, lying on a body monochord,[13,14] have been at the forefront of in situ brain research in MT.

This article aims to review and systematize current brain research by means of electrophysiological techniques applied in, or related to, MT, particularly with respect to depressive disorders.

Measuring Electrophysiological Activity of the Brain

There is only one thing that our brain cannot do and that is to stop doing something—and the end of this unresting activity is equivalent to the end of our lives: brain death. This lifelong activity, the endless stream of ongoing electrical currents in the brain, can be measured with a well-known neurological diagnostic tool called the electroencephalography (EEG). Gained with a set of electrodes applied to the surface of the scalp,

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amplified currents can be analyzed and rescheduled to the related events. It is possible to analyze the EEG visually or to quantify the EEG traces by computer-aided methods. The quantified EEG (QEEG) can be transformed to a surface map of EEG activity, exhibiting topographic variations in amount, percentage, and amplitudes of brain waves.[15] Results of an EEG experiment are mostly shown in a distinct brain wave pattern of a chosen time frame exhibiting more or less amount of wave ranges like alpha (α), beta (β), theta (θ), or delta (δ) waves, their amplitude power, changes in frequency, and topographic distribution. Such topographic activation patterns differ on frequency ranges (δ = 1-3 Hz, θ = 4-7 Hz, α = 8-12 Hz, and β = 13-30 Hz). This is an important feature of the EEG because dominant brain wave frequency ranges represent arousal and vigilance states that correspond to different consciousness aspects of the measured experience.

The EEG is used in pharmacological tests as a marker of vigilance states induced by pharmacological agents.[16] Today, in neurology, EEG is used mainly in differential diagnosis of epilepsy, disorders of consciousness, delirium, metabolic diseases, Creutzfeld-Jakob disease, and sleep polysomnography.[17] In psychophysiology, it is sensitive to personality factors, linkable to psychological test batteries and is interpreted as a somatic indicator of psychological processes.[18] Because of the time-locked occurrence of EEG, it has been used to show cerebral changes in music perception and experience compared to rest.[19] Therefore, we have a dynamic indicator that is sensitive to personality, situation, and cognitive cerebral strategies and also shows inter- and intraindividual differences in music perception.[20]

EEG, Sensory Data, and Correlated Experience

We know that brain activity is central to human cognitive and perceptive functions. By recording synchronized or desynchronized brain waves we represent this relationship graphically by utilizing topographic maps, wavelets, etc.

We could record sensory data from efferent pathways of the auditory system by using auditory evoked potentials (AEPs) because those frequency patterns basically reflect responses to signals traveling along the auditory pathway through brain stem, mid-brain, and cerebrum, which can be measured just a few milliseconds after an acoustic stimulus.[21] The continuous EEG discussed here, however, shows its event-related reactions of the subject in its complex ways, including auditory and other sensory data, as represented in the ongoing brain activity. This gives us a more or less stable physiological marker of individual cerebral interaction related to behavioral interventions. To achieve comparability, normative EEG databases have been developed.[22] Currently, unlike other brain imaging techniques, various EEG analysis tools offer a comparison of individual EEG records to integrated normative EEG database. This includes age-, gender-, and condition-matched controls, in order to estimate *z*-scored deviation from normality.

Still, we have to be aware that complex stimuli are represented by a pattern of firing across ensembles of neurons transmitting *electro*physiological information patterns, visible with an EEG apparatus. If we compare those event-related patterns with patterns derived during rest, then we may see a difference. This leads us to the center of the *psycho*physiological measuring problem, which is discussed in philosophy as "psychophsiological parallelism."[23] On one hand, we have personal music experience and, on the other, a parallel obtained, event-related EEG trace exhibiting some describable features like frequency and amplitude.

> The problem is that the experience and their phenomenological, that means describable expressions [here—a neuronal correlate] are distinct modalities of perception, that exist together but do not exchange or explain each other. The relationship between the modalities is there, because they exist together in the same time and space related coordination [translation by the authors].[23(p8)]

Music Perception in the EEG

To our knowledge, one of the first EEG studies on music dates back to 1959.[24] Research on music and the EEG reflects the problem of interindividually distinct music experiences. EEG coherence analysis shows intraindividually constant EEG coherence profiles during music perception, but those profiles spread over the whole cortex.[21] Davidson and Hugdahl conclude that variations reflect individual perceptual differences and can be observed in the baseline measures (ie, in the rest EEG) before administering sound bits, music fragments, or words.[25] Music listening seems to involve many different brain areas but is believed to have a right hemispheric dominance[26] as results in EEG research conveyed.[21,22,27] Further, early research on music making, comparing musicians and nonmusicians, reported increased right parietal hemispheric activation for nonmusicians but not for musicians, indicating that musical training has an influence on EEG asymmetry scores (see the following); that is, nonmusicians showed more right hemispheric activation.[28,29] However, in her review on human brain mapping methods of music perception, Sergant insists that there is no real evidence that music seems to be processed dominantly in the right cerebral cortex,[30] and over the last 20 years widespread networks of human brain functions have been described processing music and its emotional and cognitive involvement with a bilateral distribution.[19]

Emotional modulation of limbic structures, activation of the perception-action mediation in premotor areas, and intentional processes of social cognition in frontal and temporal areas are discussed as possible neuroscientific concomitants of music therapeutic action.[31] A study on frontotemporal lobar degeneration in 26 patients indicated the importance of frontotemporal areas for the recognition and processing of emotion in music.[32] Further, increases in the density of gray matter of Broca area have been found in orchestra musicians,[33] indicating the relevance of musical training for frontotemporal brain plasticity.

Nonverbal expression of emotional content through music creation, and subsequent verbal reflection of its personal meaning, is part of the therapeutic relationship established during MT.[34] When processing musical structure, syntactic and semantic violations of musical expectations have been shown to correlate with early right anterior negative EEG activity (ERAN) in right inferior frontal cortex structures,[35] while syntactic incongruities in speech have been correlated with left-lateralized negative EEG responses (ELAN) of Broca area.[36] Processing of music and language has been observed in frontotemporal areas.[37]

Applications of EEG in MT

Frontal Processing of Emotion in Music. Schmidt and Trainor[38] showed that frontal alpha asymmetry (FAA; a hemispheric lateralization coefficient, describing the power ratio between 2 homologous electrodes on the left and the right side of the brain) distinguished the valence of musical excerpts. Participants exhibited greater relative left frontal EEG activity to musical excerpts representing joy and happiness and greater relative right frontal EEG activity to excerpts representing fear and sadness. When listening to music rated as representing positive valence, significant left frontal activity changes in EEG were found.[39] A series of studies demonstrated an *immediate* effect of pleasurable music listening on FAA in depression; that is, during and after music listening, a relatively right-sided frontal activity of adolescents with depression[40] shifted toward relatively left-sided activity. These results indicate an influence of music listening on frontal processing during depression (see next paragraph).

Theta changes in frontal areas also seem to demonstrate emotional processing of music. Frontal midline θ power (FMT; a distinct array of electrodes in the frontal part of the brain) increases over the time course of listening to pleasant music,[41] during state-dependent recall of dance and music,[42] and fronto-central θ power increases when pleasant music is associated with emotional valence.[43]

Improvisational MT and Depression Treatment. According to the World Health Organization (WHO),[44] depressive disorders are the leading cause of disability worldwide in terms of total years lost due to disability. One of the unresolved issues in this context is that treatment in depression still follows a trial-and-error regime, as there are no reliable predictors at hand, allowing us to determine who will benefit from a certain treatment and who will not. The EEG derived biomarker seems to be a promising tool to predict treatment response in the near future.[45] Most consistently, in participants with depression, a left-sided frontal hypoactivation of α power (α asymmetry) has been described in several studies.[16,17] However, although FAA and FMT seemed to have a high reliability regarding the validity of the EEG as a biomarker for MT treatment, more research is needed.[4]

Emotion processing while listening to music shows immediate effects on the EEG, in terms of α and θ manifestations. The aim of the study by Fachner et al was to find out whether these effects are lasting and can be observed in an additional resting EEG recording, that is, the one not taken during or directly after listening[40] but after a course of active MT.[5] Therefore, in a 2-armed randomized controlled trial (RCT) with 79 clients, they compared standard care (SC) with MT added to SC at intake and after 3 months. Correlations between anterior EEG, Montgomery-Åsberg Depression Rating Scale (MADRS) and the Hospital Anxiety and Depression Scale–Anxiety subscale (HADS-A), power spectral analysis (topography, means, and asymmetry), and normative EEG database comparisons were explored. After 3 months of MT added to SC, MADRS and HADS-A scores were significantly decreased. Further, lasting changes in resting EEG were observed, that is, significant absolute power increases at left frontotemporal α but most distinct for θ (also at left frontocentral and right temporoparietal leads). Music therapy differed from SC at F7-F8 (FAA, $P < .026$) and T3-T4 (θ, $P < .005$) asymmetry scores, pointing toward decreased relative left-sided brain activity after MT (see Figure 1); further increased pre-/post-FMT and decreased HADS-A scores ($r = .42$, $P < .05$) were observed.

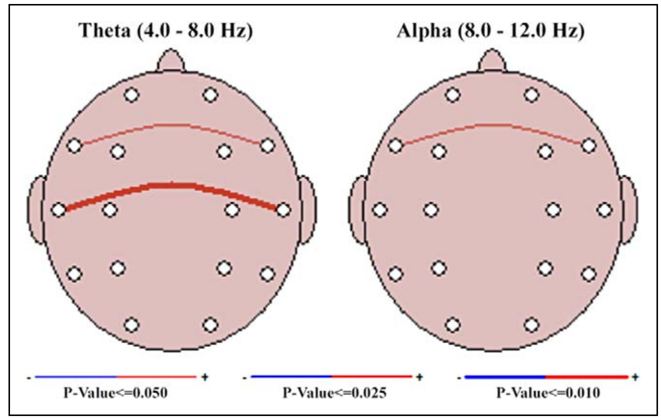

Figure 1. Intergroup (post MT mean—post SC mean) asymmetry change was significant (independent *t* test) for F7-F8 (alpha $P < .026$; theta $P < .03$ [represented as thin lines]; $df = 57$;) and T3-T4 (theta $P < .005$ [represented as thick line]; $df = 57$). Red indicates increase in asymmetry between power values at homologous electrodes; positive (alpha) value indicates greater left (alpha) power, that is, less cortical activation in the left hemisphere (asymmetry) lateralization coefficient calculated by 200 $\times$ (L − R/L + R); linked mastoid reference, all right-handed. MT indicates music therapy; SC, standard care; *df*, degrees of freedom.

Anxiety and Attention Focus. The FMT has been suggested as a potential marker for anxiety.[46] Given the high comorbidity of depression with anxiety,[47] which may also be relevant for patients with a primary diagnosis of depression. A significant correlation of FMT and HADS-A after MT indicated a link between anxiety and power changes.[5] Thus, according to the findings on anxiolytic medication and θ increases,[48] results reported in the study by Fachner et al suggest that MT helps to reduce anxiety in clients with depression, which in turn is reflected in increased FMT power.

Balconi et al[49(p151)] identify frontal θ as playing a significant role in "monitoring the attentional significance of emotions."

Anterior and FMT power may reflect positive emotion and internalized attention as suggested in a study on meditation.[50] The FMT is identified and discussed as a correlate of heightened mental effort and sustained attention observable in states of low-level awareness.[42,48,51] Erkkilä et al[34] discussed low-level awareness as an ingredient of preconscious creative processes in the therapeutic play space of effortless improvising. Pizzagalli et al[52] linked θ increases in mid-frontal areas to cerebral metabolism changes in the anterior cingulate cortex. In addition to the findings of Pizzagalli et al elicited from clients with depression, another music listening study reported that θ increases were linked to equivalent dipole activity in the middle cingulate cortex induced by music with emotional valence and arousal.[43] In the study by Sammler et al,[41] FMT increased significantly when comparing the EEG before and after 22 seconds of listening to music with content previously rated as being pleasant. Gruzelier[51(pS107)] describes the functional increases in power and coherence in the θ frequency range as indicators for internal creative cognitive associations that "arise from integration through the co-activation by slow wave activity of distributed neural networks." The differences in lateralization and power in the study of Fachner et al[5] may indicate that MT clients have learned to relax and focus their attention on internal processes differently than the SC clients who have not been through the processes of psychodynamic improvisation.[34]

Conclusion

In comparison with the neuroimaging methods, EEG displays some striking advantages, particularly in the study of music and MT paradigms: it has a higher temporal resolution, is less invasive, and is nowhere near the expensive functional magnetic resonance imaging and positron emission tomography. We showed that the application of EEG in a natural-like MT setting is feasible and warrants detection of MT-related changes in resting EEG in participants with depression. In future, EEG recordings might be helpful in serving as a biomarker, for example, in prediction of treatment responses. Still, the use of EEG in MT is hampered by some technical restrictions. Recent developments of telemetric EEG hardware applications allow to use bigger[53] or smaller portable EEG units[54] in order to record data while performing music and so on. Such advancements might broaden the possible field of application of EEG recording in MT research. Thus, for EEG and MT, being on the same wavelength becomes even more likely.

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