ELSEVIER

Neuroscience Letters 277 (1999) 37–40

Neuroscience Letters

www.elsevier.com/locate/neulet

A marker for differentiation of capabilities for processing of musical harmonies as detected by magnetoencephalography in musicians

R. Beisteiner[a,b,*], M. Erdler[a,b], D. Mayer[a,b], A. Gartus[a,b], V. Edward[a,b], T. Kaindl[a,b], S. Golaszewski[c], G. Lindinger[a,b], L. Deecke[a,b]

[a]Department of Neurology, General Hospital and University of Vienna, Währinger Gürtel 18–20, A-1090 Vienna, Austria
[b]Ludwig Boltzmann Institute for Functional Brain Topography, Währinger Gürtel 18–20, A-1090 Vienna, Austria
[c]Department of Magnetic Resonance, Innsbruck University, A-6020 Innsbruck, Austria

Received 9 September 1999; received in revised form 11 October 1999; accepted 14 October 1999

Abstract

This investigation was designed to study the characteristics of a marker for harmonic processing and to test whether it could be used for differentiating harmonic processing capabilities. The first three chords of an ordinary musical cadenca were presented to the left ear to establish a harmonic context followed by a harmonic or non-harmonic target tone. Cadencas were presented rapidly and randomly in different keys to render the task difficult. Results showed a specific P3m (magnetic P300) effect to the non-harmonic targets which was only visible in subjects with low target recognition errors. Low resolution electro-magnetic tomography current density maps showed P3m sources in the right temporoparietal, left temporoparietal and frontocentral brain areas with right temporoparietal sources being strongest and most reliable. The results offer new possibilities to selectively study harmonic variables in music processing.

Keywords: Music perception; Harmonic processing; Human audition; Magnetoencephalography; Evoked magnetic fields, P3m

The ability of human brains to categorize harmonic aspects of musical material depends on the tonal and harmonic hierarchies as acquired through exposure to a certain musical style (e.g. western tonal, north Indian, Balinese music, for review see Ref. [11]). Tonal hierarchies define sets of tones belonging to certain musical keys (e.g. the seven tones of C major) and define occurrence probabilities for each tone in given musical contexts. Theoretical music and neuropsychological studies provided corresponding evidence about what kind of tonal hierarchies exist in western tonal music and found the following descending order: first-fifth-third-remaining pitches corresponding to C-G-E-(D,F,A,B) within a C major key (compare Refs. [14,12]). Since tonal hierarchies influence expectations about best tonal or harmonic continuations [18] they are essential for the understanding of music and for emotional commitment as induced by generation of musical expectancies and their fulfilment or non-fulfilment. A well suited way to establish a musical key and thus to set up a tonal and harmonic hierarchy is presenting a musical cadenca (four successive chords on the fundamental – the fourth – the fifth – the fundamental). The cadenca presents the whole tonal material of the base key of a piece of music within the first three chords and generates strong expectations about what kind of tones are probable to follow. For monitoring brain activity related to music processing, electrophysiological techniques have been shown to be a valuable tool (e.g. [1,2,17]). In an interesting electroencephalographical (EEG) study Janata and Petsche [9] and Janata [10] used the harmonic features of the musical cadenca to probe chord hierarchies by presenting the first three chords followed by a highly expected, less expected or unexpected target chord. Janata [10] used a late positive evoked response as marker for harmonic expectancy violation. Several electrophysiological studies (for review see Ref. [2]) have shown, that late positive evoked responses (P300 [10], LPC [4], P600 [16]) occur with musical expectancy violations. Interestingly, although in other studies the most expected musical event never produced a late positive component, the study of Janata [10] showed a large P300 also to the most expected target chords. The amplitude of the P300 systematically

* Corresponding author. Tel.: +43-1-40400-3117; fax: +43-1-40400-3141.
E-mail address: roland.beisteiner@akh-wien.ac.at (R. Beisteiner)

0304-3940/99/$ - see front matter
PII: S0304-3940(99)00836-8

varied with the degree of expectancy violation but the main effect obviously was not related to harmonic processing. It was interpreted as a 'closure effect' by Janata. Similarly, also with other studies [13,16] the late positive components described could have been influenced by non-harmonic cues since event-related potential (ERP) components are sensitive to a large variety of stimulus and context aspects. Those include effects related to physical or perceptual differences of targets which might influence off effects or neuronal network set-up (compare [5]), different musical expectations due to differing musical contexts or simple memory effects due to targets which repeat context stimuli. The goal of this study therefore was twofold. First, to generate a specific marker for harmonic processing detectable by magnetoencephalography by excluding non-harmonic cues as much as possible within a P3m (magnetic P300) design. Second, to test whether this marker could be used for differentiating harmonic processing capabilities of subjects experienced with western tonal music.

Subjects had to listen to a series of cadencas sounding the tonic (I) – subdominant (IV) – dominant (V) chords in root position followed by a target tone. The first three chords set up a harmonic context (musical key) generating a hierarchy of tones expected to follow. The target tone was either harmonic (member of the key) or non-harmonic to the previously presented chords. For example, if the cadenca established C major, every tone belonging to C major would be harmonic and every tone outside C major would be non-harmonic. In different trials one and the same target tone occurred in four different harmonic functions relative to the fundamental of the cadenca: the fundamental itself $P = 0.25$), the third ($P = 0.25$), the sixth $P = 0.25$) or the non-harmonic minor second ($P = 0.25$). Eleven different target tones (sinus tones taken from a chromatic scale) were used and for every tone four cadencas existed corresponding to the four different harmonic functions of the target tone (Fig. 1). Thus, in total 44 different cadencas existed (11 target tones, four cadencas per tone). This procedure provided physically identical sets of target tones for every harmonic function tested (fundamental, third, sixth, minor second). The task of the subject was to count the non-harmonic target tones (i.e. the minor seconds) without vocalizing. This was done to allow performance judgement. Note, that the counting procedure should not influence P3m effects since only when the target was completely evaluated (i.e. after the P3m), counting could start. Thus counting related ERP differences should show up after the P3m effect. All cadencas were presented in a completely randomized order. Nine subjects, eight male and one female (mean age 28, range from 22 to 35) took part in the experiments. All subjects were right handed and had no history of neurological illness. They regularly practised musical instruments since childhood (duration 10–28a, mean 15a) and were trained at a musical academy. Investigations were done with a whole-head magnetoencephalography (MEG) system (CTF Inc., Port Coquitlam, Canada) with 143 MEG sensors. In each of three runs 300 cadencas were presented via a plastic tube to the left ear. Unilateral stimulation was used to isolate magnetic field components associated with harmonic processing as much as possible and avoid component overlap due to bilateral acoustical input. In addition three simple tone matching runs were presented, which were not analyzed for this paper. Between the runs the subjects had to report their counts of the non-harmonic minor second. The data were digitized at a sample rate of 62.5 Hz using a low pass filter of 20 Hz and a high pass filter of 1 Hz. Noise reduction was done with a 3rd order software gradiometer. Every 700 ms one sound (either chord or target tone with a duration of 400 ms) and every 6 s one trial (consisting of three chords and the target tone) was presented. The data were recorded from 3.1 s before to 1.5 s after target onset. For avoiding artefacts due to head movements, the heads of the subjects were wrapped up with a gauze bandage in order to restrain their heads in the dewar. The subjects sat in a comfortable chair and were asked not to move during the recording time and to fix their gaze on a cross in front of them. The behaviour of the subjects during data acquisition was monitored with a camera. The whole experiment lasted about 2.5 h. After acquisition, every trial was visually screened twice for artefacts due to head or eye movements and artefact containing trials were discarded. Only datasets where artefact free trials comprised at least 60% of all trials recorded, were accepted and averaged separately for each condition.

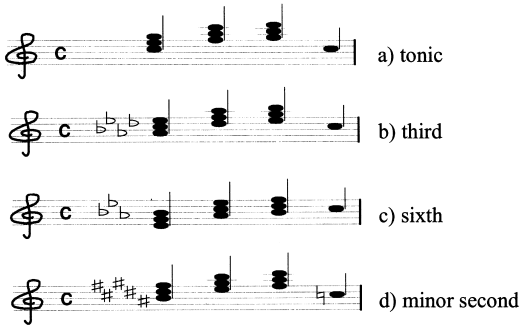

Fig. 1. The four possible cadencas existing for one target tone (here pitch c) and occurring with equal probability. In total 11 different target tones existed resulting in a total of 44 different cadencas presented in completely randomized order.

For analyzing the effects of harmonic violation, the evoked fields of the tonic target tone were compared with those of the minor second, as the tonic has the strongest harmonic representation and maximal differences in the evoked fields to the minor second can therefore be expected. P3m generation was detected by comparing field and signal course differences between the two conditions and by inspecting difference waveforms between the tonic and minor second targets within a time range of 300–800 ms post target tone onset. At the P3m maxima, current sources contributing to the peak were defined using the low resolution electro-magnetic tomography (LORETA) methodology

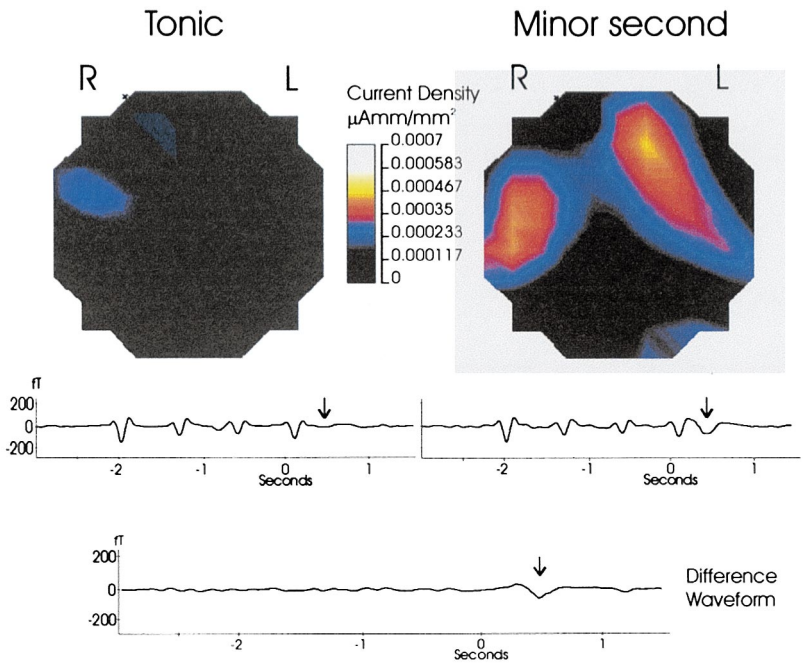

Fig. 2. Current density maps of one subject on a transverse brain slice running through temporal and frontal areas. Upper left: current densities with the tonic target tone. Upper right: current densities with the minor second target. Left is right. Middle: corresponding signal courses for a right temporal channel showing the four evoked magnetic field complexes for chord 1–3 and the target tone (presented at 0 s). The arrow indicates P3m with the minor second at a latency of 464 ms. Lower: subtraction of the two waveforms above showing the P3m effect being the only significant difference between the tasks.

[15] as implemented in the CURRY 4.0 data analysis software. LORETA in 3D solution space was chosen since it computes current distributions over the whole brain volume without apriori assumptions for the number of sources and since a recent comparison of LORETA and Minimum Norm Least Squares methods with simulated data showed superior performance of the LORETA methodology [7]. The following settings were used for data analysis: noise estimate: channelwise 20th percentile, volume conductor: three concentric shells, current density settings: lambda 1, L2 Norm, grid for current source locations: 10 mm intergrid distance with 17 planes covering the spherical head model.

Results showed a clear P3m with the non-harmonic target in six out of nine subjects. None of these subjects showed a comparable deflection with the tonic target (compare with Fig. 2). However, some of them showed a component immediately preceding the P3m with reversed field patterns resembling the N350 component as described by Patel et al. [16]. This effect was not further analyzed. Concerning current source distributions, the most reliable component contributing to the P3m effect was localized in the right temporoparietal area (Table 1). This localization was found in all subjects. Additional major sources were found in frontocentral (three subjects) and left temporoparietal (three subjects) brain areas. Left temporoparietal current sources were always weaker than right ones. Although slight tendencies sometimes existed, the remaining three subjects showed no clear P3m. To evaluate individual performance, counts of the minor second were analyzed. Ss showing a P3m (Ss 1–6) had much better counting results compared with those without (Ss 7–9). The correct number of disharmonic minor seconds for each run would have been 75 out of 300. Ss 1–6 counted 74 on average (S1: 79, S2: 79, S3: 74, S4: 61, S5: 74, S6: 77), whereas this number was 124 for Ss 7–9 (S7:131, S8:144, S9: 96).

Table 1
Location of major current sources of the P3m found with non-harmonic target tones

Subject	Right temporoparietal	Left temporoparietal	Frontocentral
1	X		
2	X	X	
3	X	X	X
4	X		
5	X	X	X
6	X		X

The results indicate that a highly selective marker for harmonic processing may be generated with careful experimental set-up. As mentioned above, late positive components are sensitive to a variety of parameters such that it is difficult to isolate specific effects, especially when trying to find a marker for harmonic processing. With this study special care has been taken to avoid non-harmonic cues for target evaluation. The harmonic context (cadenca) showed an identical construction for all targets. Probability for a specific target to occur was

identical for all four target tones. The four target groups (tonic, third, sixth, minor second) comprised exactly the same 11 tones from a chromatic scale thereby excluding variable evoked off effects. The cadencas were presented in randomly changing musical keys based on the chromatic scale and thus showed no intertrial relationship. To minimize short-term memory effects concerning the presented harmonic context, target tones were presented instead of target chords. All this ensured that only if the subject was able to recognize the minor second as disharmonic relative to the context heard before could a P3m occur. No other cues were possible. Results show that subjects reliably solving the task (subjects with good counting results) generated a clear P3m to the non-harmonic minor second. Its specificity for harmonic context violation is demonstrated by the fact, that no comparable component was found for the tonic. The most reliable current source was located in the right temporoparietal area. Right hemisphere advantages for harmonic processing have been described several times, however, it has to be kept in mind, that only left ear stimulation has been used with our study. The specificity of this P3m effect was further supported by its dependency on discrimination performance. Although slight tendencies sometimes were visible, subjects with bad counting results did not show a P3m. Since countings of these subjects were considerably worse, it might be interesting to determine the performance limit necessary for generation of an unequivocal P3m with further experiments. Variation of P3 effects corresponding to differing performance levels of musicians and non-musicians have already been described [3,6,8]. The marker studied in this investigation however, even differentiates harmonic processing capabilities within a homogeneous group of regularly trained musical subjects. In this respect it is important to keep in mind, that our task design was difficult, even for musically trained subjects. First, pure sinus tones lacking harmonics which are important for pitch determination [19] were used as targets and presented only to one ear. Second, stimuli were presented rapidly and musical keys were changed randomly irrespective of key relationships with every trial, requiring a continuous and rapid change of the current representation of tonal hierarchies [11,5] – a situation very prone to interferences. Note, that only with successful set-up of the correct tonal hierarchies, expectancy violations and thus a P3m could occur. This means that our subjects harmonic processing performance differed with their capability for rapid adjustment to new harmonic contexts. Third, a high level of attention was required over a long period of time. Due to these difficulties, all subjects showed counting errors. However, only with subjects where the number of errors was small, a P3m occurred.

In conclusion, we have shown that a highly specific marker for cognitive abilities as complex as harmonic processing exists and that it separates subjects with differing harmonic processing capabilities. This offers new possibilities to selectively study harmonic variables in music processing. With left ear stimulation the most important P3m generator is located in the right temporoparietal area.

This work was supported by the Austrian Science Foundation (FWF, P12451Med). The authors are grateful to Anja Menze and Daniela Huter for valuable help in performing pilot studies.

[1] Beisteiner, R., Altenmüller, E., Lang, W., Lindinger, G. and Deecke, L., Musicians processing music – A DC potential study. Eur. J. Cogn. Psychol., 6 (1994) 311–327.
[2] Besson, M., Electrophysiological studies of music processing. In I. Deliège and J. Sloboda (Eds.), Perception and Cognition of Music, Psychology Press, East Sussex, 1997, pp. 217–252.
[3] Besson, M. and Faita, F., An event-related potential (ERP) study of musical expectancy: comparison of musicians with non-musicians. J. Exp. Psychol.: Hum. Percep. Perform., 21 (1995) 1278–1296.
[4] Besson, M. and Macar, F., An event-related potential analysis of incongruity in music and other non-linguistic contexts. Psychophysiology, 24 (1987) 14–25.
[5] Bharucha, J.J. and Stoeckig, K., Priming of chords: spreading activation or overlapping frequency spectra? Percep. Psychophys., 41 (1987) 519–524.
[6] Crummer, G.C., Hantz, E.C., Chuang, S.W., Walton, J.P. and Frisina, R.D., Neural basis for music cognition: initial experimental findings. Psychomusicology, 7 (1988) 117–126.
[7] Fuchs, M., Wagner, M., Köhier, T. and Wischmann, H.A., Linear and non-linear current density reconstructions. J. clin. Neurophysiol., 16 (1999) 267–295.
[8] Hantz, E.C., Crummer, G.C., Wayman, J.W., Walton, J.P. and Frisina, R.D., Effects of musical training and absoulte pitch on the neural processing of melodic intervals: a P3 event-related potential study. Music Percep., 10 (1992) 25–42.
[9] Janata, P. and Petsche, H., Spectral analysis of the EEG as a tool for evaluating expectancy violations of musical contexts. Music Percep., 10 (1993) 281–304.
[10] Janata, P., ERP measures assay the degree of expectancy violation of harmonic contexts in music. J. Cogn. Neurosci., 7 (1995) 153–164.
[11] Krumhansl, C.L., Music psychology: tonal structures in perception and memory. Annu. Rev. Psychol., 42 (1991) 277–303.
[12] Lerdahl, F., Tonal pitch space. Music Percep., 5 (1988) 315–350.
[13] Levett, C. and Martin, F., The relationship between complex music stimuli and the late components of the event-related potential. Psychomusicology, 11 (1992) 125–140.
[14] Meyer, L.B., Emotion and Meaning in Music, University Chicago Press, Chicago, IL, 1956.
[15] Pasqual-Marquis, R.D., Michel, C.M. and Lehmann, D., Low resolution electromagnetic tomography: a new method for localizing electric activity in the brain. Int. J. Psychophys., 18 (1994) 49–65.
[16] Patel, A.D., Gibson, E., Ratner, J., Besson, M. and Holcomb, P.J., Processing syntactic relations in language and music: an event-related potential study. J. Cog. Neurosci., 10 (1998) 717–733.
[17] Petsche, H., Etlinger, S.C., EEG and Thinking, Verlag der Österreichischen Akademie der Wissenschaften, Wien, 1998.
[18] Schinuckler, M.A., Expectation in music: investigation of melodic and harmonic processes. Music Percep., 7 (1989) 109–150.
[19] Terhardt, E., Pitch, consonance and harmony. J. Acoust. Soc. Am., 55 (1974) 1061–1069.