Comparative analysis of brain activation in trained musicians during attentive motionless listening of regular and irregular rhythmic patterns

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Abstract: - Professional musicians have learned to perceive music using different strategies; one of them is rhythmic grouping, commonly referred as rhythmic perception. Specifically, most studies suggest that perception of regular rhythmic patterns in musicians favors a specialization of the left hemisphere. This paper suggests that the use of irregular rhythmic sequences favour an activation of different brain areas from those observed in previous studies during perception of regular rhythmic sequences.

Keywords: - Rhythm, Perception, Irregular rhythms, Motor-related areas, Rhythm processing, fMRI

1 Introduction

In recent decades, music has become the target of study of a con stellation of human and natural sciences. Listening to music is an active cognitive process that involves analyzing and anticipating musical events. Information available is analyzed and categorized by rules that allow finding a stab ility and understanding of the metric structure [1].

It has been observed that due to this logical th inking, musicians develop a lateralizatio n to the left h emisphere during the perception of music, compared with non-musicians [2]. The cause of this hemispheric lateralization, especially in relation to passive and active functions, cannot be ignored [3]. Since listening to music is generally a "p assive" activity, where the l istener is not asked to make decisions according to what he is listening, having an active role would not reflect the neural process that commonly participates in the processing of rhythm.

Neuroimaging has shown that musical stimuli activate auditory, linguistic, and less expectedly motor-related cortical and s ubcortical areas (i.e. Basal Ganglia (BG), Primary and Supplementary Motor cortices, Red Nucleus and Cerebellum). Moreover, for the performance of these interrelated tasks, cerebral structures such as th e left hemisphere, BG and Supplementary Motor Cortex are activated in trained musicians [4].

It has been suggested that BG activation is not only coincident, but necessary for keeping up with simple regular rhythms, as sh own by the results of discrimination tests of patients with Parkinson´s Disease, a degenerative disorder of the CNS that disrupts BG functions [5]. That study also suggested that BG are strongly linked to the internal generation of beat. In spite of consistent data correlating the activation of m otor-related structures and rhythm perception, further conclusive evidence is nee ded to cla rify the role of BG either calculating rates related to musical structure or allowing the synchronization of internal and external rhythms to th e individual. The presen t study attempts to make a contribution in this regard.

On the other hand, the importance of the right hemisphere in rhythm processing has been dem onstrated in people without musical training [6], because they listen to music in a global way. Mu sical experience modifies this process, and there is greater activation in the left hemisphere [7]. The above suggests, that musicians tend to analyze an d anticipate musical eve nts, due to t heir experience and training i n this field. This research takes this into account by including exclusively professional musicians.

Aims

To investigate whether the areas recruited for irregu lar rhythm processing differ from the ones required for regular rhythm processing, particularly the motor-related areas, and whether instrument specialization (i.e. m elodic vs harmonic- melodic musicians) affect rhythm processing in the brain.

2 Method

Test subjects where classified as harmonic or harmonic-melodic according to t heir instruments. Musicians deal with rhythm in various manners according to their specialization.

A singer, for example, thins of music in a horizontal way, while a pianist thinks music in a vertical way. Taking this into account, the sample was composed of 14 musicians: 5 women and 9 men. 13 regular and 13 irregular rhythms were presented randomly to the subjects.

2.1 Subjects

a) 3 pianists
b) 3 composers
c) 1 organist
d) 2 guitar players
e) 1 flutist
f) 1 bass player
g) 3 singers

2.2 Instructions

Musicians were instructed t o mentally decipher the time signature of each rhythm without moving; it was possible for them to say that no group was found, while subjecting them to EPI-based fMRI.

2.3 Stimuli

Regular patterns in western music are characterized by the presence of a constant pulse and musical accents, helping musicians to form a hierarchical organization (duple, triple, and quadruple) as well as exp ectations of future events in music. In this way, we can say th at grouping is the most essential component of m usical understanding, and that time between the events, rather than their duration, determines the perceived rhythm. Metric organization of irregular patterns is different compared to western organizations, making it difficult to create musical expectations while finding the b eat. Ambiguous rhythmic patterns, might give different metrical interpretations. Despite this fact, it is i mportant to mention that irregular patterns used for this research have a musical meaning in their context, which was a vita l element in the design of the test.

Irregular rhythmic patterns were selected by a test ap plied to an outgroup of musicians among 113 sound samples of Indian, African and Flemish music. All of the patterns, regular and irregular, had a length between 7 to 13 seconds. Regular rhythms were caref ully composed to have complete musical ideas, whereas irregular patterns were selected to have complete cycles in the same length.

Irregular patterns had 3 main characteristics:

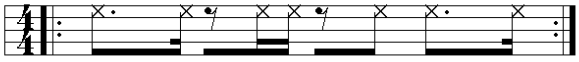
1) India. Stimuli used had a big organization of pulses and an irregular appearance of t he beat. The manner in which in Indian talas are g rouped, is con sidered an impossible grouping in the common used period of western music.

10 Standards		
Tala	**Pulses**	**Group**
Tintal	*16*	*4 x 4*
Sitarkhani	*16 3-3-2/*	*4 x 4*
Kehanwa	*8 3-3-2/*	*2x4 (accentuated)*
Dadra	*6*	*2x3*
Rupak	*7*	*3+2+2*
Jhaptal	*10*	*2+3+2+3*
Ektal	*12*	*6x2*
Charchar	*14*	*3+4+3+4*
Chowtal	*12*	*6x2*
Dhammar	*14*	*5+2+3+4*
3 Special Forms		
Tala	**Pulses**	**Group**
Ardha Jaital	*6 ½*	*3+2+1 ½*
Upa Dasi	*10 ½*	*7x1 ½*
Chartal Ki Sawari	*11*	*2+2+2+2+1 ½+1 ½*

Table 1. Tala Grouping

2) Africa. There is a co mmon use of m ultiple layers of rhythm. Interwoven patterns do not follow a main beat. African rhythmic structure is entirely divisive in nature but may divide time in to different fractions at the same time, typically by the use of hemiola or three-over-two (3:2) [8]. It is t he interplay of several elements, inseparable and equally essential, that produces the "varying rhythmic densities or motions" of cross-rhythmic texture

Key patterns, also known as bell patterns, express a rhythm's organizing principle, defining rhythmic structure and epitomizing the complete rhythmic matrix. They represent a condensed expression of all the movements open to musicians and dancers [9]. Musics organized around key patterns convey a two-celled (binary) structure, a complex level of African cross-rhythm [10].



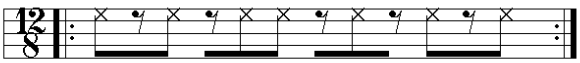


Figure 1. African Standard Pattern

3) Spain. Flemish Palos have a composite meter. Their metric organization is irregular due to its additive nature. Measures are obtained by addition, therefore, in a non-proportional way; for this reason they have also been called asymmetric rhythms. When patterns are repeated, they form metrical structures in which the beat is not isochronous and the division of the beat is distributed in juxtaposed sequences of two and three subunits.

According to their metric structure, Flemish Palos can be divided into five categories:

12 Pulses
Groups of 12 pulses (amalgam of 6/8 and 3/4 bars). Which in turn are divided into those who use the: • *Soleá:* *Por bulerías, bulerías, bulerías por soleá, alegrías, caña, polo, mirabrás, caracoles, romera, cantiñas, bambera, alboreá, romance, zapateado catalá.* • *Seguiriya:* *Cabales, liviana, serranas, toná-liviana.* *Patterns of Guajira and Petenera, use the amalgam in a simple way.*
Duple and Quadruple Organization
Taranta o taranto, tientos, mariana, danza, tangos, zambra, farruca, garrotín, rumba, danzón, colombiana, milonga.
Triple Organization
Fandango de Huelva, fandango malagueño, sevillanas, verdiales.
Polyrhythm
Tanguillo and Zapateado
Free Metric
Toná, debla, martinete, carcelera, cantes camperos, saeta, malagueña, granaína, media granaína, rondeña, cantes de las minas (minera, taranta, cartagenera, levantica, murciana).

Table 2. Flemish Palos Grouping

3. RESULTS

Despite every stimulus across experimental groups lead to activation of motor-related structures, the areas or structures recruited were not always the same. For example, in the cohort of melodic instrumentalists, BG were noticeably activated while listening to regular rhythms; on the other hand, the cerebellum was more active while listening to irregular rhythms.

This might give evidence of differential neural activation between regular and irregular rhythm processing in occidental professional musicians; moreover, we report differential activation when comparing the two cohorts.

3.1 Regular Patterns

Movements of the arms, hands and fingers in pianists are significant, so they are not necessarily related to speech, but to motor activity that is also located in the Broca area. Its activation in this case, in spite of being passive processing, may be due to the fact that the study subjects could have imagined how the rhythmic stimuli are played.

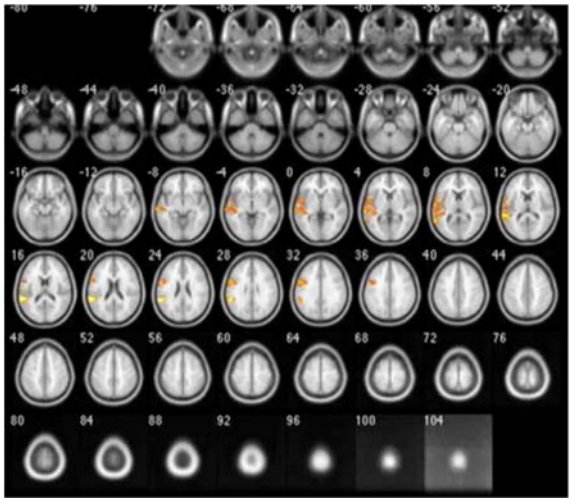


Figure 2. Melodic Musicians

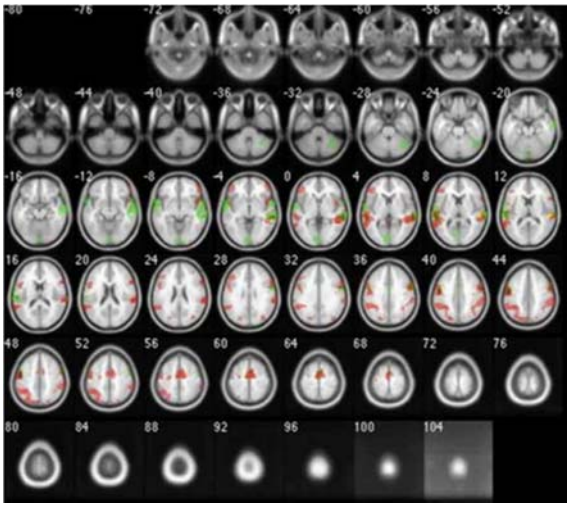


Figure 3. Harmonic - Melodic Musicians

3.2 Irregular Patterns

Irregular patterns make it difficult to find a group and create expectations due to the movement of the beat in different places within a cycle. It is not possible to find a beat unless rhythmic training in this tradition has been received. This kind of stimuli can help to understand processes related to adaptability and the use of previously

reported brain areas. However, it is considered necessary to use a larger sample to corroborate these results.

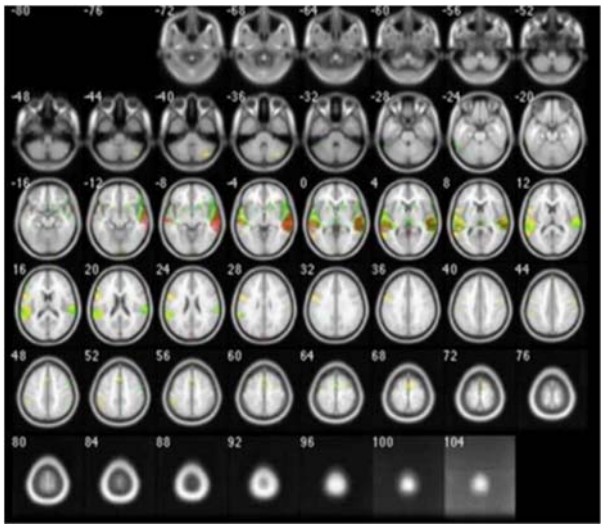


Figure 4. Melodic Musicians

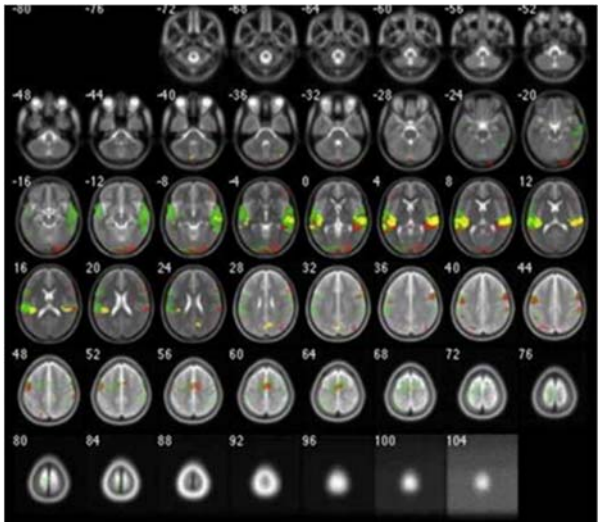


Figure 5. Harmonic – Melodic Musicians

4 Discussions

Although it is kno wn that each musician has his own strategies and ways of processing rhythm, according to his area of expertise, evidence of these was not found in previous research, or how specialization in a particular aspect of music could modify these processes.

These results help to understand how rhythm perception is processed in the brain, knowing that subjects of study are professionals and certa inly know the d ifferent elements of rhythm, and their use in a Western musical context. The use of rhythmic patterns from a di fferent musical context can help to understand the processes related to adaptability and th e use of prev iously reported brain areas.

Limb and his collaborators proposed that listening to rhythm favors a lateralization in the left hemisphere [11]; however, the issue was to know if t his lateralization was cau sed to expectations and comprehension of elements in rhythm. Another partial conclusion reached previously, indicated t hat hemispheric lateralization was no t due to logical thinking, but to the rap id and non-holistic perception that is carried out in the left hemisphere of people with advanced musical training. Nevertheless, it is considered that these conclusions are not applicable to the results obtained in this investigation due to the differences in the types of stimuli used by Zatorre and his collaborators.

5 Conclusion

The difference in brain activation in both groups suggests that the development of the skills needed to interpret each instrument generates a sp ecialization in the perception of rhythm. As well, this study raises new questions about the differential contribution of other motor-related areas in t he processing of diverse rhythmic patterns.

One of the questions considered was to know if cognitive operations are modular or i f they are distributed through domains. Understanding its functioning can help to establish cognitive and perceptual theories of m usic. Results obtained in this study corroborate previ ous data of m otor-related areas activation during music stationary listening; however, the circuits activated differed among conditions and instrument specialization, suggesting a sp ecial function of BG fo r regular rhythm processing (in accordance to Grahn´s results).

Talking about musical representations, it is in teresting to know the type of information that is i nternalized, how it is st ored and the way it is in terpreted. It is a matter of determining how the different perceptual events distributed over time are i ntegrated into a meaningful structure [13].

The obtained images show that musical training leads to a left h emispheric lateralization of th e brain when processing regular rhythmic patterns. This left lateralization may b e due to the fact that music and language share very sim ilar characteristics, and that musicians understand their structure.

On the other hand, processing of irregular rhythmic patterns does not diminish this lateralization, but involves the activation of new cerebral areas (basal ganglia and cerebellum). The activ ation of these new areas varies depending on the type of instrument, in the case of harmonic-melodic instrumentalists, activation of the cerebellum was observed, whe reas in m elodic instrumentalists basal ganglia was activated.

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