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How does Music Modulate Electroencephalographic Rhythms and Autonomic Responses?*

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Abstract

Music influences human emotions and behaviors, potentially modulating cerebral and autonomic functions. This study investigates whether variations in musical tempo induce distinct changes in electroencephalographic (EEG) activity, heart rate (HR), and respiratory rate (RR) in eight healthy individuals, comparing musicians and non-musicians. Polysomnographic recordings monitored EEG (delta, theta, alpha rhythms), HR, and RR during wakefulness while participants listened to two musical themes at different tempos. Results showed significant EEG changes, with theta rhythm exhibiting the most pronounced variations across tempos, suggesting its role in processing tempo changes. Non-musicians displayed greater increases in RR and HR variability compared to musicians, who showed moderated autonomic responses, possibly due to musical training. These findings highlight tempo's impact on neuro-autonomic processing and suggest that musical training may enhance control over autonomic responses, offering insights into music's therapeutic potential.

Keyphrases

Music processing, tempo, audition, EEG rhythms, heart rate, respiratory rate, rhythm variability.

Introduction

Human behavior is driven by complex motivations that, while not always apparent from a rational perspective, are oriented toward experiences of satisfaction. Music plays a significant role in shaping human emotions and motivations, eliciting emotional responses and modulating complex behaviors. These effects are reflected in alterations in cerebral cortex activity and autonomic functions, such as heart rate and respiratory rate (Ooishi et al. 2021). Internal rhythms, critical for processing and executing cognitive and physiological functions, may be influenced by external rhythms to optimize performance. The human brain possesses the ability to decode musical structures, distinguishing parameters such as *tempo*. This study investigates whether different versions of the same musical theme, modified solely in *tempo*, induce distinct changes in the electrical activity of the cerebral cortex, as well as in breathing and heart rate, during wakefulness. Additionally, it explores whether individuals with formal musical training (musicians) exhibit different responses compared to those without such training. The goal is to provide insights into how the brain and autonomic nervous system process music and its *tempo* variations.

Methods

Polysomnographic recordings were conducted in eight healthy individuals to monitor electroencephalographic (EEG; T3, T4, T5, T6; 10-20 System) activity, heart rate (HR), and respiratory rate (RR) during wakefulness, as auditory processing varies during sleep (Velluti 2018). These signals were processed offline, comparing a baseline silence period with responses evoked by two musical themes—"Oh, Pretty Woman" (Orbison) and Ravel's "Bolero"—presented at three different *tempos*: unchanged, slower, and faster (Pro Tools 8.0, Digidesign), delivered through headphones. During recording sessions, volunteers remained lying in wakeful relaxation with closed eyes in comfortable conditions. An initial 5-minute silence period served as the baseline, followed by a sequence of alternating 2-minute music and 2-minute silence periods for each *tempo*. Ten 5-second time windows were selected for each condition. Power spectrum analysis (Fourier), amplitude spectrum, and relative power of delta (δ, 0.5–3.9 Hz), theta (θ, 4–7.9 Hz), and alpha (α, 8–12 Hz) waves were used to process the selected windows, comparing baseline with music at different *tempos*. HR and HR variability (HRV) were recorded via electrocardiogram, and RR was measured using a respiratory belt. Statistical analysis employed the Student's t-test, Wilcoxon test, and Bonferroni correction for multiple comparisons.

Results

Analysis of EEG activity revealed the following findings: (1) The three studied frequency bands—delta (δ, 0.5–3.9 Hz), theta (θ, 4–7.9 Hz), and alpha (α, 8–12 Hz)—exhibited changes when comparing silence to different musical *tempo* conditions. (2) The theta rhythm showed the most pronounced variations, with significant differences observed between music and silence and across different *tempos*. (3) The delta rhythm displayed the least change, likely due to recordings being conducted during wakefulness, as this frequency is predominantly associated with slow-wave sleep. (4) The alpha rhythm exhibited a decrease, consistent with the expected alpha blockade in response to sensory stimulation.

Regarding respiratory and cardiac parameters, comparisons between musicians and non-musicians yielded the following results: (1) Breathing became more rhythmic and rapid during music exposure in both groups,

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with non-musicians showing a greater increase. (2) In non-musicians, heart rate increased across all *tempos* of the musical themes compared to baseline, whereas musicians experienced an initial heart rate increase followed by a decline below baseline levels after the third *tempo* change. (3) Non-musicians exhibited higher heart rate variability (HRV) in the presence of music compared to musicians.

Discussion

Among the EEG rhythms studied, distinct processing appears to occur for different *tempo* variations. Theta activity emerges as the rhythm most sensitive to *tempo* changes, aligning with prior findings on its role in information processing (Herweg et al. 2020; Lu et al. 2022). Animal studies have demonstrated dynamic temporal correlations between theta rhythm and auditory processing under various sound stimulation conditions and during behavioral changes (Pedemonte, Peña, et al. 1996; Pedemonte, Pérez-Perera, et al. 2001; Liberman et al. 2009). In humans, theta rhythm is known to support episodic memory, learning, and memory consolidation, facilitating associative memory, working memory, cognitive control, and rhythmic shifts (Herweg et al. 2020; Lu et al. 2022).

Conclusion

The observed autonomic changes were consistent with studies indicating that brain rhythms, particularly theta rhythm in animals, modulate vegetative activity alongside sensory processing (Pedemonte, Rodriguez, et al. 1999; Pedemonte, Goldstein-Daruech, et al. 2003; Pedemonte, Rodriguez, et al. 2005). Heart rate and respiratory rate responded to music in both musicians and non-musicians, though these responses were more moderate in musicians. These results suggest that prior musical training may enhance control over autonomic responses to musical stimuli, potentially due to learned regulation through instrumental practice.

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Contributions

All authors contributed to the study. MP was responsible for the study design and manuscript revision.

References

[1] N. A. Herweg, E. A. Solomon, and M. J. Kahana. "Theta oscillations in human memory." *Trends in Cognitive Sciences* 24.3 (2020), pp. 208–227. DOI: 10.1016/j.tics.2019.12.006 (cited p. 2).

[2] T. Liberman, R. A. Velluti, and M. Pedemonte. "Temporal correlation between auditory neurons and the hippocampal theta rhythm induced by novel stimulations in awake guinea pigs." *Brain Research* 1298 (2009), pp. 70–77. DOI: 10.1016/j.brainres.2009.08.089 (cited p. 2).

[3] J. Lu, A. Moussard, S. Guo, Y. Lee, et al. "Music training modulates theta brain oscillations associated with response suppression." *Annals of the New York Academy of Sciences* 1516.1 (2022), pp. 212–221. DOI: 10.1111/nyas.14854 (cited p. 2).

[4] Y. Ooishi, M. Kobayashi, M. Kashino, and K. Ueno. "Presence of three-dimensional sound field facilitates listeners' mood, felt emotion, and respiration rate when listening to music." *Frontiers in Psychology* 12 (2021), p. 650777. DOI: 10.3389/fpsyg.2021.650777 (cited p. 1).

[5] M. Pedemonte, N. Goldstein-Daruech, and R. A. Velluti. "Temporal correlation between heart rate, medullary units and hippocampal theta rhythm in anesthetized, sleeping and awake guinea pigs." *Autonomic Neuroscience: Basic and Clinical* 107.2 (2003), pp. 99–104. DOI: 10.1016/S1566-0702(03)00143-3 (cited p. 2).

[6] M. Pedemonte, J. L. Peña, and R. A. Velluti. "Firing of inferior colliculus auditory neuron is phase-locked to the hippocampus theta rhythm during paradoxical sleep and waking." *Experimental Brain Research* 112.1 (1996), pp. 41–46. DOI: 10.1007/BF00227176 (cited p. 2).

[7] M. Pedemonte, L. Pérez-Perera, J. L. Peña, and R. A. Velluti. "Sleep and wakefulness auditory processing: Cortical units vs. hippocampal theta rhythm." *Sleep Research Online* 4.2 (2001), pp. 51–57 (cited p. 2).

[8] M. Pedemonte, A. Rodriguez, and R. A. Velluti. "Hippocampal theta waves as an electrocardiogram rhythm timer in paradoxical sleep." *Neuroscience Letters* 276.1 (1999), pp. 5–8. DOI: 10.1016/S0304-3940(99)00767-8 (cited p. 2).

[9] M. Pedemonte, A. Rodriguez, and R. A. Velluti. "Electroencephalographic frequencies associated with heart changes in RR interval variability during paradoxical sleep." *Autonomic Neuroscience: Basic and Clinical* 123.1-2 (2005), pp. 82–86. DOI: 10.1016/j.autneu.2005.09.003 (cited p. 2).

[10] R. A. Velluti. *The Auditory System in Sleep*. 2nd ed. Amsterdam: Elsevier-Academic Press, 2018. ISBN: 978-0-12-810476-7 (cited p. 1).