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Comparing Brain Responses to Different Styles of Music through Their Real and Imagined Interpretation: An Analysis Based on EEG Connectivity Networks †

González, A. [1], Modroño, C. [2] Santapau, M[3]. and J.J.González [2,*]

[1] Departamento de Historia del Arte, Universidad de La Laguna (Spain); agonzabr@ull.edu.es
[2] Departamento Ciencias Médicas Básicas, Universidad de La Laguna (Spain); jugonzal@ull.edu.es
[3] Departamento de cuerda, Conservatorio Profesional de Requena (Spain); santapaucello@gmail.com
* Correspondence: agonzabr@ull.edu.es

Abstract: The aim of this work was to assess brain responses of expert cellists during a real (INT) or imagined (IMG) interpretation of two musical styles with different learning/training cognitive roots. EEGs of 12 cellists were recorded while they interpreted (INT/IMG) previously memorized excerpts of tonal-baroque (T) and atonal-contemporary (A) music and, at rest (R). Phase synchronization functional connectivity measurements among different cortical regions were computed from the EEG data and at different frequency bands (FB). These were then thresholded using surrogate data tests. Brain network construction and graph-metric analysis was performed for each FB and condition/interpretation. Global graph-indices statistical results showed that regardless of FB: a) the node degree and density presented significant differences among-conditions T, A and R during IMG and between-interpretations with INT>IMG only for A; b) global (GE) and local (LE) normalized efficiency (vs random network), indices measuring network information exchanges, exhibited a similar small-world network structure (SW) in T, A and R during INT; however, during IMG, SW changed in T and A but due to a significant LE increase with LE(A)>LE(T)>LE(R). Statistical node topographic maps results showed significant differences for graph degree (INT>IMG) and for LE (IMG> INT) in A for certain nodes of delta and theta EEG FB networks. Styles differences appearing only during IMG (e.g., the SW) indicate that IMG requires/involves different cognitive functions/processes to those in INT. The analysis and previous results allowed the discrimination of representative musical styles from different periods which receive a different cognitive learning in the musicians' life.

Keywords: music; functional connectivity; EEG.

1. Introduction

Professional musicians interpret different musical styles throughout his career, also use musical imagination as a tool for training and studying music. This way of working makes the musician an excellent model for the study of different perceptual, cognitive and emotional functions in processes of imagination. Indeed, it is known that in the process of musical imagination, the musical images formed are a mental representation of the music in which underlying mechanisms of perception are active and committed to it [1]. It is also known that, in the absence of sound, specific musical imagination tasks consistently recruit belt and peri-belt regions of the auditory cortex [2, 3] and also enhance functional interactions between the temporal cortex and auditory cortex [4]. In an analysis of electroencephalographic EEG activity in violinists during both real and imagined interpretation, bilateral activations of the opercular regions was found [5]. Also using EEG analysis, the process of musical imagination induced an activation of the alpha EEG band significantly stronger than during musical perception [6]. In general, the networks involved in musical imagination seem to be associated with auditory processing, sensorimotor coordination, memory retrieval, and cognitive and emotional control ([7,8]. In one of the few studies on brain connectivity during musical performance using fMRI [9] it was reported that both real performance and musical imagination involve the supplementary motor area (SMA): musical imagination increased (compared to rest) the connectivity of the SMA with extended brain regions related to cognitive control, motor planning and syntactic processing. These authors also propose that the SMA network builds "the internal representation of musical performance" by integrating multimodal information required for representation. Recently, these authors [10] also found, during musical imagination, a greater CF of the parital angular gyrus with other brain areas such as the precuneus, hippocampus and amygdala. With the exception of these works, we do not find in the literature works on brain connectivity during imagined performance compared to the real one, and none that addresses this comparison in the performance of different musical styles by musicians with different performance / cognitive background in these styles. We consider this issue to be of interest in the opportunity / need to teach different musical styles in conservatories. With this purpose, our work addresses the real and imagined interpretation of two musical styles of different musical structure (tonal and atonal) related to different cognitive levels with the learning and professional life of expert musicians. For this we use several indices of graph theory applied to the EEG functional connectivity networks computed during the real and imagined interpretation tasks in those styles.

2. Materials and Methods.

Participants were12 right-handed healthy professional cellists, mean age 39.25± 6.56 (SD) (7 males and 5 females), more than 20 years training and experience in musical practice and active professional practice. They received verbal and written information about the type of study and were previously provided with a document to sign their consent. The two excerpts to be interpreted were: the first (T) consisted in the 26 s of a tonal excerpt (T) of Sarabande (II Suite for solo cello, J.S. Bach); the second (A) was a transformation of Sarabande composed by one of the authors (A. González, see characteristics at Brain Sci. 2021, 11(2), 159) with contemporary atonal (A) music characteristics (same duration as T). Each participant received the two musical extracts that they had to perform by mail one month beforehand so that they could prepare their training and memorization. Acquisition of EEG Signals: during the interpretation, inside an electrical isolated room, the participants with the EEG electrodes cap on, remain seated with their eyes closed and covered by a mask could hear the start instructions for each task through nearby speakers. A blocked experimental design was used in the EEG study. The whole experiment was conducted in a single session where the cellist had to start the real (or imagined) interpretation of the extract (T or A) when they received a key word instruction through the speakers and went to Resting (R) after 26 s when they received the corresponding order. The process was repeated six times and the order of the extracts to be performed was altered to avoid habituation according to the block (Resting - task) sequence as follows: (R-A-R-T-R-T-R-A-R-T-R-A-R-A-R-T-R-A-R-T-R-T-R-A). Monopolar EEG records were carried out using a 19 electrodes cap (Frontals Fp1-2, frontals dorsal F3-3 and ventral F7-8, interhemispheric Fz, Cz, temporal T3-4, posterior T5-6, parietal C3, C4, P3, P4, Pz and occipitals O1-2). The EEG recording procedure, the pre-processing procedure for selecting non-artefactual EEG episodes in each condition, the calculus of the phase synchronization index to estimate the functional connectivity (FC) between the 19 electrodes pairs, the data surrogate test to threshold functional connectivity indices previously to the graph indices computations were similar to those used in our recent work [11]. As in this work, from each 19x19 connectivity matrix, central topological indices of each EEG-FC network (at each EEG frequency band) were obtained for each node and then averaging for all nodes: average node degree and graph density were computed for connectivity global network alteration. Also normalized versus random network of local (NLE) and global efficiency (NGE) -indices representing how efficiently a network exchanges information at local and global level (vs random network)- were computed to study small-world (NLE>1; NGE ~1)

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structure alterations in the different musical conditions considered. Finally, as in Gonzalez et al., 2021, MANOVA for repeated measurements (here repeated factors were: real and imagined interpretations; tonal, atonal and resting conditions and 5 EEG frequencies bands) to check the existence for the global graph indices of statistical differences among repeated factor or significant interactions between them. Moreover, permutation test- a method that adjusts the p-values in a way that controls for the family wise error rate- for comparisons between the nodal indices (here the node degree and NLE) of two graphs, and to build topographic maps of the graph indices statistical significance between different contrasts.

3. Results

The MANOVA test for the interpretation INT factor was significant for the average node degree (F statistic= 23.76, Degree of Fredom=1-11 and Probability=0.000) and graph density (F=24.26, DF=1-11 and P=0.000) with real-INT > imag-INT regardless of repeated factor TAR (tonal T, atonal A and resting R) and FBs (delta…gamma EEG frequencies). Also, the INT*TAR interaction shows significant alteration for degree (F=8.72, DF=2-10 and P=0.006) and density (F=12.75, DF=2-10, P=0.001). Paired post-hoc tests for this interaction (see Figure 1 A2 and B2 for significant P values) show that: a) the 2 indices were significant greater during real-INT in T and in A music than during its imag-INT performance; b) when comparing separately T, A and R conditions during real-INT or imag-INT, only significant results among conditions during imag-INT were found: the 2 graph indices magnitude were greater at R than during T or A conditions; moreover, T-A differences were significant only for the graph density index (with T>A). Although the INT * TAR * FB interaction does not show statistical significance, their mean values and confidence intervals obtained during real-INT or imag-INT, in the 3 performance conditions TAR and in the 5 FBs, are shown in Figure 1 (left column) for comparative purposes with the topographic results showed below.

The results of the MANOVA test corresponding to the normalized (vs. random network) local (NLE) and global (NGE) efficiency show only significant results for NLE. Indeed, NLE showed significant results for the INT factor (F=26.12, DF=1-11 and P=0.000) resulting greater in imag-INT than in real-INT. Figure 2 shows that NLE and NGE magnitudes were closest to those expected for a small-world type network (NGE ~ 1 and NLE > 1) mainly during real-INT for all TAR conditions and FBs. During imag-INT the small-world network structure alters - in relation to the real-INT performance- because NLE increase (irrespective of TAR and FB) (NGE does not change). Furthermore, it was found that IN*TAR factor shows significant interactions (F=12.60, DF=2-10 and P=0.001) : while in real-INT there were not NLE changes with TAR conditions, during imag-INT the NLE was greater during T and A than in R and also was greater in A than in T (see statistical levels at Fig. 2-A2). Therefore, small-world deviation (due to NLE alterations) appears only during imag-INT and it is because NLE moved away from 1 (i.e., network increases its local information transfer relative to that of a random network) while NGE (the global information transfer indices) does not change. In addition, during imag-INT, this effect appears more prominent during A that during T music which was near to the R condition. This result did not manifest during real-INT.

Results of the graph metric at the node level: topographic maps. Only the heads and nodes that presented statistical significance through the corresponding permutations test were plotted and/or pointed out below. The results for the average node degree were as follows (Figure 3): Significant nodes during real-INT in the Tonal - Resting contrast: Delta Band: Cz. Theta Band: T6, O2, Cz. Alpha Band: O1, P4, Cz. Beta Band: Cz. Gamma Band: Fz, Cz. During imag-INT (IMG) Tonal - Resting contrast: Delta Band: F3, C4. Theta Band: C3. Alpha Band: F3, O1, F4, F8, T6, O2, Fz. During real-INT for Atonal – Resting contrast: Delta Band: O2, Fz, Cz. Theta Band: Fp1, T5, O1, T6, O2, Cz. Alpha Band: O1, O2, Cz. Beta Band: Cz. Gamma Band: Cz. During imag-INT Atonal – Resting contrast: Delta Band: all nodes. Theta Band: all nodes. Alpha Band: all nodes except F3, C3, Cz, C4. Gamma Band:

F3, C3, P3, T5, P4, T6, Cz, Pz. The results for the normalized local efficiency were as follows (Figure 4): Significant nodes existed only in Atonal – Resting contrast, they were: Delta Band: all nodes except Cz, C4, T4. Theta Band: all nodes except C3, Pz, O. Alpha Band: P3, F8, Fz. Beta Band: T3, T4, Fz. Gamma Band: F7, C3, T3, P3, T5, O1, Fp2, F8, P4, O2, Pz.

3.1. Figures.

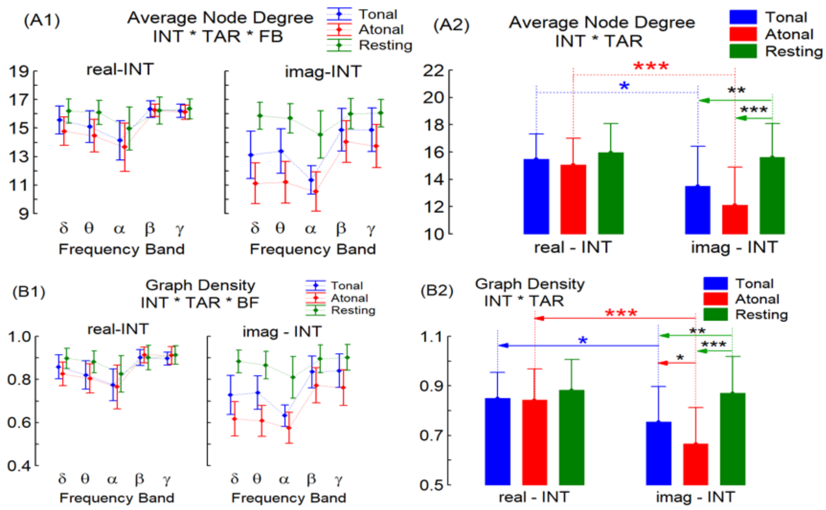

Figure 1. Mean values (95% confidence interval) for the average node degree (A1, A2) and graph density (B1, B2) of EEG graph/network. In the left side (A1, B1) the cross interactions (INT * TAR * FB) between the two INT performance modes (real-INT and imag-INT), the 5 frequency bands FB (delta-δ, theta-δ, alpha-δ, beta-δ and gamma-γ) and the 3 musical conditions (tonal, atonal music and rest) can be visualized. In the right column (A2, B2) the INT*TAR cross-interactions (irrespective of FB) between real-INT / imag-INT and the 3 musical conditions are show. Asterisks * are for the significance levels of the posteriori comparisons between pairs of repeated factors (* for $p < 0.05$, ** for $p < 0.01$, and *** for $p < 0.001$).

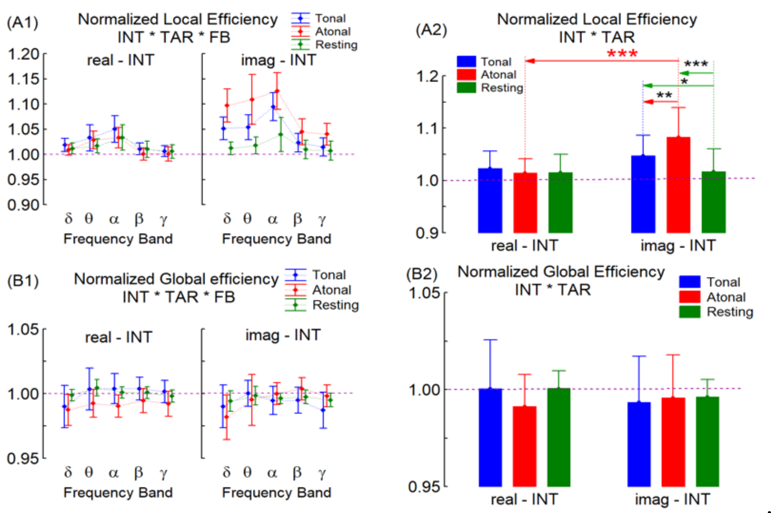

Figure 2. As in Figure 1 but for the normalized local (A1, A2) and global (B1, B2) efficiency of the EEG graph/network. The red line indicates the limit value for a random network according to the selected normalization process.

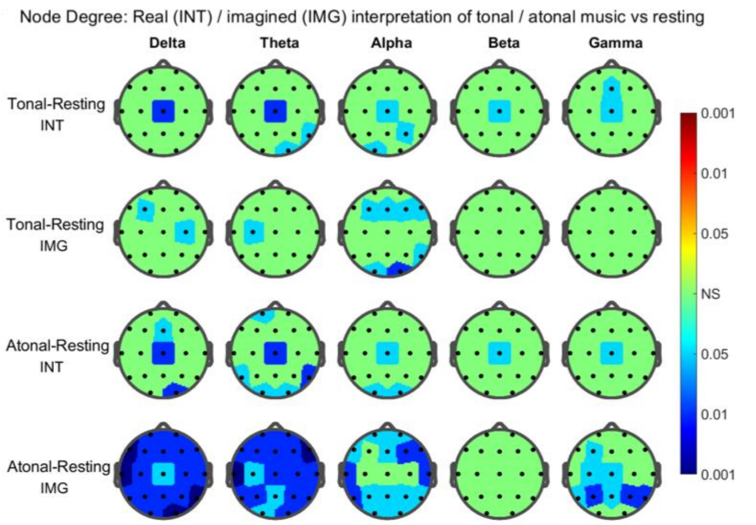

Figure 3. Statistical significance values of the node degree Tonal-Resting or Atonal-Resting difference during real (INT) and imagined (IMG) interpretations (left column) for the five graphs/head nodes of each EEG frequency band indicated. Color area around each node corresponds to the significance level P in the color-bar on the right (valid to all heads); the colors were associated with the three levels of significance ($p < 0.001$, $p < 0.01$, and $p < 0.05$) by using three range of reds when difference was positive or three blues range when it was negative. NS in green for nodes without statistical significance.

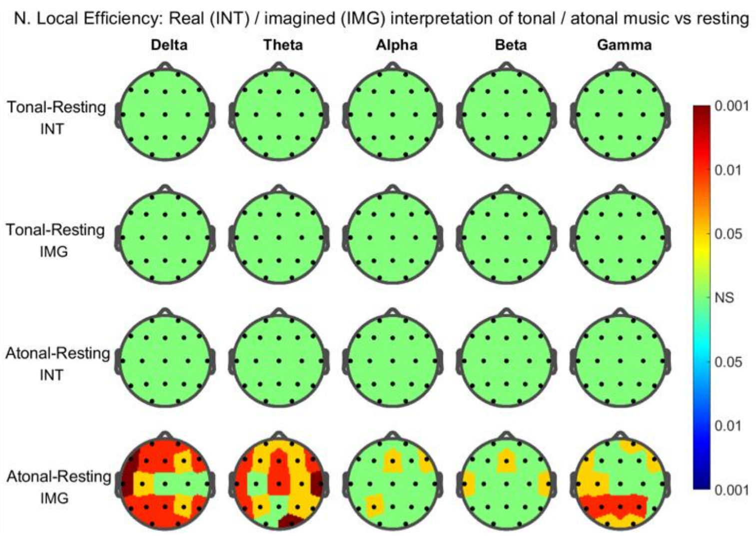

Figure 4. As in Figure 3 but for the normalized local efficiency.

4. Discussion

The real interpretation (real-INT) of the tonal (T) and atonal (A) music extracts similarly alters the cortical connectivity by decreasing the nodal degree (versus resting (R)) of the interhemispheric central frontal cortical area Cz under which underlies the supplementary motor area (SMA). This effect occurs mainly in the networks / graphs of the delta and theta frequency bands (FB) (see Fig. 4). The imagined interpretation (imag-INT) of T music does not produce this effect nor significantly alter the global connectivity in any of the networks of the different FBs. On the contrary, the imag-INT of extract A prominently modifies cortical connectivity, decreasing the nodal degree vs R of most of the cortical zones in the delta and theta networks, of the temporal zones (mainly T3, T4) in the alpha network and of the parietal nodes in the gamma network. Therefore, the responses to the real-INT of both styles T and A are similar, involving in both styles the cortical motor zone close to the SMA and do not differ in any of the FB networks. However, the response to the INT-image of both styles is totally different, inappreciable in T music and very prominent in the case of A music. From these results, it seems that the real-INT in the selected EEG paradigm is not able of discriminating musical styles; only the motor activity of the musician related to body postural stabilization and coordination of both sides during bimanual action, that is, the control of movements that are internally generated rather than triggered by sensory events seem to be reflected. In fact, in our paradigm, only alteration in the connectivity of SMA appears without differences between T and A styles. By the contrary, imag-INT clearly discriminate both music styles; it seems that in this kind of interpretation cognitive and emotional requirements predominate and in our EEG paradigm no motor areas except during A is reflected. At this respect it must be argued that, T music is a music whose structure and syntax is rooted in the brain development of the musician from the beginning of his professional learning. On the other hand, the A music does not have the same cognitive and emotional root as the T one, which would explain the results of the imag-INT of A music. The only work with which we can compare our results is one in which it is reported that during the imagined interpretation of tonal music in an fMRI analysis [9] the connectivity of the SMA area with other brain centers is altered. Our results do not coincide with those of these authors, we found alterations of the SMA area in the real interpretation of music T and A. Only in the imagined Interpretation of music A we found cortical motor areas involved in some of the FC-EEG networks (delta, theta and gamma). Probably the different paradigms used are the causes of the discrepancies. Finally, the results of the indices measuring the transmission efficiency of local and global information in each EEG network analyzed here, are conclusive, only the imagined interpretation of atonal music produces important alterations of the small-world structure by increase (in relation to a random network) of the local efficiency mainly in the delta, theta and gamma networks and of different cortical zones depending on the network. Therefore, the imagined interpretation of the style of music that has a lesser cognitive root in the musician is the one that seems to produce a cortical response (in our paradigm) clearly different to music styles of more rooted in the brain of the musician.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

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Conflicts of Interest: The authors declare no conflict of interest.

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