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·Original Article·

Brain oscillations and electroencephalography scalp networks during tempo perception

Yin Tian[1,2], Weiyi Ma[2], Chunyang Tian[2], Peng Xu[2], Dezhong Yao[2]

[1]*Bio-information College, Chongqing University of Posts and Telecommunications, Chongqing 400065, China*

[2]*Key Laboratory for NeuroInformation of the Ministry of Education, School of Life Science and Technology, University of Electronic Science and Technology of China, Chengdu 610054, China*

Corresponding authors: Yin Tian and Dezhong Yao. E-mail: tiany20032003@163.com, dyao@uestc.edu.cn

ABSTRACT

In the current study we used electroencephalography (EEG) to investigate the relation between musical tempo perception and the oscillatory activity in specific brain regions, and the scalp EEG networks in the theta, alpha, and beta bands. The results showed that the theta power at the frontal midline decreased with increased arousal level related to tempo. The alpha power induced by original music at the bilateral occipital-parietal regions was stronger than that by tempo-transformed music. The beta power did not change with tempo. At the network level, the original music-related alpha network had high global efficiency and the optimal path length. This study was the first to use EEG to investigate multi-oscillatory activities and the data support the tempo-specific timing hypothesis.

Keywords: EEG scalp network; alpha; beta; theta; tempo

INTRODUCTION

Tempo, which is the rate of periodic events that listeners perceive to occur at regular intervals, is an important property of music and can influence the expressiveness and mood effects of music[1,2]. Based on behavioral findings, two competing hypotheses have been proposed on tempo-transformation perception, the relational invariant timing hypothesis which proposes that tempo transformations are perceptually invariant when a melody is transformed to a different tempo but its frequency ratios are maintained[3], and the tempo-specific timing hypothesis which holds that the tempo-transformed performance is perceptually unnatural, based on the idea that expressive timing in musical performance is related to the global tempo[4,5]. Thus, the cognitive basis of tempo perception still needs further examination.

Scalp electroencephalography (EEG) with high temporal resolution can reveal brain activity associated with processing of the dynamic aspects of musical structure. Using magnetoencephalography (MEG)/EEG, studies have shown that various brain structures are activated in the perception of temporal structure in music[6-8]. However, the dynamics of the brain processes underlying tempo perception remain unclear.

The classical EEG frequency bands are defined based on the oscillatory rhythms in EEG traces under specific behavioral states. Different frequency components may represent different functions. Theta in the frontal midline regions (Fm theta) is linked with musical emotional arousal[9]. Alpha power is inversely related to brain activity[10]. In addition, alpha oscillations in the bilateral occipital-parietal areas are associated with musical tempo perception; such that alpha power is stronger with original music than with tempo-transformed music[11]. Beta-band activity in somatosensory-related cortex may be associated with motor inhibition[12], and it also synchronizes between two remote electrode sites when information is transmitted from one brain region to another[13]. Therefore, the engagement of these three oscillations might indicate the dynamic processing of musical tempo perception. To our knowledge, few studies have examined the multi-oscillatory activities and the scalp EEG network for music tempo perception. Thus, this study determined whether the oscillatory activity of the Fm theta, the bilateral occipital-parietal alpha, and the bilateral somatosensory beta are associated with the arousal level, naturalness, and musical motor-related inhibition, respectively, in music tempo perception. Furthermore, we also investigated the information transference of scalp EEG networks structured by each specific oscillatory band during tempo perception.

PATICIPANTS AND METHODS

Participants

Twenty participants (16 males, 4 females, 26.9 ± 4.5 years) participated in the behavioral ratings for the music stimuli tested. Twelve right-handed males (22.4 ± 4.5 years) consented to participate in the EEG study. None reported any formal musical training, or had prior exposure to the tested music. Nor had they a history of mental or neurological disorders. Informed consent was obtained prior to the study, and the participants were paid. All experiments were approved by the Ethics Committee of the University of Electronic Science and Technology of China.

Procedure

A Mozart sonata (piano) was presented by a computer binaurally through headphones at different tempi: moderately-decreased transform (26 beats per minute, bmp), original (52 bmp), moderately-increased transform (78 bmp), and ultra-transform (138 bmp). Half of the participants heard the slower music before the faster music and the other half *vice versa*. In behavioral rating tasks, participants rated each music piece (naturalness, emotional status, arousal level, and probability of the original tempo) on a 9-point scale[4].

EEG Recording and Data Analysis

EEG was recorded with a 128-channel EEG system (sampling rate: 500 Hz, impedance <40 kΩ). The data were re-referenced to the infinity reference using REST software[14-16]. For each of the four tempi, a 48-s EEG segment from each participant with artifacts removed was used for further analysis.

The power spectra of three frequency bands, theta (4–7 Hz, Fpz), alpha (8–13 Hz, PO3/PO4), and beta (14–30 Hz, TP7/TP8), were generated. The EEG data were subjected to Fast-Fourier Transform analysis to obtain the power of each frequency band.

Eighteen regions of interest (ROIs), Fp1, Fp2, Fz, F3, F4, F7, F8, C3, C4, T7, T8, Pz, P3, P4, P7, P8, O1, and O2, defined in the 10-20 international electrode system were used to construct the network. The coherence between ROI pairs was used to measure the interaction, i.e., the edge. After the weighted network was calculated, a threshold that guarantees the connection of the network was used to binarize the network. Based on the binarized network, clustering coefficients, shortest path-length, local efficiency and global efficiency were calculated to evaluate the local and global characteristics of the network.

RESULTS

Behavioral Results

The behavioral results are shown in Fig. 1A. Repeated measures ANOVAs with one factor (tempo) showed that tempo variations affected perceptual naturalness [$F(3,57) = 20.29$, $P < 0.001$], arousal level [$F(3,57) = 38.77$, $P < 0.001$], and probability of original rating [$F(3,19) = 30.50$, $P < 0.001$]. But non-significant main effects were observed for preference and emotional status, indicating that tempo transformations did not influence listeners' preference and judgment of emotional status for a musical piece. Paired *t*-tests (Bonferroni-adjusted) further revealed that the naturalness rating decreased from the original (7.15 ± 1.53, mean ± SD) to the moderately-transformed (26 bmp, 5.95 ± 1.60; 78 bmp, 4.90 ± 1.94, both $P < 0.05$), then to the ultra-transformed tempo (3.55 ± 1.84, $P < 0.05$), but did not differ between the two moderately transformed tempi ($P > 0.1$). Furthermore, the 52 bpm music (8.25 ± 0.85) was rated more likely to be the original music than the three tempo transformations ($P < 0.05$). For the arousal level, both 138 bmp (7.75 ± 1.16) and 78 bmp music (7.35 ± 0.67) were more exciting than slower music (52 bmp, 6.50 ± 0.88; 26 bmp, 4.55 ± 1.53), but there was no difference between 138 bmp and 78 bmp.

Power Spectrum

Fm theta power was submitted to repeated-measures ANOVA with one factor: tempo [$F(3, 33) = 8.79$, $P < 0.01$]. *Post hoc t*-tests revealed that the theta power of the ultra-transformed (138 bmp, 3.02 ± 0.11) and the moderately-increased tempi (78 bmp, 3.58 ± 0.17) were significantly

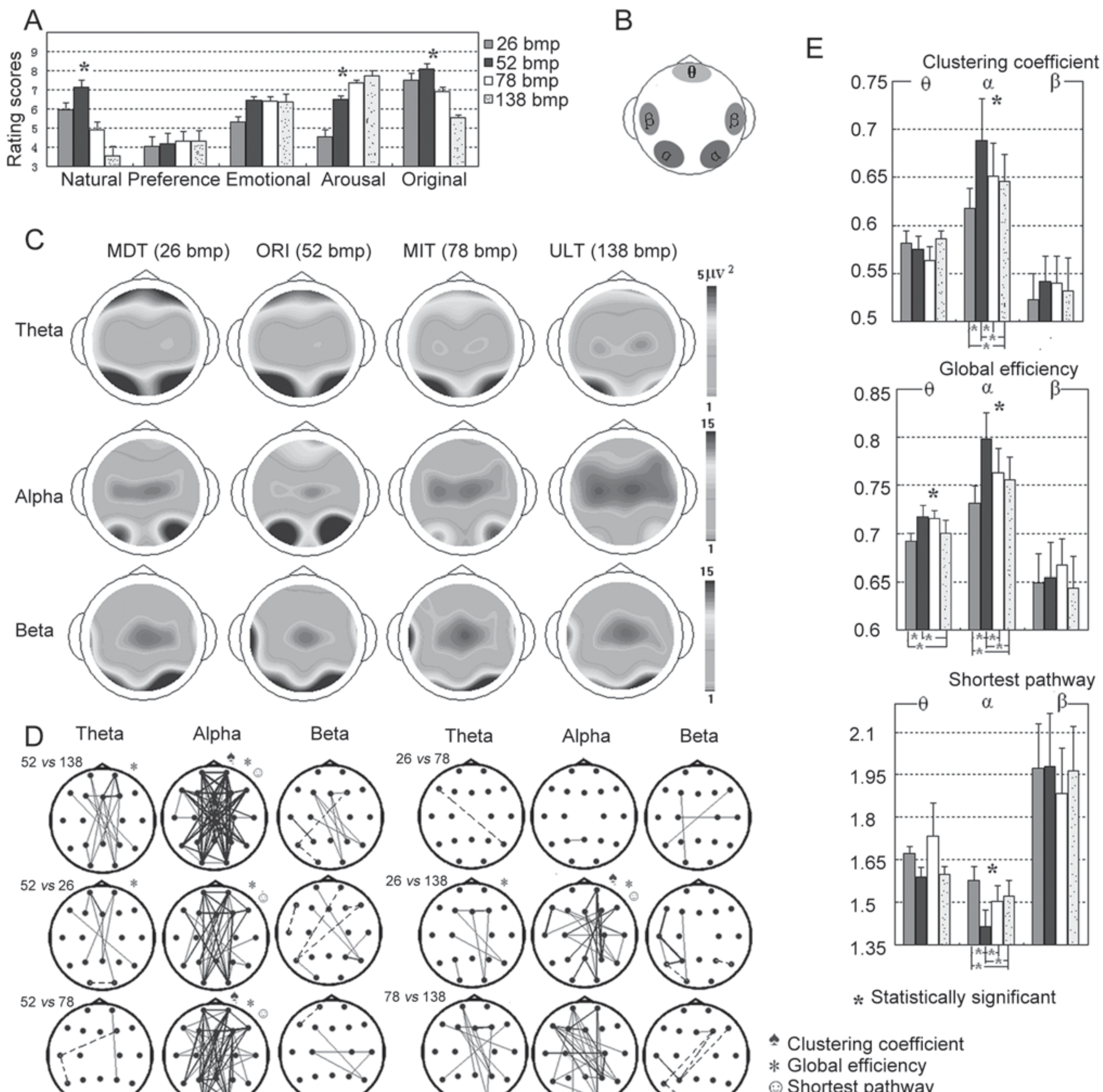

Fig. 1. Spectral mapping and corresponding discrepancy scalp EEG networks for specific frequency bands. A: Behavioral results. B: Specific oscillatory activations at specific regions of interest. C: Spectral distribution mapping. D: Scalp EEG network discrepancy. The solid lines denote the edges that had statistically significant increased linkage between the two networks, and the edge thickness delineates increased strength; the dotted lines denote decreased strength. E: Network properties of (C). MDT: moderately-decreased transform; MIT, moderately-increased transform; ORI, original; ULT, ultra-transform.

smaller than that of slower music (52 bmp and 26 bmp) (all P <0.05). In addition, the theta power of the original (52 bmp, 4.01 ± 0.19) was also less than the moderately-decreased tempi (26 bmp, 4.33 ± 0.19, P <0.05).

Bilateral parietal-occipital alpha was analyzed by 4 (tempo) × 2 (hemisphere) repeated-measures ANOVA. There was a marginally significant main effect of hemisphere [F(3, 33) = 4.47, P = 0.058], with alpha power being stronger in the right than in the left hemisphere. A significant main effect of tempo [F(3, 33) = 4.56, P <0.05] also occurred. Separate one-way ANOVA further analyzed the alpha power in each hemisphere, and found significant main effects of tempo in both the left and right occipital-parietal regions. Separate paired-sample Bonferroni adjusted t-tests revealed that in each hemisphere, alpha power significantly decreased from the original (left, 13.25 ± 1.47; right, 17.02 ± 1.72) to the moderately-transformed (26 bmp: left, 9.71 ± 1.28; right, 11.76 ± 1.41; 78 bmp: left, 8.19 ± 0.87; right, 11.08 ± 1.16), and then to the ultra-transformed (left, 6.06 ± 0.59; right, 7.91 ± 0.71) tempo music (all P <0.05).

Bilateral somatosensory-related beta was also submitted to a 4 (tempo) × 2 (hemisphere) repeated-measures ANOVA. A significant main effect of hemisphere emerged, such that the left hemisphere had a stronger somatosensory-related beta power than the right hemisphere [F(3, 33) = 9.80, P <0.01]. None of the other power measures reached significance.

Scalp EEG Network

One-way repeated-measures ANOVA with tempo was used to test the network properties on the different oscillatory-band networks. On the alpha network, significant effects of tempo on cluster coefficient, global efficiency, and shortest path-length were found [all F(3, 33) >8.82, P <0.001]. On the theta network, a significant effect of tempo on global efficiency was found [F(3, 33) = 8.79, P <0.05] (Fig. 1E). *Post hoc* tests revealed that (1) on the alpha network, the cluster coefficient and the global efficiency of the original music were higher than those of the three types of transformed music (all P <0.05), and the values for the 26 bmp tempo were lower than those for the 138 bmp tempo. The shortest path-length of the original tempo was shorter than that of any of the three transform tempi. (2) On the theta network, the global efficiency of the 26 bmp tempo was lower than that of the original (52 bmp) and ultra-transform (138 bmp) tempi (both P <0.05), and the global efficiency of 52 bmp was higher than that of the 138 bmp tempo. None of the other analyses of the network properties revealed significant effects (all F <1) (Fig. 1E).

DISCUSSION

Fm Theta and the Music Arousal of Tempo

Fm theta power (Fig. 1C) decreased from the slower (26 bmp) tempo to the original tempo, and then to the fast (78 bmp) and the ultra-fast (138 bmp) tempi. This finding indicated that Fm theta power is inversely associated with the arousal level induced by tempo changes, consistent with the behavioral rating of arousal and previous findings[17]. Therefore, Fm theta power can provide a reliable electrophysiological index of the perception of arousal induced by tempo changes.

Bilateral Occipital-Parietal Alpha and Musical Naturalness of Tempo

We found that occipito-parietal alpha power (Fig. 1C) decreased from the original tempo to the moderately-transformed (both 26 and 78 bmp) tempi, and then to the 138 bmp tempo, consistent with the behavioral ratings of naturalness. In addition, Ma *et al.*[9] found that alpha power changed with the naturalness rating of a musical performance. Based on the finding that the occipito-parietal alpha is associated with attention[10], the change in posterior alpha may be related to the possibility that tempo-transformed music is more attention-getting than the original music.

Bilateral Somatosensory-related Beta and Music-Motor Inhibition for Tempo

Previous research found that music makes listeners move or start motor preparation[18]. The higher beta power (Fig. 1C) in the left somatosensory-related region may reflect motor inhibition. The left hemisphere inhibition in the beta-band may be related to the right-handedness of our subjects. But no difference was found in music perception with tempo.

EEG Scalp Network and Tempo Perception

The four properties of the EEG scalp network consist of two aspects: (1) local information processing (cluster coefficient and local efficiency), and (2) processing and transfer of global information at the network level (path-length and global efficiency).

In the alpha network, we found that the original tempo had a higher cluster coefficient and global efficiency and shorter path-length than the transformed tempi (Fig. 1D, E). These properties showed that the alpha network might have a stable and powerful information processing and transfer ability with regard to the naturalness perceived at the original tempo. Furthermore, the alpha network discrepancy (Fig. 1D) also demonstrated that the network related to the original music had a denser connection between the frontal and posterior occipito-parietal areas than the tempo-transformed tempi. This denser connection and the optimal (i.e. shortest) path-length may guarantee efficient processing and information transfer of the original music. Therefore, the alpha network provides evidence to support the tempo-specific timing hypothesis.

In the theta network, we found the global efficiency of the original tempo was significantly higher than that of the 26 bmp and 138 bmp tempi, but did not differ from that of the 78 bmp tempo (Fig. 1E). This finding was partly consistent with the aforementioned Fm theta power. The difference may be due to the fact that the Fm theta power is associated with local regions (i.e. anterior areas) concerned with arousal, while the theta network is associated with the whole network level concerned with music perception.

Beta oscillatory activity is associated not only with motor inhibition but also cognitive processes. For example, an unchanged level of beta oscillatory activity might indicate no change in the cognitive or perceptual set. Otherwise, high activity in the beta band means top-down control for endogenous processing[12]. In the beta network, we did not find significant differences among tempi (Fig. 1E), which suggested that there was no change in cognitive set with musical features, such as preference and familiarity. That is, the unchanged beta level is related to these features in the current tempo perception. However, the original tempo networks in the beta band showed a relatively stable connection between the left anterior area and the right posterior area, which may indicate other musical functions such as the naturalness of top-down control at the whole network level, though significant effects were not observed.

CONCLUSION

The current study is the first to investigate the relation between musical perception with tempo and the activation of multi-oscillations in local regions and at the network level. We found that Fm theta power increased with decreased arousal, bilateral occipito-parietal alpha power was higher than that of transformed tempi, and beta power did not change between tempi. These findings provide evidence from both oscillatory power and the network level to support the tempo-specific timing hypothesis. Moreover, the specific oscillatory activity might represent the different effects of musical tempo and musical perception may be attributed to the common coordination of multi-oscillatory activities.

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REFERENCES

[1] Dalla Bella S, Peretz I, Rousseau L, Gosselin N. A development study of the affective value of tempo and mode in music. Cognition 2001, 80: 1–10.

[2] Gagnon L, Peretz I. Mode and tempo relative contributions to “happy-sad” judgments in equitone melodies. Cogn Emotion 2003, 17: 25–40.

[3] Repp BH. Relational invariance of expressive microstructure across global tempo changes in music performance: An exploratory study. Psychol Res 1994, 56: 269–284

[4] Honing H. Evidence for tempo-specific timing in music using a web-based experimental setup. J Exp Psychol Human 2006, 32: 780–786.

[5] Honing H, Ploeger A. Cognition and the evolution of music: Pitfalls and prospects. Top Cogn Sci 2012, 4: 513–524.

[6] Knosche TR, Neuhaus C, Haueisen J, Alter K, Maess B, Witte OW, *et al*. Perception of phrase structure in music. Hum Brain Mapp 2005, 24: 259–273.

[7] Maess B, Koelsch S, Gunter TC, Friederici AD. Musical syntax is processed in Broca's area: an MEG study. Nat Neurosci 2001, 5: 540–545.

[8] Popescu M, Otsuka A, Ioannides AA. Dynamics of brain activity in motor and frontal cortical areas during music listening: a magnetoencephalographic study. Neuroimage 2004, 4: 1622–1638.

[9] Sammler D, Grigutsch M, Fritz T, Koelsch S. Music and emotion: electrophysiological correlates of the processing of pleasant and unpleasant music. Psychophysiology 2004, 44: 293–304.

[10] Palva S, Palva JM. New vistas for alpha-frequency band oscillations. Trends Neurosci 2007, 30: 150–158.

[11] Ma W, Lai Y, Yuan Y, Wu D, Yao D. Electroencephalogram variations in the alpha band during tempo-specific perception. Neuroreport 2012, 23(3): 125–128.

[12] Engel AK, Fries P. Beta-band oscillations-signalling the status que? Current opinion in Neurobiology 2010, 20: 156–165.

[13] Nikolaev AR, Ivanitsky GA, Ivanitsky AM, Posner MI, Abdullaev YG. Correlation of brain rhythms between frontal and left temporal (Wernicke's) cortical areas during verbal thinking. Neurosci Lett 2001, 298: 107–110.

[14] Yao D. A method to standardize a reference of scalp EEG recordings to a point at infinity. Physiol Meas 2001, 22: 693–711.

[15] Yao D, Wang L, Oostenveld R, Nielsen KD, Arendt-Nielsen L, Chen A. A comparative study of different references for EEG spectral mapping: the issue of the neutral reference and the use of the infinity reference. Physiol Meas 2005, 6: 173–184.

[16] Qin Y, Xu P, Yao D. A comparative study of different references for EEG default mode network: the use of the infinity reference. Clinical Neurophysiology 2010, 121(12): 1981–1991.

[17] Bradley MM, Lang PJ. Measuring emotion: Behavior, feeling, and physiology. In: Lane RD, Nadel L (eds.). Cognitive Neuroscience of Emotion. Oxford: Oxford University Press, 2000: 242–276.

[18] Janata P, Grafton ST. Swinging in the brain: Shared neural substrates for behaviors related to sequencing and music. Nat Neurosci 2003, 6: 682–687.