On the neural correlates of music perception: rhythm, phrases and movements

Maria Giavazzi
HST.722/Student Topic Proposal
Cambridge, November 1st 2007

(1) Introduction:

Music is found universally across human cultures and there is evidence that the ability to appreciate music develops even without explicit training (Trehub, 2003).

Like speech, music is a system in which perceptually distinct elements are organized into hierarchically structured sequences according to syntactic principles (as discussed in the work of Lerdhal and Jackendoff), but despite the similarities with language, music perception also involves the processing of complex rhythm, pitch and tension patterns which are unique to this system and which make it incredibly intricate and fascinating.

If sound perception in general triggers brain activation in distinct cortical regions, which last a few milliseconds, music cognition requires seconds for a musical phrase to be fully developed; first the primitives of music have to be identified, then they must be integrated within the unfolding musical context. This complexity is reflected in the different brain responses that are observable while someone is listening to music: activations which reveal the fine temporal structure of the stimulus coexist with activations whose dynamics follow the global development of the composition.

The current literature on the brain activity during music perception has focused, from what I can tell, on musical syntactic processing and on rhythm, in a fashion which is in my opinion very much influenced by the work that has been done in studies on language. If on one hand this allowed for fruitful comparisons between the two systems, on the other hand, the stimulus material was made very "sentence-like" and it therefore missed some crucial characteristics of real music. Very often stimuli consisted of short segments or fragments of musical pieces, which had been specifically composed or selected for the experiment. Expressive modulation of movements and dynamic aspects of an authentic musical piece where disregarded in the analysis, even though they are crucial to the perception of music.

Among all possible topics of interest in the domain of music perception, what most intrigued was the process of segmentation of the complex auditory signal into coherent units which go from being very small, to very complicated, as higher level representations are formed.

I have collected three papers which look at different levels of music perception, from *rhythm*, to *phrases* and to *movements*.

The imaging methods used in these works are appropriate for the specific level of interest: neural correlates of rhythms, which demands fine temporal resolution were explored using MEG, the perception of phrase structure was investigated with MEG and EEG. Finally, fMRI was used to study event segmentation, given that fine spatial resolution was needed and that the relevant structural changes occur over a timescale which is within the resolving power of fMRI. I have also chosen two background papers that might interest those who have little knowledge of the field and who would like to be introduced to it (in the worst case they were only useful to me); references are to be found on the last page.

(2) On event boundaries:

Perceptual event boundaries in music exist at several well-defined hierarchical levels and time scales, including discrete tones, rhythmic motifs, phrases and movements. In the following paragraphs I briefly describe what is known about the last three levels, and how the papers I'm proposing tackle the problematic in an interesting and possible fruitful way.

Before starting though, I should say that, remarkably, almost all these studies (the first and third in particular) investigate music perception using authentic music and not *ad hoc* composed pieces, so as to render the experimental condition as close as possible to our daily experience of listening to music in the real world.

Rhythm:

Some have suggested that rhythm (and its essential relationship to the temporal aspect of sound) may in fact be the most fundamental aspect of music. Hasty (1997), notes that "Among the attributes of rhythm we might include continuity or flow, articulation, regularity, proportion, repetition, pattern, alluring form or shape, expressive gesture, animation, and motion (or at least the semblance of motion). Indeed, so intimate is the connection of the rhythmic and the musical, we could perhaps most concisely and ecumenically define music as the 'rhythmization' of sound."

The first paper I'm proposing for discussion, *Popescu et al.* (Neuroimage, 2004), in an MEG study which explores the neuronal correlates related to changes in rhythm elicited by a real piece of music. A previous study of this group (Ioannides et al., 2002) categorized brain regions showing significant activations during authentic music listening according to the similarity between the spectral peaks of the sound envelope and those of regional activation curves. A further important starting point for the paper comes from both behavioral and neuroimaging studies of rhythm perception proposed that the circuitry used for timing of brief intervals is likely to be located within the motor system (SMA and pre-SMA), even in the absence of movement.

The hypothesis of the authors is that temporal deviations from the scored reference interval ratio (DRIR) occurring because of emphasis and musical expression in music execution will induce changes in the brain which can be captured by the MEG signal.

In order to measure the correlations between local brain activation and rhythmical pattern, the authors develop a *beat-tracking algorithm* which has the advantage of not requiring any prior knowledge of the tempo, or meter; instead, all the required information is derived from the acoustic signal. The degree of similarity between the rhythmicity of the music and regional brain activations was quantified by computing the correlation coefficients between the beat spectra of the musical motif and the beat spectra for each motor area separately.

Among other areas being activated, what is most interesting to notice is the activation pattern of the motor areas (PMA and SMA) there was a progressive decrease in the correlation of SMA activity with the performance-rhythm after each switch in DRIR.

Also, it is shown that that SM1 activates also in the absence of overt motor behavior; and it involved in the perception of the temporal pattern embodied in musical rhythm.

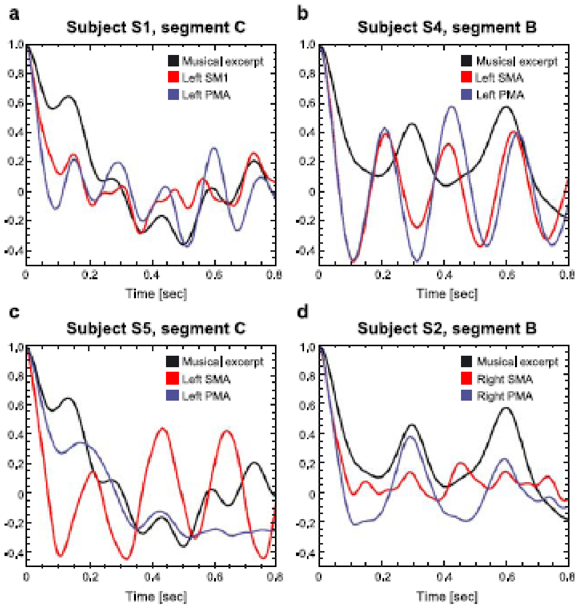

Fig. 10. Single-subject beat spectra from motor regions and the music signal. (a) Subject S1. (b) Subject S4. (c) Subject S5. (d) Subject S2. Motif segment C is used for a and c and segment B for b and d. The beat spectrum of the music is shown together with the beat spectra of left SM1 and left PMA in a, left SMA and left PMA in b, c, and right SMA and right PMA in d.

Phrase boundaries:

Phrases and boundaries between phrases have been largely studied both in linguistic theory (Selkirk, 2000) and in works on the neural correlates of language. They are of crucial importance in language processing, since they often indicate the closure of a syntactic phrase. ERP studies preceding the one I'm proposing for discussion have reported the existence of prosodic markers during syntactic parsing (Steinhauer, 1999; Pannekamp et al., 2004; among others) . At each phrase boundary, the authors found a positive shift of some hundred ms. duration and a centroparietal distribution. This component was called Closure Positive Shift (CPS).

Now looking at the structure of music, theoreticians have described for centuries musical phrases as being separate musical entities within the melodic line (Riemann, 1900). Just as it was the case with language, the correct processing of phrasing is crucial for music perception and therefore the recognition of phrase boundaries has to take place with the unfolding of the auditory stimulus.

I suggest that a recent paper *Knösche et al.* (Human Brain Mapping, 2005) could be interesting to read in the broader picture of the topic I'm proposing. The hypothesis which starts out this work is quite intuitive: given the similarity between the phrase boundary markers in both language and music, can one find a similar neural correlate to the CPS in music?

The aims of this combined EEG/MEG study are to identify an electrophysiological marker for the processing of phrase boundaries in music, to establish its topological and morphological processes and its underlying generator structure and finally to determine the relation between CPS found in language and this component.

In order to answer this question the authors analyzed different brain activities in response to phrased vs. unphrased melodies which were either extracted from not very well-known musical pieces, or newly composed.

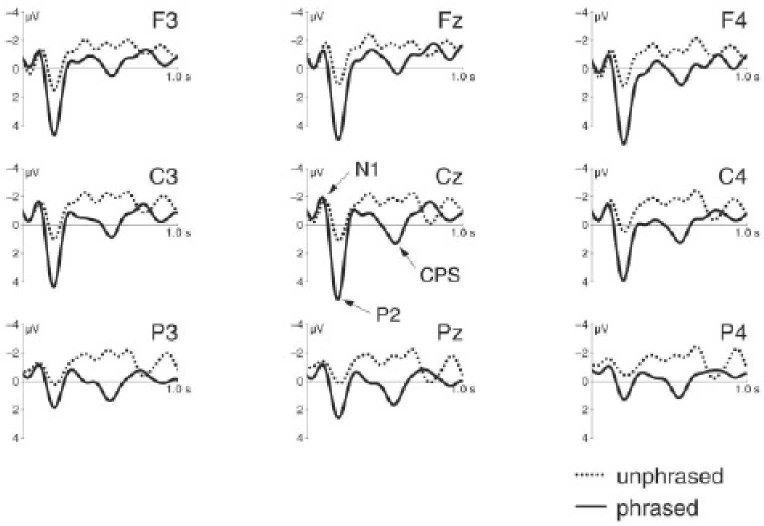

Figure 4.
Traces of selected electroencephalography channels. Solid lines denote the original condition with unmodified phrase boundaries (*phrased*). Dotted lines denote the modified condition, where the phrase boundary was filled with notes (*unphrased*). Units are microvolts. A low-pass filter of 8 Hz was applied for display purposes only.

Not surprisingly given what had been widely shown for language, but interestingly, given that we are in an other cognitive domain, the authors found a marker component of musical phrase boundaries which is to some extent similar to the CPS in language. Moreover, they show that the CPS seems to reflect memory and attention processes necessary for the transition from one phrase to the next, rather than mere detection of an acoustic boundary.

Movements:

By covering almost all the different levels of musical constituents, we have arrived to the movement, which in western classical tradition, is the highest hierarchical level within a musical work. As it is the case for phrase boundaries, at a higher level, adjacent movements within a single work are generally delimited by a number of different cues such as changes in tempo, tonality and rhythm among others.

While each movement lasts from several minutes to 10 or more, transitions between movements, which demarcate long-scale structural changes, take place over a few seconds and are perceptually salient even to non-musicians.

The third paper I'm proposing for the final discussion, *Sridharan et al.* (Neuron, 2007), is an fMRI study which investigates precisely at the neural dynamics which subserve event segmentation at the level of the musical movement. The authors look at how the brain accomplishes such segmentation by isolating brain responses immediately before, during, and after these movement transitions, whereby the stimuli are 8-to-10 min long segments of symphonies by the English baroque composer William Boyce, which contained several. well-defined movements.

The time course of activation was examined in a 10s window surrounding the point of transition, averaged over all movement transitions. and the analysis revealed a strong lateralized pattern of brain activation that peaked at the point of the movement transition (when there was no physical stimulus) and diminished progressively afterwards.

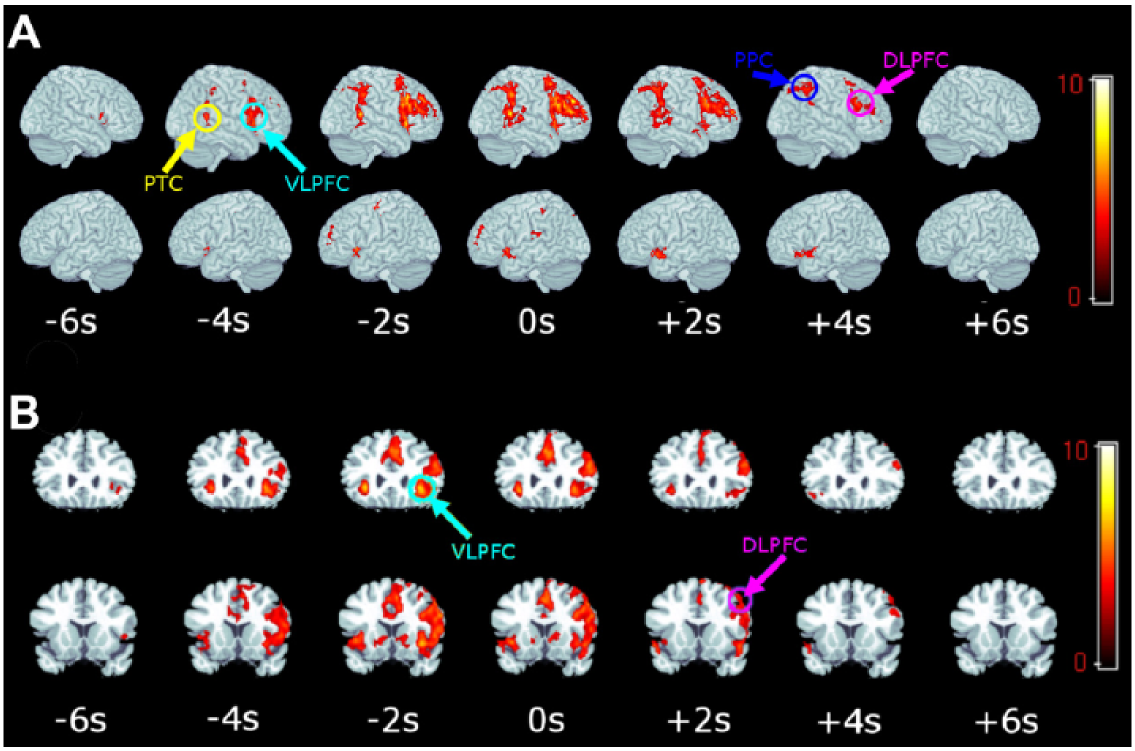

Figure 2. Temporal Dynamics of Brain Activity in a 12 s Window Surrounding the Point of the Movement Transition

(A) Surface rendering showing right (top row) and left (bottom row) hemispheric responses as a function of time (from 6 s before the point of transition to 6 s after the point of transition). Brain responses throughout the movement transition were predominantly right-lateralized. With time, activity shifted along a ventral-dorsal axis, with the ventral network—ventrolateral prefrontal cortex (VLPFC, cyan arrow) and posterior temporal cortex (PTC, yellow arrow)—active during the early part of the transition and the dorsal network—dorsolateral prefrontal cortex (DLPFC, magenta arrow) and posterior parietal cortex (PPC, blue arrow)—active during the later part of the transition.

(B) Coronal sections showing anterior (y = +27 mm, top row) and posterior (y = +16 mm, bottom row) slices through the frontal lobes. The right VLPFC, marked with a cyan arrow at t = −2 s (s), was significantly active earlier in the transition, whereas the right DLPFC, marked with a magenta arrow at t = +2 s, showed sustained activation later in the transition.

Moreover, as can be seen in the figure above, there were 2 distinct networks of brain response at the transition: (1) a ventral fronto-temporal activation in the early part of each transition (-2s), and (2) a dorso-fronto-parietal in the late part of each transition (+2s).

The finding of this experiment suggests that the right hemisphere plays a dominant role in the perceptual segmentation of salient, coarse-grained event boundaries in music, and also that the ventral network is right-lateralized not only for orienting attention to visual stimuli but also during segmentation of auditory events.

(3) Why I find this topic very interesting:

…mostly because I've always been interested in music, both perception and production, but, more relevantly, I like this topic because it provides a focused and theoretically founded approach to the study of music perception, by delimiting the object of study to one problem which is characteristic not only of music, but of most sensory stimuli, namely the segmentation of a continuous signal into coherent units. Perception of boundaries is what identifies discontinuity in a continuum, but it's also the process which allows the construction of a complex representation through the hierarchical combination of single events.

(4) Papers:

Background:

- Jackendoff R., Lerdhal F.: The *capacity for music: What is it and what's special about it?*; Cognition 100 (2006) 33-72.
- Selkirk E (2000): *The interaction of constraints on prosodic phrasing*. In: Horne M. editor. Prosody: theory and experiment. Amsterdam: Kluwer.

For the discussion:

- Popescu M. et al.: *Dynamics of brain activity in motor and frontal cortical areas during music listening: a magnetoencephlographic study*; NeuroImage 21 (2004) 1622-1638.
- Knösche T.R. et al.: *Perception of Phrase Structure in Music*; Human Brain Mapping 24 (2005) 259-273.
- Sridharan D. et al.: *Neural dynamics of event segmentation in music: Converging evidence for dissociable ventral and dorsal networks*; Neuron 55 (2007) 521-532.