

Cortical Rhythm Perception

Hearing Sources Psych 289

Spring 2013

Term Paper

Rhythm pervades everything we do. Strangers walking down the street tend to unknowingly walk at the same pace. We are more likely to move our bodies on the beat to audible rhythms [Zatorre et al., 2008]. Dancing and music have played integral roles in human evolution. This paper might even be read with some rhythmic consistency. Three ideas have emerged in the study of rhythm perception and have been used to indicate specific levels of the human rhythm percept - *beat*, *meter* and *rhythm*. *Beat* refers to individual notes and the pulsating sensation they create together. *Meter* is the background to musical rhythm and represents the organization of the grouping of beats into a rhythmic structure. Finally *rhythm* may be considered a representation of both soft and strong beats as they fit into the overall structure of an expected metric phrase. For a full treatment of this topic see [Lerdahl & Jackendoff, 1981].

The Electroencephalography (EEG) and Magnetoencephalography (MEG) neuroimaging methods have proven well suited for rhythm perception experimentation as their temporal

resolution far exceeds that of competing modern neuroimaging techniques. These methods measure fluctuations in primate scalp potentials and magnetic fields in the EEG and MEG, respectively. They arise mainly due to the synchronized activity of neural networks in or near the cortical surface. Since usually the number of data points collected in such experiments greatly exceeds the number of trials, data reduction techniques are employed to minimize the required computations for analysis of such datasets. Event related potentials (ERPs), named after their latency and polarity (i.e. the positive deflection 300 ms post stimulus is the P300), are a simple averaging of the raw trial data and in whose mean may expose a change in the background potential, usually averaging hundreds of trials together for significance. Many auditory experiments have revealed an early negative deflection 100-200 ms post stimulus, indicating a connection with pitch and melody deviants [Nittono et al., 2000], timbre discrimination [Meyer et al., 2006] and changes in pitch and intensity [Snyder and Hillyard, 1976]. Another data reduction technique popular with modern EEG/MEG research is the use of power spectral decomposition, discretizing the spectral information down to a standard 5 or so frequency bands which have been assigned importance. For example, Gamma waves have been shown to modulate with rhythm perception and simply listening to a steady-state rhythm has been shown to evoke a neural response at the stimulus frequency over motor and auditory cortices [Grahn, 2009].

Many authors are exploring the neural basis of rhythm perception with these techniques, though the area is still in its infancy as much reported evidence is either inconclusive or seems contradictory. The three articles reviewed herein represent novel ways in

which researchers have begun using EEG/MEG techniques to study rhythm perception in the past decade. In the first paper, Geiser et al. attempt to expose the neural basis of beat and meter as reflected in the early negative deflection. Then, Nozaradan et al. show that a consistent, repetitive stimulus can result in various brain responses depending on the subject's internal metric interpretation of that beat. Finally, Vuust et al. highlight MEG differences in purely rhythmic violations between musicians and non-musicians.

[Nozaradan, 2011] showed that subject's neural entrainment to beat and meter may frequency-modulate their EEG/MEG signal as a result of altering their internal rhythmic representation of a metrically-ambiguous auditory stimulus. That is, by accenting their perception of the second or third note in an auditory beat train, subject's EEG/MEG spectral envelope was increased at the sub harmonic frequency representing their imagined meter (Figure 1).

Subjects were presented an auditory stimulus which could be perceived as a steady-state 2.4 Hz beat train lasting 33 seconds. They performed one of three conditions: a control task and two perceived meter tasks. The meter tasks required subjects' voluntarily internal rhythm interpretation to accent various beats along the beat train: either a binary (accenting every 2nd note) or ternary (accenting every 3rd note) structure (Figure 2). The control condition required subjects detect a distractor sound in the beat train occurring only twice a session. EEG analysis was performed offline. All data was preprocessed using a noise-removal routine which subtracted, from each spectral bin, the average of the neighboring frequency bins (a moving-

average-type filter). For each subject, condition and target frequency, all scalp electrodes were averaged, and spectral bins created from the trial EEG data. In all conditions, a clear increase was identified in the EEG at the beat frequency (2.4Hz), known as the Beat-related steady-state EP. Furthermore, the binary meter elicited an additional response at 1.2 Hz and ternary meter at .8 and 1.6 Hz corresponding to the sub harmonic frequencies of the stimulus (Figure 3). These additional responses due to internal rhythm imagery were referred to as meter-related steady-state EPs. [Nozaradan, 2011] showed that subjects could modulate their EEG response by maintaining different metrical interpretations of a constant auditory stimulus. This result supports the resonance theory for beat and meter perception in humans [Large and Kolen, 1994].

[Geiser, 2009] attempted to identify the neural underpinnings both meter and rhythm in musicians and non-musicians via the analysis of ERPs. They presented sound stimuli of a simple sound passage (figure 4) which was varied metrically, rhythmically or tonally. Deviants in either the rhythm or meter (figure 5,6) were presented, and EEG was collected. The experiment included also a processing mode, in which subjects focused on changes in rhythm or meter (attended processing mode) or on key changes of the 2nd note up or down (unattended processing mode, rhythm and meter deviants persisted in this mode, Figure 7). The experiment thus contained two within-subject factors “processing mode” (attended-unattended) and “temporal manipulation” (rhythm-meter) and one between-subject factor “group” (musicians – non-musicians).

Behaviorally, musicians performed significantly better than non-musicians in discrimination during the temporal manipulation condition and non-musicians performed significantly worse on meter than rhythm deviants, possibly due to confusion regarding changes in time signatures. The rhythm condition elicited an early negative deflection peaking at 150 ms in both attended and unattended conditions, while the meter condition elicited the negativity in the same latency window in the *attended processing mode only* (Figure 8). Thus the effect of processing mode on the early negative deflection is different in rhythm and meter manipulations. Also, a significant difference in component amplitude for the rhythm and meter conditions was identified: Rhythm deviants elicited a potential with higher amplitude than that elicited by the meter deviant. Surprisingly, no effect was identified on subject group in the ERP data.

The fact that the metrical deviants were unable to elicit the negativity in the unattended processing condition, even in highly trained subjects, reflects a grand difference between rhythm and meter processing. The behavioral results further indicate a strong difference on performance in rhythm and meter processing as well as a significant differential effect of expertise on the detection of different temporal characteristics of a sound stimulus. In another study authors reported a similar effect in attended vs. unattended processing conditions on a temporal omission task eliciting the Early Negative Deflection [Jongsma, 2005; [Raij et al., 1997](#)].

In the third and finally study Vuuest et. al observed the effect of rhythmic violations on the MEG. They presented augmented drum sequences to both jazz musicians and “musically

inept” subjects (non-musicians), while collecting MEG. The stimuli contained a 4-beat rock rhythm in a normal configuration (sl), or with a light (sII) or heavy (sIII) departure from the rhythm near the end of the 2nd bar (figure 9). The three conditions represent increasing levels of rhythmic expectancy violations. Subjects were asked to report on a distractor in the form of augmented snare drum sounds, but were not informed about the changes in rhythm in the 3 conditions.

Analysis was performed offline and focused on the 100-20 ms temporal range. Pooling all subjects, the mean gradient amplitude (MGA) of the MEG was found to be significantly higher in the sIII condition compared to sII, and that of sII was significantly higher than sl. These results indicate that the pre-attentive response (MMN) is modulated by strength of violations to rhythm expectancy. The responses of musicians were significantly higher than for non-musicians in all 3 conditions, indicating aptitude for rhythm appears to be reflected by increased pre-attentive neuronal responsiveness.

Hemispheric differences were identified between the two groups – while both elicited significant responses to the three conditions, the region of origin differed between the two groups. In response to sIII musicians had increased activity in left temporal region, and non-musicians in the right. Latency did not differ in the right hemisphere between the two groups, although musicians’ left-lateralized responses significantly preceded the right response from both groups. For the weaker rhythmic violation (sII) large-scale field patterns in bilateral temporal regions were detected in the musicians but not non-musicians. Additionally, left

temporal activity of musicians significantly exceeded right temporal activity of non-musicians. Musicians thus appear to be more sensitive in the pre-attentive response to subtle changes in rhythm compared to non-musicians.

Prior studies reported a left lateralization of rhythm and a right-lateralization of meter. In [Vuust et al. 2009], lateralization was due mainly to musical competency and not differences in meter or rhythm. Prior work in language experiments showed a left- hemisphere MMN when the subject had a high competency to the stimulus presented. For example showed a left-hemisphere MMN elicited in response to presentation of phonemes from a native language when a right-hemisphere MMN arose from non-syllabic sounds. Additionally, showed that MMN amplitude lateralization to morse code depended on subject proficiency. After 3 months of morse code training, MMN responses arose from left-hemisphere whereas pre-training responses came from the right-hemisphere. Taken together one might conclude that a rhythm pattern which conveys meaning to the listener will pre-attentively process it in the left-hemisphere [Grahm, 2009].

The three neuroscience studies reviewed above highlight Rhythm Perception experiments using EEG and MEG to further our understanding of the beat, meter and rhythm concepts. Trained musicians have shown to be more adept at rhythm related tasks and are often used as a control group in complex rhythmic tasks. A long standing assumption that musicians recruit language centers for music performance/perception has received

considerable attention in the field, with evidence both supporting and contradicting the claim.

New theories posit the recruitment of these areas for experts in general, rather than musicians specifically [Hicock et al., 2007], indicating that advancements in this field could have implications for the experts/adept dichotomy for nearly any type of human activity.

Figures

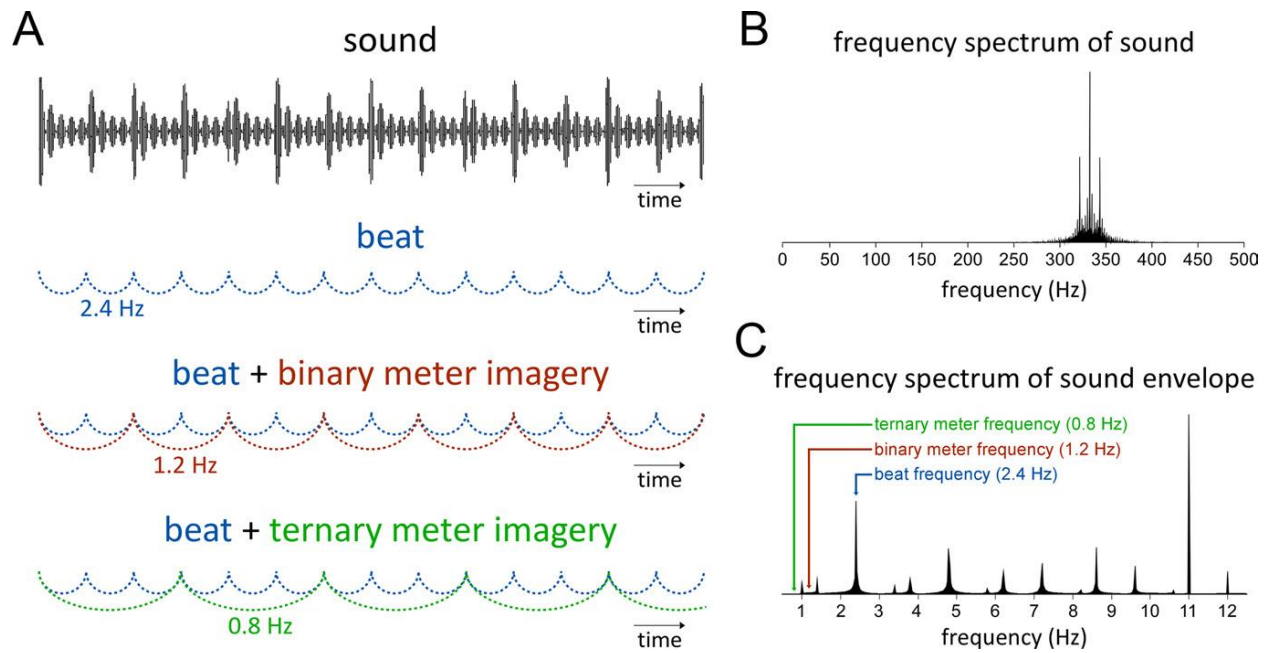


Figure 1 - Beat and Meter Entrainment Experiment [Nozaradan et al., 2009]

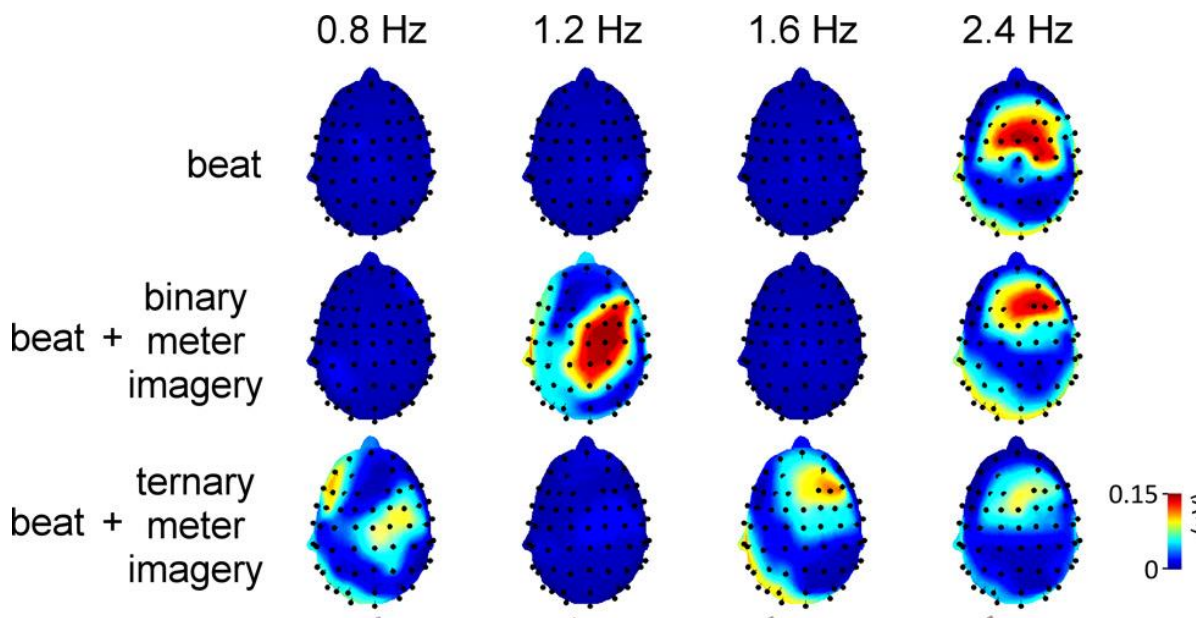


Figure 2 - Averaged Spectral Responses at the frequencies of interest over the 3 conditions [Nozaradan et al., 2009]

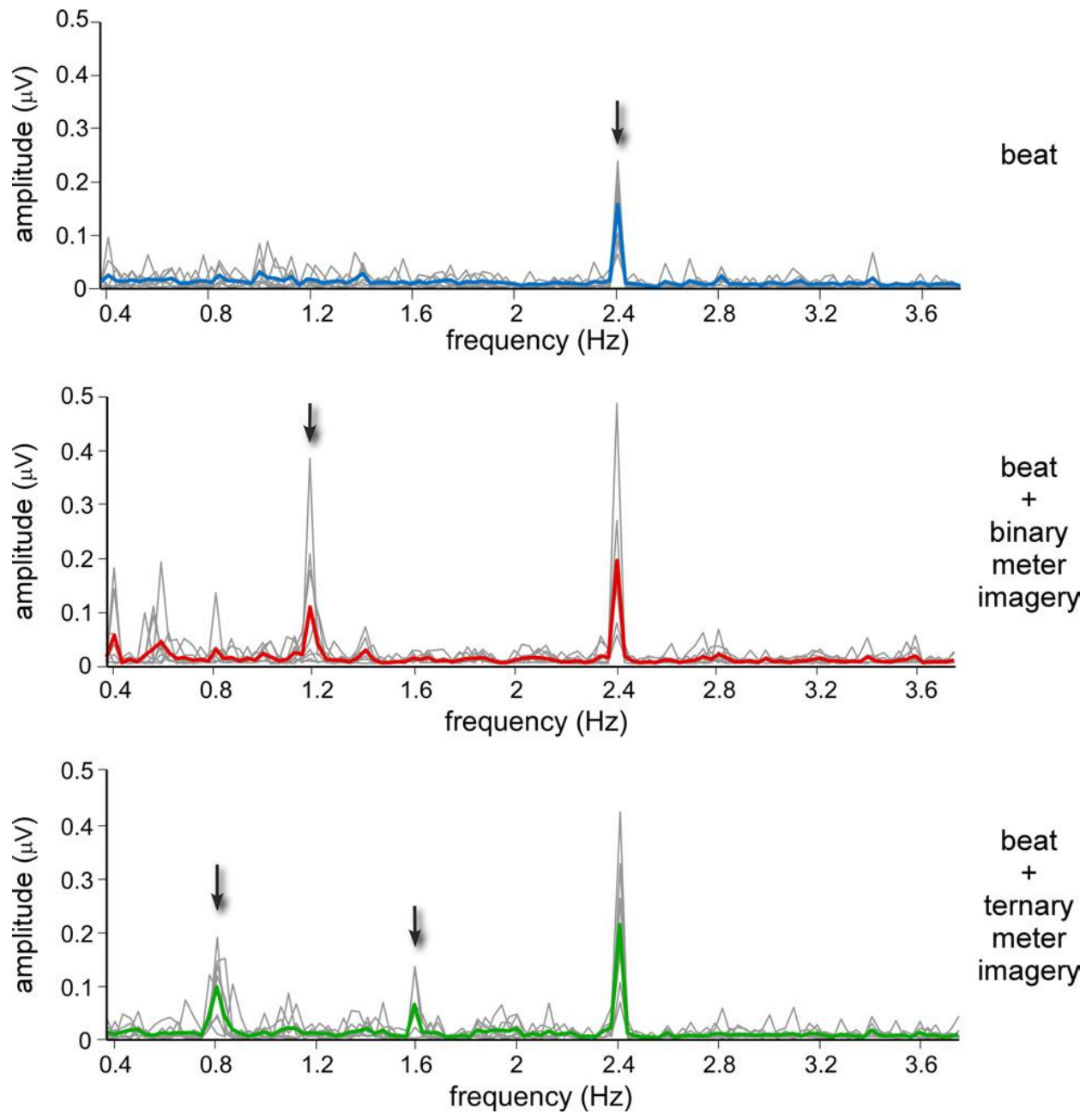


Figure 3 - Spectral Response to beat train (top), beat binary imagined meter (middle) and beat + ternary imagined meter (bottom) [Nozaradan et al., 2009]



Figure 4 - Basis of Sound Stimulus [Geisser et al, 2009]



Figure 5 - Left two passages reflect change in meter, right two are changes in rhythm [Geisser et al, 2009]



Figure 6 - Two pitch manipulations [Geisser et al, 2009]

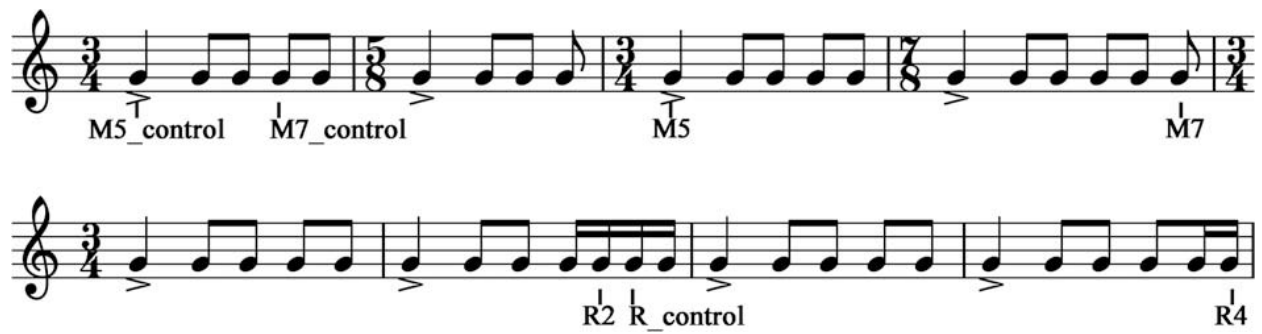


Figure 7 - Time point within the stimulus from which ERPs were calculated for each condition. [Geisser et al, 2009]

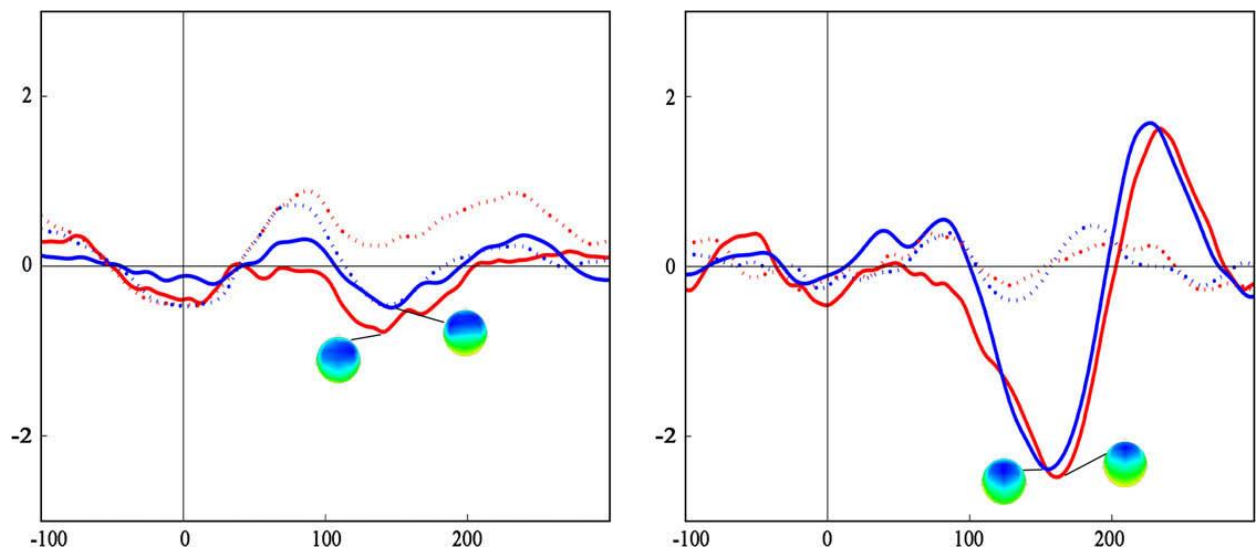


Figure 8 - ERPs related to deviant and standard stimuli. Left - meter processing; right, rhythm processing; red, attended processing; blue, unattended processing; solid line, deviant stimulus; dotted line, control stimulus. Results collapsed among all subjects. [Geisser et al, 2009]



Figure 9 – Drumbeat stimuli. (Top) regular drumbeat. (Middle). Irregular drumbeat. (Bottom) Highly irregular drumbeat.

[Vuust et al., 2009]

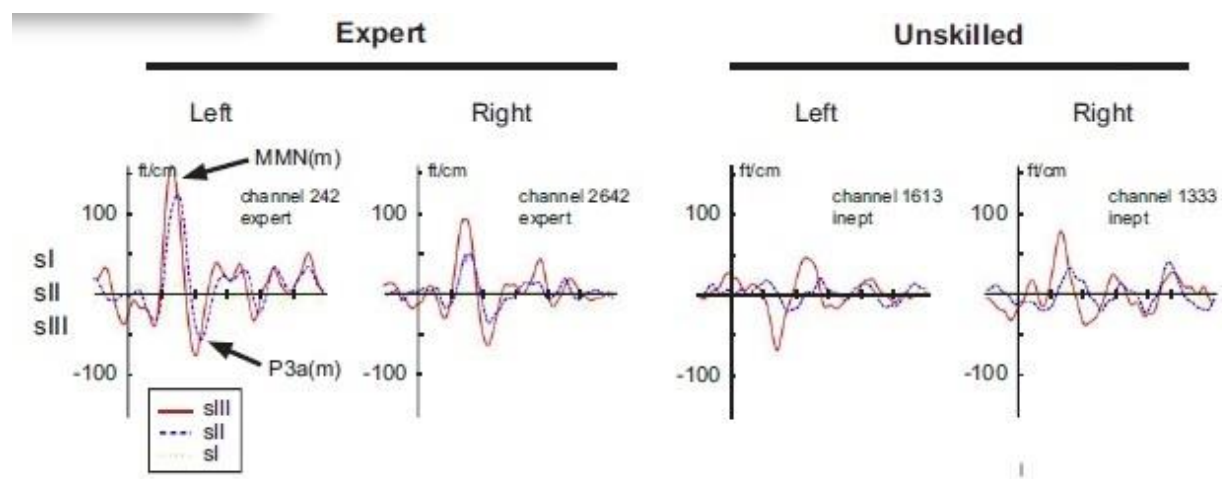


Figure 10 - Potentials for Experts and Unskilled subjects [Vuust et al., 2009]

Citations

*Chen, J. L., Penhune, V. B., & Zatorre, R. J. (2008). *Listening to musical rhythms recruits motor regions of the brain. Cerebral cortex, 18(12), 2844-54.*

Hicock G., Poeppel D. (2007). *Cortical Organizations of Speech Processing. Nature Reviews Neuroscience Vol 8 May 2007 pp393*

Jongsma ML, Eichele T, Quian QR, Jenks KM, Desain P, Honing H, et al. *Expectancy effects on omission evoked potentials in musicians and non-musicians. Psychophysiology, 42: 191–201,2005.*

Large EW, Kolen JF (1994). *Resonance and the perception of musical meter. Connect Sci 6:177–208.*

Lerdahl F and Jackendoff R. *On the theory of grouping and meter.*

The Musical Quarterly, 67: 479–506, 1981.

Geiser E., Meyer M. (2009). *Early electrophysiological correlates of meter and rhythm processing in music perception. Cortex 45 (2009) 93-102*

Nozaradan, S. Mourax A., (2011). *Tagging the Neuronal Entrainment to Beat and Meter J Neuroscience 31(28) 10234-10240*

Raij T, McEvoy L, Makela JP, and Hari R. *Human auditory cortex is activated by omissions of auditory stimuli. Brain Research, 745:134–143, 1997.*

Vuust P., Roepstorff A. (2009). *Predictive coding of music – Brain responses to rhythmic Incongruity*. Cortex 45 80-92