Musicians and the gamma band: a secret affair?

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While listening to music, a significant high degree of phase synchrony in the γ frequency range globally distributed over the brain was found in subjects with musical training (musicians) compared with subjects with no such training (non-musicians). No significant differences were found in other EEG frequency bands. Listening to neutral text did not produce any significant differences in the degree of synchronization between these two groups. For musicians, left-hemispheric dominance was found during listening to music. The right hemisphere was found to be dominant for non-musicians in text listening. The high degree of synchronization in musicians could be due to their high ability to retrieve musical patterns from their acoustic memory, which is a cogent condition for both listening to and anticipating musical sounds. *NeuroReport* 12:371–374 © 2001 Lippincott Williams & Wilkins.

Key words: Binding; EEG; Gamma oscillations; Music; Phase synchronization

INTRODUCTION

Synchronization is one of the most basic phenomena in which neuronal assemblies of distant brain areas communicate with each other in order to find a meaning in a complex environment [1,2]. Rhythms in the γ-range (>30 Hz) are thought to be strongly correlated with cognitive tasks involving long-range synchronization [3,4]. It has also been emphasized [5] that the γ-band activity serves as a mechanism for binding various intricate aspects of object perception into a unitary whole. In this study we analyzed spontaneous EEG recorded from two broad groups, musicians and non-musicians, while they were listening to a piece of music written by J.S. Bach and to a neutral text. The general aims of the present study were threefold: (i) to search for differences, if any, in the degree of phase synchrony between the two groups for processing these two tasks, (ii) to probe the role of different frequency bands, and (iii) to measure in which way the processing in terms of phase synchrony was different between these two cognitive tasks.

MATERIALS AND METHODS

Spontaneous EEG signals (standard 10-20 system) were recorded for 90 s from 20 male subjects (10 musicians, mean age 25.7 years, each with at least 5 years of musical training and 10 non-musicians, mean age 25.4 years with no musical training) by 19 electrodes at standard 10-20 position [6] with a sampling frequency of 128 Hz, in different conditions: listening attentively to a piece by J.S. Bach (*French Suite No. 5 for Harpsichord*, Gigue: the piece was not known to the subjects) and listening to a text (a short story, 'Versündigung gegen die Nachwelt' by H. Weigel, read by Christiane Hoerbiger). Baseline drifts in EEG were removed by subtracting a polynomial of second order and detrended signals were band-pass filtered to extract the components associated with different frequency bands: δ (0.025–4 Hz), θ (4–7 Hz), α (7–13 Hz), β (13–30 Hz) and γ (30–50 Hz).

Classically, two periodic oscillators are synchronized in phase if their relative phase difference is zero for all time. For noise-free coupled identical oscillators, phase synchronization and frequency locking are synonymous. For systems with small internal noise or nonlinear chaotic systems, relative phases are not zero due to the phase slips of $\pm 2\pi$ and the relative phases are stable only between two phase slips. For strong and unbounded noise (i.e. Gaussian noise), phase slips occur in an irregular way, so the segments of nearly stable phase are very short and the relative phase difference series perform a biased random walk [7] (this is unbiased only at the center of the synchronization region); thus, the detection of phase synchrony is not trivial for such cases and it can only be inferred in statistical sense [8]. In this report, we adopted the method of analytical signal approach [9], which is well suited for measuring phase synchrony for noisy and non-stationary signals [10]. Briefly, the instantaneous phase of a time series $\{x(k)\}$ is given by $\mathrm{atan}(x_h(k)/x(k))$, where $\{x_h(k)\}$ is the Hilbert transform of $\{x(k)\}$, and the distribution of relative phases mod 2π for a pair of time series was obtained. To characterize the strength of phase synchrony, the index $\rho = (H_{max} - H)/H_{max}$ was computed where H is the entropy of the earlier distribution and H_{max} is the maximal entropy. The higher the value of ρ, the stronger the degree of phase interaction.

For each frequency band, computations were done using a non-overlapping window of 6 s duration. Within each window 171 values of ρ are produced considering all possible combinations between 19 electrodes. Further, to assess the strength of phase synchrony in musicians compared to non-musicians, we carried out a normalization procedure to obtain synchrony values comparable between near and distant electrode pairs. Given ρ_{ij} (ρ for electrode pair i and j), let μ_{ij} and ν_{ij} be the mean and variance computed from the set of non-musicians; the relative phase synchrony values are computed as: $\sigma_{ij} = (\rho_{ij} - \mu_{ij})/\sqrt{\nu_{ij}}$. If $\sigma_{ij} > 2$, it can be inferred that the degree of phase synchrony between electrode pair i and j, was significantly higher for musicians than non-musicians.

RESULTS

Figure 1 shows the topographic profiles of phase synchrony (ρ) in the γ frequency range, averaged over all possible combinations of each electrode for each position for both groups during listening to music and text, respectively. In both groups, midline electrodes emerged as most influential ones in their neighbourhood. This can be due to the presence of more neighbouring electrodes for midline than for lateral electrodes. These average profiles are similar in shape for both groups as well as for both tasks. However, there are several substantial points to be mentioned. First, during listening to music, the degree of synchronization is much higher than that in non-musicians; in all electrode combinations, significant increases ($p < 0.0001$) were found for musicians. Second, there were no significant differences between these two groups while listening to a neutral text. Finally, the amount of total phase synchrony in the brain dropped significantly for both groups during text listening.

In order to probe the role of other frequency bands, the whole study was repeated for these bands, as mentioned before. The main results obtained from our studies of phase synchrony showing the important role of the γ band in the musicians are summarized in Fig. 2. Phase synchrony in the four frequency bands (δ, θ, α and β) did not differ significantly between the musicians and non-musicians during perceptions of music. Only phase synchrony in the γ range was found to be significantly higher for musicians during this task. While listening to the text, no statistically significant difference was found between the two groups.

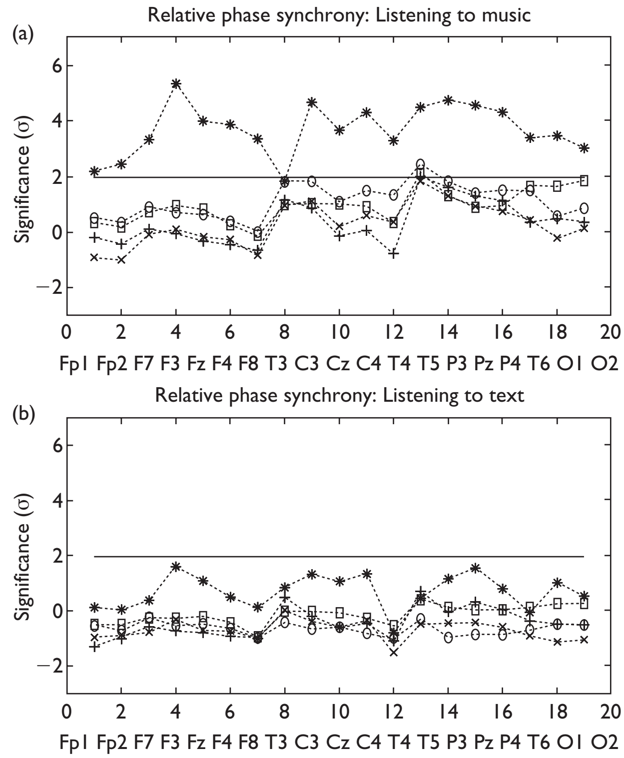

Fig. 2. Phase synchrony for musicians relative to non-musicians in terms of σ, during listening to music (**a**) and to text (**b**). Results (averaged over windows, subjects within each group, and for all possible combinations for each electrodes) are shown in five frequency bands: δ (circles), θ (squares), α (crosses), β (x), and γ (*). Horizontal line ($\sigma = 2$) denotes the level of significance above which the degree of phase synchrony in musicians is significantly higher than that of the non-musicians. No other band except γ was significant while listening to music.

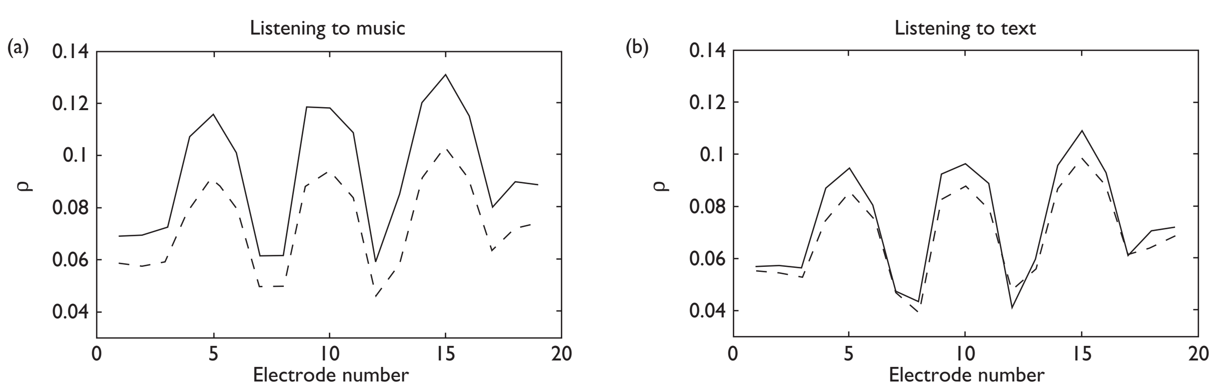

Fig. 1. Phase synchrony (ρ) in the γ range for musicians (solid line) and for non-musicians (dotted line), averaged over non-overlapped windows and over subjects within each group, for all possible combinations for each electrode (F1, F2, F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1 and O2 numbered as 1, ..., 19) during listening to J.S. Bach (**a**), and to a neutral text (**b**). Note that for musicians the higher degree of phase synchrony induced by music but not by text.

We also studied the variations of time sequence of phase synchrony incorporating different electrode combinations i.e. intrahemispheric, interhemispheric, and with midline electrodes. During the entire perception of music, in the musicians (Fig. 3a), midline cortical areas and the left hemisphere have stronger phase synchronization than the right hemisphere (Mann-Whitney rank sum test, $Z = 5.13$, $p < 0.001$), whereas for non-musicians (Fig. 3b) such clear discrimination was not explicit ($Z = 1.22$, not significant). During silent listening to text (Fig. 4) the right hemisphere was more dominant ($Z = 3.75$, $p < 0.01$) for the non-musicians.

DISCUSSION

The results presented here raised two broad questions: why, in musicians, is a high degree of synchronization induced by music but not by text, and (ii) why do only frequencies in the γ range emerge as significantly different. There is increasing evidence that γ frequencies serve for temporal binding of information from various sensory modalities converging into association areas for the formation of meaningful concepts [3–5,11–15]. The repeated synchronous firing of neurons in co-stimulated areas may underlie γ oscillations which probably do not represent information itself but rather provide a temporal structure for correlation in the neurons that do encode specific information [16]. Therefore, it is not surprising that γ oscillations play a momentous role in the perception of music in which a variety of acoustic items such as pitch, loudness, timbre, melodical and harmonical structure, rhythm and others, have to be combined together to perceive the acoustic blend as music. One main process while perceiving music (apart from listening) is the involvement of working memory for classifying, first, the acoustic events just passing by and, secondly, for anticipating. Broadly speaking, we anticipate what we already know; thus, trained musicians implicitly retrieve an extensive collection of musical patterns from their memories. Furthermore, a trained ear incessantly shifts focus between various aspects for higher order, looking for 'edges' of musical objects. All these processes have to be coordinated instantaneously. For a musician, the greater power of his musical memory and of their anticipatory ability may be one reason for such high degrees of synchronization in the γ range.

The question of hemispheric dominance has been the subject of a greater number of studies with, however, conflicting results, probably due to the fact that different

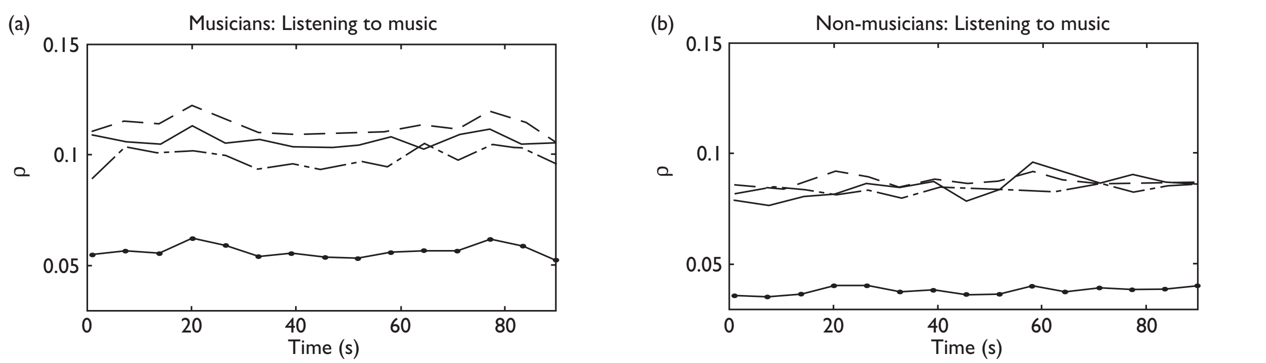

Fig. 3. (**a**) Time course of phase synchrony in γ-band while listening to J.S. Bach for musicians and (**b**) for non-musicians. Results were averaged over all subjects within each group and all possible electrode combinations as follows: within left hemisphere (solid line), within right hemisphere (– · – · –), with midline electrodes (——), and for inter-hemispheric connections (connected by large dots). In musicians, apart from the highest degree of phase synchrony related to midline, the left hemisphere possesses higher phase synchrony than the right. In non-musicians, no differences between these three combinations are evident.

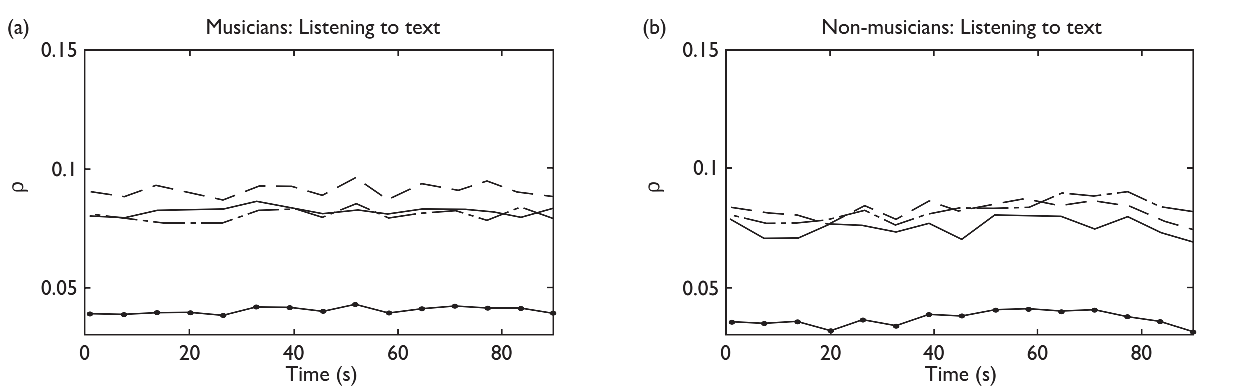

Fig. 4. As for Fig. 3, but while listening to text.

musical elements were investigated by a diversity of procedures including EEG [17], ERP [18], PET [19] and rCBF [20]. The present study touched this problem only marginally. Our results in this respect, however, indicate a stronger phase synchrony in the left than the right hemisphere in musicians than non-musicians during listening to music. The question, however, whether this asymmetry is contingent upon handedness (all subjects were right-handed) has to be left open. As for (silently) listening to text, no difference in phase synchronization was found between the two groups.

CONCLUSION

This brief report demonstrates that musical training has a strong impact on the degree of induced phase synchrony in the γ frequency range during processing music but not during text-processing. Since perception of music involves so many hidden degrees of freedom (among others mood, personality, inherent musical ability etc.), the true reason for this induced synchrony in the γ band in musicians may remain a secret. If the working hypothesis stands, then we predict that during listening attentively to any kind of music, enhancement in the degree of phase synchrony in the γ frequency range for musicians is always likely.

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