PERCEPTION AND PROCESSING OF MUSICAL SCALE STRUCTURES: A CROSS-CULTURAL ERP STUDY

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ABSTRACT

Background. So far, two approaches have been used to study the cross-cultural side of music perception: a) the 'probe-tone method' and b) behavioral tests to investigate the stages before and after musical enculturation. Modern methods of brain science have the decisive advantage of measuring responses not only pre-verbally, but also directly and simultaneously while listening to music.

Aims. The current experiment was designed to examine how members of different cultures perceive musical scales with various structures. It is based on event-related potentials (ERPs) as a method of study. The P300 component was used as an indicator for underlying cognitive processes.

Method. Five German, five Turkish and five Indian musicians listened attentively to four types of heptatonic scales played in an upward movement - the European scales 'major' and 'harmonic minor', the equiheptatonic Thai scale and the Turkish makam Hicaz. Scales were combined in pairs in five different blocks according to the 'oddball paradigm'. Bioelectrical activity was registered at Fz, Cz and Pz.

Results. Analyzing block 1 (major scale versus Thai deviant scale), data analysis revealed a P300 as well as a non-expected negative shift, named 'processing negativity'. The negative shift was found after clear pitch identification wherever the difference in frequency between the deviant scale-tone and the standard scale-tone had a sufficient amount.

Furthermore, both non-Western groups showed a large P300 as a reaction to the first tetrachord, for those two groups, *scale-tone 4* obviously had the function of a cognitive reference point. For German musicians, *Thai-tone 7* elicited a large P300, revealing violation of the 'leading tone expectancy'. After having perceived *scale-tone 8*, Indian musicians did not respond to the whole scale-pattern as they are used to a different form of playing and performing scales, i.e. the combination of upward and downward scale movement, termed 'arohana' and 'avarohana'.

Conclusions. Universal listening strategies (e.g. 'categorical perception', 'pattern perception') are modified by culturally imprinted scale material. Both components, the P300 and the 'processing negativity', serve as bioelectrical markers for the interaction of processing strategies and culture-specific material.

1. INTRODUCTION

Up to now, the cross-cultural aspect of music perception has been investigated on the basis of two methods, testing only the behavioral responses of subjects: a) on the 'probe-tone method', used in the bi-cultural studies of Castellano et al. and Kessler et al. [1, 6]. and b) on the developmental approach, i.e. on the investigation of stages before and after musical enculturation e.g. Lynch et al. and Trehub et al. [7, 11]. The current study is an attempt of combining the disciplines 'comparative musicology' and 'cross-cultural research' with 'cognitive neuroscience'. The intercultural aspect is realized by taking two factors into account: 'subjects' and also 'stimuli'. Event-related potentials (ERPs) are used as the method of study. ERPs consist of several positive and negative deflections (components) which may indicate special aspects of cognitive information processing. In the present experimental design, the so-called P300 component was used [e.g. 3].

2. METHODS

2.1. Subjects

Five German, five Turkish and five Indian musicians, aged 20 to 54, all male, no hearing deficiencies, participated in the ERP experiment. It was carried out at the audiotechnical laboratory of the Institute of Musicology at the University of Hamburg. The group of German musicians mainly consisted of young conductors; none of them had experience in listening to non-Western music. The Turkish participants were members of an amateur 'saz ensemble'; the Indian group exclusively comprised professional musicians, playing traditional percussion and string instruments of India.

2.2. Stimuli

The stimulus material consisted of four heptatonic scales: The European major and harmonic minor scales, the Thai scale made of equal steps and the makam Hicaz of the Turkish art music. The tone material was binaurally presented through earphones, each scale had the starting pitch of 493,88 Hz (= scale-tone b'). All stimuli were generated on a programmable synthesizer (Roland JD 800), interval sizes (in cents) were precisely adjusted with the 'pitch coarse'- and 'pitch fine'-buttons of the synthesizer. Every single tone was based on a pulse wave of the sound catalogue; stimulus duration was 200 msec, and the interstimulus interval (stimulus onset to stimulus onset) was 540 msec. Each trial, made up of eight scale-tones, started after a rest of two seconds. From this tone material, pairs of scales were combined with each other in five different block arrangements. Each block consisted of 60 scales. They were split up in 45 standard and 15 deviant scales according to the 'oddball paradigm' [e.g. 3].

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2.3. Tasks

In order to keep subjects attentive, they had to perform two tasks within a block: a) the silent counting of the deviant scale-form (which is a standardized task of the oddball paradigm) and b) the identification of the standard and deviant scale-structure; results should be written down during the pauses.

2.4. Apparatus And Recordings

Scalp electrodes were attached to the anterior-posterior midline with electrode placements at Fz, Cz and Pz.. In addition, a vertical electro-oculogram was registered for the control of blinking artifacts. For this experiment, a time constant of 0,3 sec was chosen, and the high cut-off frequency was 140 Hz for all raw data. The sampling rate was 667 Hz for each channel.

2.5. Data Analysis

Artifact free trials were averaged separately for each subject, each block, scale-tone, electrode site and sort of scale, resulting in single ERP-potentials which were baseline-corrected afterwards. Grand averages for each group have been generated by means of the SPSS software. Unexpectedly, many of the graphs additionally revealed negative shifts with an onset latency of at least 430 msec. Thus, data input for statistical analysis consisted of maximum amplitude values within two time intervals (range I: 270 msec - 430 msec to detect significant P300 activity and range II: 430 msec - 540 msec to check out, if negative shifts were significant).

Step 1 of the computation was a one-factor analysis of variance to examine the effect of the factor 'cultural imprintment' on scale perception per se (ONEWAY, dependent variable: M1T1P1 to M2T8P3 (M for 'mode', i.e. standard or deviant status of scales, T for 'scale tone' and P for 'electrode placement'), independent variable: CULTURE (three levels, i.e. German, Turkish and Indian groups); for paired comparisons, the Scheffé-test was applied; results were considered significant at $p<.05$ and $p<.01$). Step 2 of the analysis consisted of a four-factor repeated measures design of variance, done with the SPSS command MANOVA and restricted to the omnibus F-test (repeated measures factors: 'mode' (standard and deviant status of scales), 'scale tone' and 'electrode placement', the between-subjects factor was 'culture'; statistics were Greenhouse & Geisser corrected; the level of significance was $p<.05$). In addition, a t-test for paired samples was computed for each electrode.

3. RESULTS

Block 1 (major standard scale versus Thai deviant scale)

Scale-tone 2. Tone 2 of the Thai scale elicits a negative shift with an amplitude maximum in the second time interval (Fig. 1 and 2). At all electrode sites, German musicians also reveal a negativity for the second tone of the major standard scale (Fig. 1). For all cultural groups, the amplitude differences between the major standard- and the Thai deviant-potentials are verified by significant results of the t-test for paired samples (Fz: $t(14) = 2.49$ $p<.05$ Cz: $t(14) = 3.73$ $p<.01$ Pz: $t(14) = 3.88$ $p<.01$).

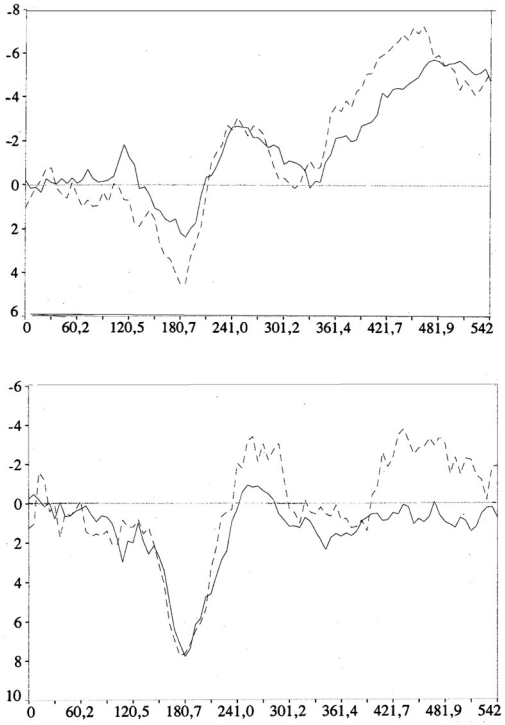

Figure 1 and 2: Grand average ERPs of German musicians (upper diagram) and Indian musicians (lower diagram). Electrophysiological reactions to tone 2 of the major standard scale (solid line) and tone 2 of the Thai deviant scale (broken line), scalp site Cz. Analyzed time interval: 430 msec - 540 msec. Horizontal axis: time in msec, vertical axis: average Cz in µV; negativity is up.

Scale-tone 4. When perceiving the fourth tone of the major standard scale, Indian and Turkish musicians respond with a P300 and a so-called 'long lasting positivity' at Fz and Cz (Fig. 3).

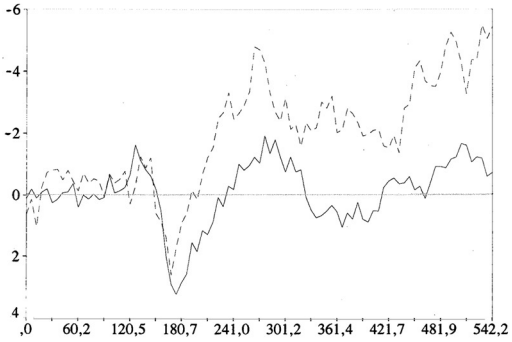

Figure 3: Grand average ERPs of Indian musicians. Reactions to tone 4 of the major standard scale (solid line) and tone 4 of the Thai deviant scale (broken line), recording at Fz. Analyzed time interval: 270 msec - 430 msec.

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Scale-tone 7. German participants react to the seventh tone of the Thai deviant scale; they reveal a clear P300 component at all electrode sites (Fig.4). Indian musicians show a similar brainelectrial response, although amplitude values are smaller. For electrode placements Cz and Pz, the results of the t-test are significant (Cz: t(14) = -2.35 p<.05 Pz: t(14) = -2.73 p<.05).

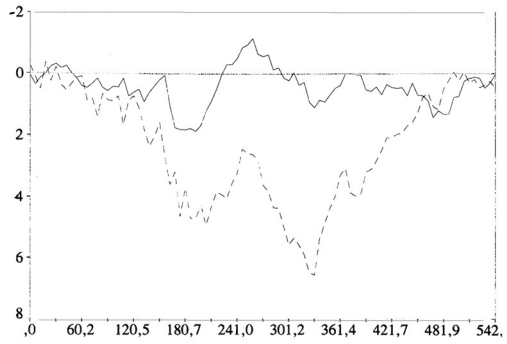

Figure 4: Grand average ERPs of German musicians. Bioelectrical reactions to tone 7 of the major standard scale (solid line) and tone 7 of the Thai deviant scale (broken line), scalp site Fz. Analyzed time interval: 270 msec - 430 msec.

Scale-tone 8. Analyzing ERP reactions to the eighth tone of the Thai deviant scale, German subjects show a long lasting positivity at all electrode positions (Fig. 5). Indian musicians did not reveal such form of positivity (Fig. 6). The t-test shows the following significant results: Fz: t(14) = -2.86 p<.05 Cz: t(14) = -3.38 p<.01 and Pz: t(14) = -3.7 p<.01.

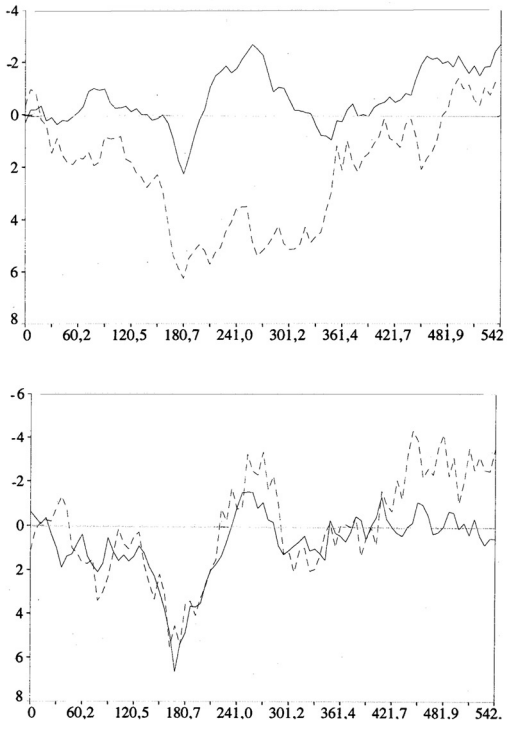

Figure 5 and 6: Grand average ERPs of German musicians (upper diagram) and Indian musicians (lower diagram). German group: Bioelectrical reactions to tone 8 of the major standard scale (solid line) and tone 8 of the Thai deviant scale (broken line). Indian group (for comparison only, different block arrangement): Bioelectrical reactions to tone 8 of the Thai standard scale (solid line) and tone 8 of the major deviant scale (broken line), recordings at Cz. Analyzed time interval: 270 msec - 430 msec.

4. DISCUSSION

Block 1 (major standard scale versus Thai deviant scale)

Scale-tone 2. The negative shift reflects the effort of cognitive processing after sensorial perception. Thus, it is named 'processing negativity'. Nonetheless, it should not be mixed up with a component of the same name which was originally found by the Finnish neuropsychologist R. Näätänen when making use of a dichotic listening task [8]. In the current study, a negative shift could always be detected after clear pitch identification wherever the difference in frequency between the deviant scale-tone and the corresponding standard scale-tone had a sufficient amount. Thus, the difference in amplitude between the Thai and the major potential-curves in the second time interval is understood as a bioelectrical indicator of interval judgement based on 'categorical perception', a concept, which is often used to describe the listening behavior of professional musicians [9]. For both non-Western groups, the frequency difference of 28,6 cents between the second tone of the Thai scale and the second tone of the major scale seemed to be sufficient to develop two different perceptual categories for cognitive pitch processing in the working memory. For Western musicians on the other hand, perceptual categories with tonal zones of ± 50 cents around the center of a given semitone can generally be assumed. The actual frequency difference was obviously too small to evaluate both pitch impressions within two separate perceptual categories. Thus, it is quite likely that German musicians process both pitches within one category according to the principle of the so-called adaptive listening ('Zurechthören'). In the second time interval however, their traces of the Thai- and the major potentials reveal a smaller difference in amplitude than those of Indian and Turkish musicians.

Scale-tone 4. For non-Westerners, the fourth tone of a scale can generally be considered as an anchor point or frame tone. It is the final point of the first (disjunctive) tetrachord which is a basic element in the tone systems of Arab-Turkish and Indian people [5, 10]. The positive shift in the first time interval probably indicates a special listening strategy of Turkish and Indian musicians, reflecting a kind of 'retrospective cognitive judgement of four-tone-segments' (tetrachord portions) within a scale.

Scale-tone 7. For German musicians, Thai tone 7 causes a violation of the overlearned 'leading tone expectancy'. This violation elicits a 'context updating process' [2], i.e. a revision of the culture specific template of the European major scale. The updating process is indicated by a large P300. When analyzing the brain activity of non-Western musicians, it was only possible

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to draw a similar conclusion for Indian musicians. This result can be explained by the various forms of scale structure in the tone systems of Arab-Turkish and Indian people, structures which are also mentally represented in subjects' minds. Anyhow, it is demonstrated in the compendia of Signell and Jairazbhoy that only 50 percent of the 'makam scales' and 50 percent of the so-called 'that scales' include a semitone between step 7 and step 8, equivalent to the leading tone in the diatonic system. The other half of scale-types is characterized by a whole-tone at that point.

Scale-tone 8. In order to explain the brain reactions to scale-tone 8, a hypothesis of the German neuropsychologist R. Verleger is brought in [12]. According to Verleger, a P300 indicates the 'closure of a cognitive epoch' which could also be understood as a 'Gestalt in time'. Hence, a P300 component, evoked by the eighth scale-tone, reflects 'pattern perception' and also 'pattern recognition'. German and Turkish participants did indeed respond with a large P300 to the termination of the scale-template. Indian musicians did not reveal this form of positivity. Their missing P3-reaction can possibly be explained by the Indian traditional practice of playing scales in a combination of upward and downward movement, termed 'arohana' and 'avarohana'.

5. GENERAL DISCUSSION

Having a look at the listening concepts and strategies that are used by members of two or even all three cultural groups ('categorical perception', 'pattern perception', 'evaluation of tetrachords') the question is, if these strategies represent basic universal principles beyond any cultural imprintment. The results of my ERP study show that none of these listening strategies can exclusively be traced back to this universal idea. Rather, all listening principles, indicated either by the processing negativity or by a P300 component, are the outcome of both, the universal as well as the culture-relativistic aspect. In detail, the influence of culture is evident a) in dissimilar bioelectrical reactions of Western and non-Western musicians when comparing the frequency difference of the deviant scale-tone and the corresponding standard scale-tone ('categorical perception', see scale-tone 2), b) in contrary listening habits of Western musicians and non-Western musicians when perceiving tetrachord portions (see scale-tone 4) and c) in different forms of playing and perceiving musical scale templates (Indian musicians vs. German and Turkish musicians, see scale-tone 8, 'pattern perception'). To sum up, listening strategies, which are assumed to be universal per se, undergo a change whenever applied to 'culture-imprinted material', i.e. in this case 'culture-specific scale-structure'. The interaction between universal principles of perception and culture-specific stimulus material is confirmed by two bioelectrical components - the P300 and the processing negativity. In line with this interpretation is the following statement of the music psychologist D. Harwood: "A search for universals cannot usefully focus on musical content … Rather, we should direct our attention to how music is made - how it is performed, heard, understood and learned. The process of understanding and participating in the musical behaviour of one's community may be more universal than what is to be understood and performed." [4, p. 51].

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