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Effects of harmonics on aesthetic judgments of music: an ERP study involving laypersons and experts

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The purpose of the study was to test whether aesthetic judgments of music are affected by expertise or harmonic violation of musical sequences. The participants were 14 musical experts and 13 laypersons; they were asked to judge the beauty and correctness of extracts from J.S. Bach's chorales. Experts and laypersons showed different late positive potential (LPP) responses to the appraisal of correctness. LPP also proved to be sensitive to the extent to which the extracts violated harmonic expectations. The relationship between the early right anterior negativity potential (ERAN) and the harmonic correctness of chords was similar in laypersons and experts.

Key words: event-related potentials, late positive potential, early right anterior negativity, music processing, expertise, music aesthetics

INTRODUCTION

Meyer (1956) hypothesized that music listeners expect to hear certain musical sequences and that fulfillment of these expectations about, for example, harmony triggers affective reactions associated with relaxation, whilst violation causes tension. Steinbeis and others (2006) confirmed this hypothesis in a study using original arrangements of extracts of J.S. Bach's chorales. Extracts were selected due to their unexpected structure in terms of harmony. The researchers developed two additional versions of the chorales: expected and completely unexpected ones. In the harmonically expected versions an original chord was replaced with a tonic chord whereas in the very unexpected versions it was replaced with a Neapolitan chord. They showed that violation of harmonic expectation was positively associated with evaluation of overall emotionality of a musical extract and with the electrodermal response to the music (EDA).

Late positive potential (LPP) is an electrophysiological response to affective stimuli which starts about 300-400 ms after stimulus onset. LPP amplitude is affected by the emotional intensity of a visual stimulus (Cuthbert et al. 2000, Foti et al. 2009, Schupp et al. 2004). In addition, the LPP effect is stronger for arousing stimuli which are capable of eliciting a greater EDA (Cuthbert et al. 2000). To date there has been no research on the effect of violation of harmonic expectations on LPP amplitude. One of the goals of this study was to test the hypothesis that LPP amplitude, like the EDA strength in studies conducted by Steinbeis and colleagues (2006), varies according to the extent to which harmonic expectation is violated.

The LPP effect is also influenced by type of task (Foti and Hajcak 2008, Hajcak et al. 2006, Hajcak and Nieuwenhuis 2006, Moser et al. 2006) and level of expertise in the field of music (Müller et al. 2010). Müller and others (2010) presented simple musical sequences to participants and found that the LPP amplitude was larger in laypersons when they were evaluating the beauty of chord sequences rather than their correctness. In experts however LPP amplitude was similar on the two tasks. The authors suggested that simple stimulus material could be too transparent for experts. If experts used the same analytical processes to assess both beauty and correctness, then the similarity in their LPP amplitudes on the two tasks is understandable. In our studies we followed Müller and colleagues' suggestion (2010) and used fragments of J.S. Bach's chorales instead of simple musical sequences.

On the basis of questionnaire-based research by Istók and others (2009) we assumed that the adjective "beautiful" is the most salient and central to the concept of "beauty" which underlies aesthetic responses to music. Istók and others (2009) found that "beauty" was the adjective most frequently associated with "touching", an adjective used to express an emotional state evoked by music (see Konečni 2008). Müller and colleagues (2010) suggested that the adjective "beautiful" was most appropriate linguistic concept for expressing the aesthetic value of music.

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To summarize, the purpose of our study was to test the hypothesis that chords violating the harmonic correctness of a piece of music will elicit a greater LPP effect than chords that do not violate harmonic expectations. We also expected that the amplitude of the LPP would be positively related to the degree of the harmonic violation. Because we chose to use complex musical material, we expected that differences in the LLP would be observed in both an aesthetic judgment and a judgment of the harmonic correctness of the chord sequences in experts as well as laypersons.

Apart from investigating LLPs, we analyzed early right anterior negativity potential (ERAN) elicited by harmonic violations in a piece of music. ERAN is an early wave of negative charges indicating a difference in EEG recording for harmonically unexpected event compared to expected one. EARN is spreading in the right frontal areas with peak amplitude about 200ms (Müller et al. 2010). It is associated with cognitive processing of the principles of harmony in music (Brattico et al. 2013). ERAN is generally observed for chords which violate musical context in a strong degree compared to chords which do not violate musical context (Koelsch et al. 2000, 2002, Koelsch nad Jentschke 2008, Maidhof and Koelsch 2011). However, the effect is also observed for chords which are ambiguous in terms of the correctness with the rules of music (Müller et al. 2010, Steinbeis et al. 2006). Thus ERAN amplitude is affected by the degree to which harmonic expectations are violated (Koelsch et al. 2000, Steinbeis et al. 2006). ERAN is also modified by musical expertise of the listener (Koelsch et al. 2002, Müller et al. 2010). On the basis of studies by Koelsch and others (2000), Müller and others (2010) and Steinbeis and others (2006), we expected that ERAN amplitude would vary according to the magnitude of the harmonic violation and the participants' level of musical expertise.

The problem of the impact of harmonic violation on aesthetic judgments of music have been already taken (Jaśkiewicz et al. 2014). The analysis did not take into account an early event-related component though. Investigating early and late processes together will give a new insight in the phenomena of syntax processing according to the type of judgment. Additionally, new analysis of late effects allow to give interpretation which are more specific to the described component.

METHODS

Participants

Twenty-nine participants took part in the study. Data from two subjects had to be excluded because of poor signal quality. Fourteen of the remaining twenty-seven participants were musical experts (eight female and six male; M_{age}=20.5, SD=1.56; three of participants left-handed) and 13 were laypersons (seven female and six male; M_{age}=22.9, SD=1.34; one participant left-handed). The experts included graduates or students of music at primary or secondary education level who had at least four years' experience of playing a musical instrument or singing. The experts devoted approx. 10 hours a week to musical practice. In contrast the laypersons had never learned to play a musical instrument or taken singing lessons. None of the participants reported a history of neurological injury or mental disorder. All subjects consented to take part in the study.

Stimuli

We used the same fragments from five of J.S. Bach's chorales as were used by Steinbeis and colleagues (2006) in their studies: No. 7 (BWV 17.7), No 21 (BWV 153.5), No. 52 (BWV 429), No. 60 (BWV 133.6), No. 84 (BWV 197.5) (Riemenschneider 1941). All these fragments contained an experimental chord. Depending on the chorale, the experimental chord occurred 9 to 14 chords from the beginning and 5 to 14 chords before its end, thus giving listeners enough time to develop musical expectations before the experimental chord occurred. At the same time, the variation in sequential position of the experimental chord made it difficult for the listeners to predict its occurrence. Each of the five chorales was presented with one of three experimental chords:

1) expected, the tonic chord;
2) unexpected, used by Bach in the original chorale and
3) very unexpected, that is, the Neapolitan chord.

The fragments of chorales were played on the piano by a professional pianist and recorded as MIDI files. Then every fragment was altered to one of three versions by putting appropriate experimental chord for each version. The three versions of each fragment differed only in the experimental chord. In total we used 15 different versions of the chorale fragments (five fragments in three versions each). Regardless of version, fragments were played at a tempo which ensured that the experimental chord, together with the subsequent pause, lasted for at least 1100 ms. To preserve the natural sound of the pieces we did not set rigid limits for the duration of the experimental chord and the following pause. The fragments of chorales used in the study lasted from 13 to 21 seconds.

Procedure

The experiment consisted of an introductory phase and a test phase. In the introductory phase participants were familiarized with the experimental procedures; they judged the beauty and correctness of fragments of Bach chorales which were not used in the test phase. Participants were given no explanation of "beauty" or "correctness". The procedure was the same in both experimental phases (Fig. 1). At the end of the introductory phase participants were asked whether the task was understandable. The introductory phase lasted about 15 minutes, depending on the participant; it was followed by the test phase.

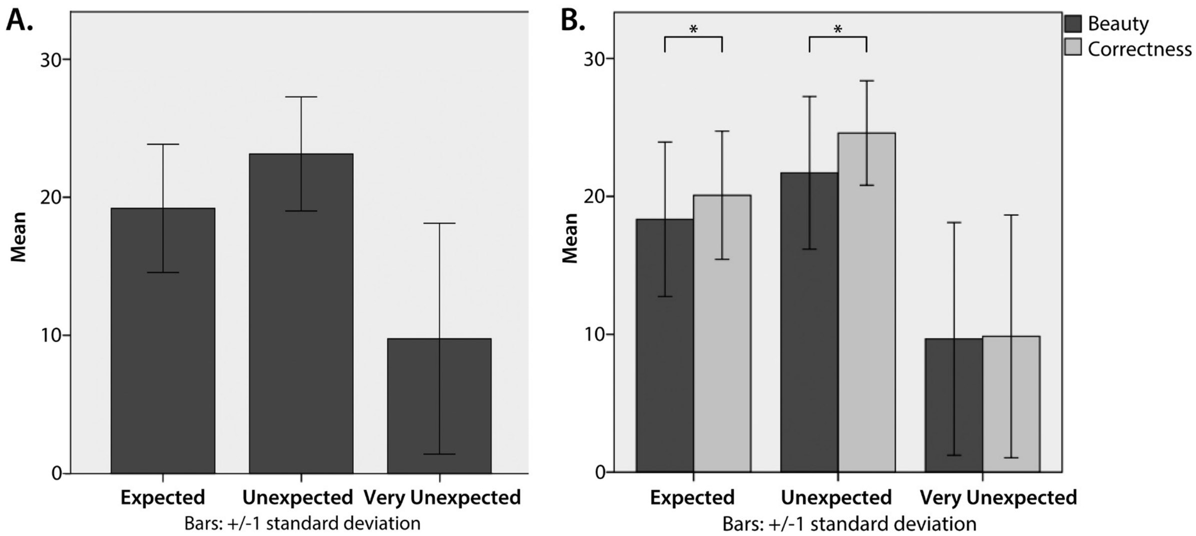

Fig. 1. A trial from the task.

At the start of a trial a point was displayed in the center of a screen placed in front of the participant for 800 ms, after which one of the following questions appeared, 'Beautiful?' or 'Correct?'. The question was presented for 1200 ms and then the point reappeared and was displayed until the end of the musical stimulus presentation. The chorale fragment begun 800 ms after the point appeared; after the chorale there was a 200 ms pause. Then a chart with the words 'Yes' and 'No' was displayed. The chart disappeared when the participant pressed one of the two response buttons on the keyboard. The procedure was the same for all trials.

To reduce the risk of fatigue stimuli were presented in six sets (30 trials per each set). Three sets, the first, third and fifth sets, were followed by a 15-second break. After the second and the fourth set presentations, impedance was measured and the EEG headband position and electrode conductivity were adjusted accordingly.

Each variant of the chorale was presented 12 times (six times in correctness trials; six times in beauty trials). Each participant made 180 decisions (90 for correctness judgements task and 90 for beauty judgements task). The order in which stimuli were presented was pseudorandom, such that no more than three stimuli belonging to the same experimental chord category and no more than three trials of the same judgment type could be presented in succession. After completing the experimental phase participants completed a brief questionnaire about their musical education. The study lasted approx. two hours.

Apparatus

A Geodesic EEG System 300 (EGI Inc., Eugene, OR, USA) connected to 64-channel HydroCel GSN and a high-input impedance amplifier (200 MOhms, Net Amps, EGI Inc., Eugene, OR, USA) was used in the experiment. Amplified analog voltages (0.01–100 Hz bandpass) were digitized at 250 Hz. The impedance of individual sensors was adjusted to below 50 kΩ, which is considered acceptable for this system (Ferree et al. 2001, Tucker 1993). Impedance was measured after the second and the fourth sets of trials and electrode conductivity was readjusted using the same procedure as when the cap was first placed on subject's head. Adjusting electrodes' conductivity during breaks was necessary for the EEG caps used in the experiment. Horizontal and the vertical electrooculograms (EOGs) were recorded to control for ocular artifacts in the EEG. Net Station Version 4.4 (Electrical Geodesics, Eugene, OR, USA) was used to record EEG data. E-Prime 2.0 Professional (Psychology Software Tools, Pittsburgh, PA, USA) with Extensions for Net Station synchronization with Geodesic EEG 300 was used for stimulus preparation and presentation. We used a 17-inch LCD monitor with a display resolution of 1280×1024 pixels. Sound was played through Yamaha HS-50M speakers placed 60 cm from the participant, who indicated his or her responses using two buttons on a Geodesic Subject Response Pad keypad (Electrical Geodesics, Eugene, OR, USA).

Data analysis

Event Related Potentials analysis. Only data from the test phase were analyzed. In order to calculate analysis was carried out using Matlab version 7.9.0 (toolbox EEGLAB, version 12.0.2.0b). First, data were filtered to remove activity below 0.1 Hz and above 20 Hz to remove data that did not represent brain activity [FIR filter (pop_eegfiltnew function) with 9276 filter order was used]. Then the data was segmented into epochs lasting 1300 ms (–100 ms before the onset and 1200 ms after the stimulus onset) with the unexpected/expected chord as the onset cue. A real stimulus onset was monitored using a custom-made hardware to detect sound card latency for each trial. Next independent component analysis (ICA) was used to remove muscle and eye movement artifacts. ICA was performed on the whole dataset (despite the electrode conductivity adjustments during the breaks in signal acquisition). On average 18.03 (SD=9.52) components were removed per subject. For statistical analysis we used data from 12 electrodes (F3, FZ, F4, C3, CZ, C4, P3, PZ, P4, O1, OZ, O2). Time windows of ERAN effects was the same for very unexpected and unexpected chords (160–240 ms). They were selected after checking the difference wave course. LPP analysis used data from the 500–650 ms from experimental chord onset time window, following Hajcak and colleagues (2006).

Behavioral data analysis. Participants gave their yes/no answers for beauty and correctness judgments. For analysis positive answers ("yes") were marked as 1, negative answers ("no") were marked as 0. Answers were counted for two tasks separately. Every subject gained six scores of answers: correctness judgments of stimuli with expected chord (1), correctness judgments of stimuli with unexpected chord (2), correctness judgments of stimuli with very unexpected chord (3), beauty judgments of stimuli with expected chord (4), beauty judgments of stimuli with unexpected chord (5), beauty judgments of stimuli with very unexpected chord (6). Then, a repeated measures ANOVA with factors: chord type (3), task (2) and group as between--subjects factor (layperson, expert) were conducted. When the assumptions of the ANOVA were not satisfied, the correction of the degrees of freedom using the Geisser Greenhouse test (GG) was used and the value of GG epsilon (ε) was given.

RESULTS

Bahavioural results

The ANOVA indicated the effect of Group ($F_{1, 25}$=0.75, P>0.05) was not significant indicating that there were no difference between experts and laypersons in their ratings of beauty and correctness of stimuli. The main effect Task ($F_{1, 25}$=5.98, P<0.05, η^2=0.19) showed participants judged stimuli as correct (M=18.16) more often than as beautiful (M=16.52). The main effect of Chord Type was significant ($F_{1.10, 27.46}$=94.47, P<0.001, η^2=0.79, ε=0.55) – stimuli with very unexpected chord were judged as the least beautiful and correct (M=9.70) whereas stimuli with unexpected chord (Bach's originals) were judged as the most beautiful and correct (M=23.12). Additionally, a *post hoc* analysis (Bonferroni, P<0.05) of an interaction effects of Task and Chord Type ($F_{1.42, 35.39}$=4.69, P<0.05, η^2=0.16, ε=0.71) indicated stimuli with expected and unexpected chords were judged more often as correct (M_{exp}=20.07, M_{unexp}=24.59) than as beautiful (M_{exp}=18.33, M_{unexp}=21.70). There were no difference in ratings of correctness (M=9.85) and beauty (M=9.67) for stimuli with very unexpected chord (Fig. 2).

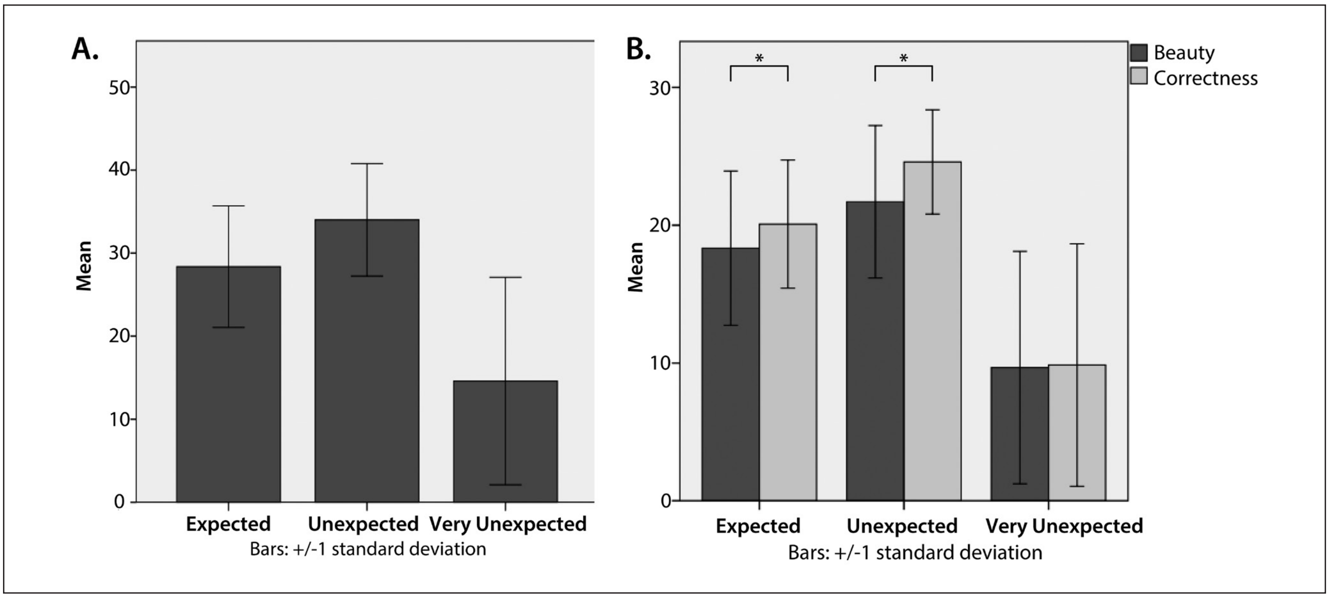

Fig. 2. Results for three types of chords of their beauty and correctness counted (A) together as a number of positive answers and (B) separately for two kinds of judgments (beauty and correctness).

ERP analysis in the early time window

Differences in responses to expected *vs.* unexpected chords and expected *vs.* very unexpected chords were analyzed in separate analysis using a time window of 160-240 ms after onset of the experimental chord presentation. The time window was specified after the detection of peaks in amplitudes.

The average amplitude (M_{diff}) for the unexpected chords was 0.37 μV more positive than for expected chords during this time window. This difference in amplitude did not give a negative deflection of difference wave (unexpected – expected chords) – higher positive amplitudes were observed for unexpected than for expected chords (Fig. 3). The ERAN has opposite characteristic. Despite no ERAN effect for unexpected chord the statistical analysis for that time window where conducted in order to check differences between expected and unexpected chords. The data were analyzed using repeated measures ANOVA with Chord Type (expected, unexpected), Task (judging beauty, judging correctness), Side (right [F4, C4, P4, O2], middle [FZ, CZ, PZ, OZ], left [F3, C3, P3, O1]) and Area (frontal [F3, FZ, F4], central [C3, CZ, C4], parietal [P3, PZ, P4], occipital [O1, OZ, O2]), as within-subjects factor and Group as between-subjects (layperson, expert). When the assumptions of the ANOVA were not satisfied, the correction of the degrees of freedom using the Geisser Greenhouse test (GG) was used and the value of GG epsilon (ε) was given.

There were main effects of Chord Type ($F_{1, 25}$=4.34, P<0.05, η^2=0.15), Side ($F_{2, 50}$=4.51, P<0.05, η^2=0.15), indicating lower amplitudes on the right side, and Area ($F_{1.66, 41.38}$=45.30, P<0.001, η^2=0.64, ε=0.55), indicating higher amplitudes at front and central electrodes. There was no main effect of Group ($F_{1, 25}$=0.76, P=0.393) and the interaction between Chord Type and Group factors was also non-significant ($F_{1, 25}$=0.19, P=0.668). There were, however, significant interactions between Side and Area ($F_{6, 15}$=2.42, P<0.001, η^2=0.09) and between Chord Type and Area ($F_{1.86, 47.13}$=14.40, P<0.001, η^2=0.37, ε=0.628).

Because the Chord Type by Area interaction indicated differences in amplitude between anterior and posterior electrode sites only data from frontal and central areas were included in the further ANOVA. There was an effect of Chord Type factor ($F_{1, 25}$=10.38, P<0.05, η^2=0.29), indicating higher amplitudes in response to unexpected chords than expected chords. The Side effect ($F_{2, 50}$=4.24, P<0.05, η^2=0.145) and Side by Area interaction ($F_{2, 50}$=6.78, P<0.05, η^2=0.145) remained. The highest amplitudes were observed in the central area. There were, however, no Group differences ($F_{1, 25}$=0.58, P=0.455).

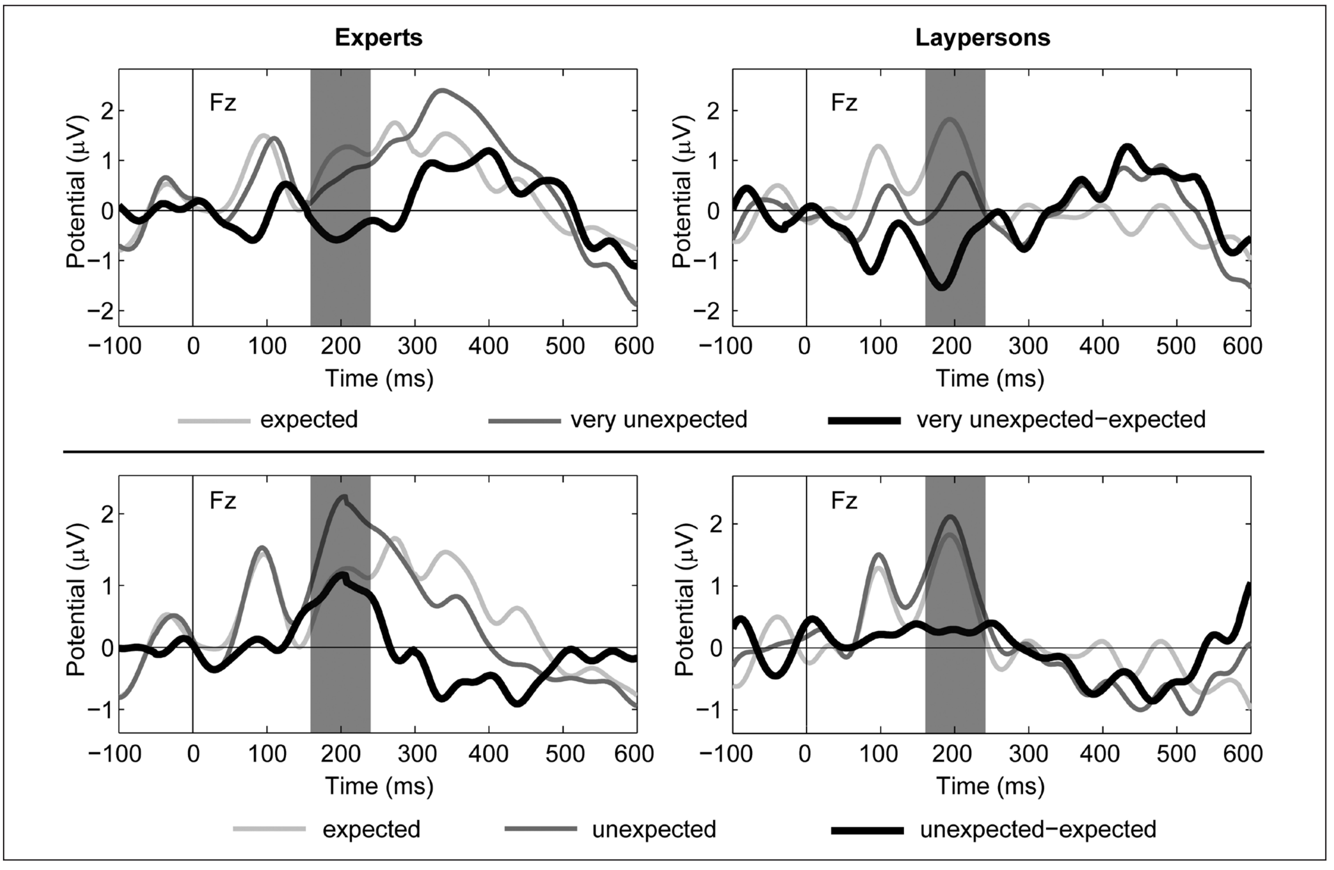

Fig. 3. Grand averages of ERPs recorded at FZ during presentation of experimental chords for the various chord types in separate voltage–time diagrams for experts (left panel) and laypersons (right panel). The time window (160 to 240 ms) for quantification of effects is marked in light gray.

The very unexpected chord elicited an early negativity in both music experts and laypersons (Fig. 3). Data in the time window 160–240 ms after the onset of experimental chord were analyzed. In this time window the average amplitude (M_{diff}) was 0.48 μV more negative for very unexpected chords than for expected chords (Fig. 4). A repeated measures ANOVA was conducted with Chord Type (expected, very unexpected), Task (judging beauty, judging correctness), Side (right [F4, C4, P4, O2], middle [FZ, CZ, PZ, OZ], left [F3, C3, P3, O1]) and Area (frontal [F3, FZ, F4], central [C3, CZ, C4], parietal [P3, PZ, P4], occipital [O1, OZ, O2]) as within-subjects factors and Group as between-subjects factor (layperson, expert).

There was an effect of Chord Type ($F_{1, 25}$=8.14, P<0.05, η^2=0.25). A Side effect ($F_{1.46, 36.40}$=5.52, P<0.05 η^2=0.18, ε=0.728), indicating that the lowest average amplitudes were recorded on the right side, and an Area effect ($F_{6, 150}$=3.27, P<0.05, η^2=0.116) were also noted. The observed effect may be defined as ERAN for very unexpected chords. There was no main effect of Group ($F_{1, 25}$=0.86, P=0.363) and no Group by Chord Type interaction ($F_{1, 25}$=0.21, P=0.650). However there were interactions between Side and Area ($F_{6, 150}$=3.27, P<0.05, η^2=0.12) and between Group and Task ($F_{1, 25}$=4.64, P<0.05, η^2=0.16).

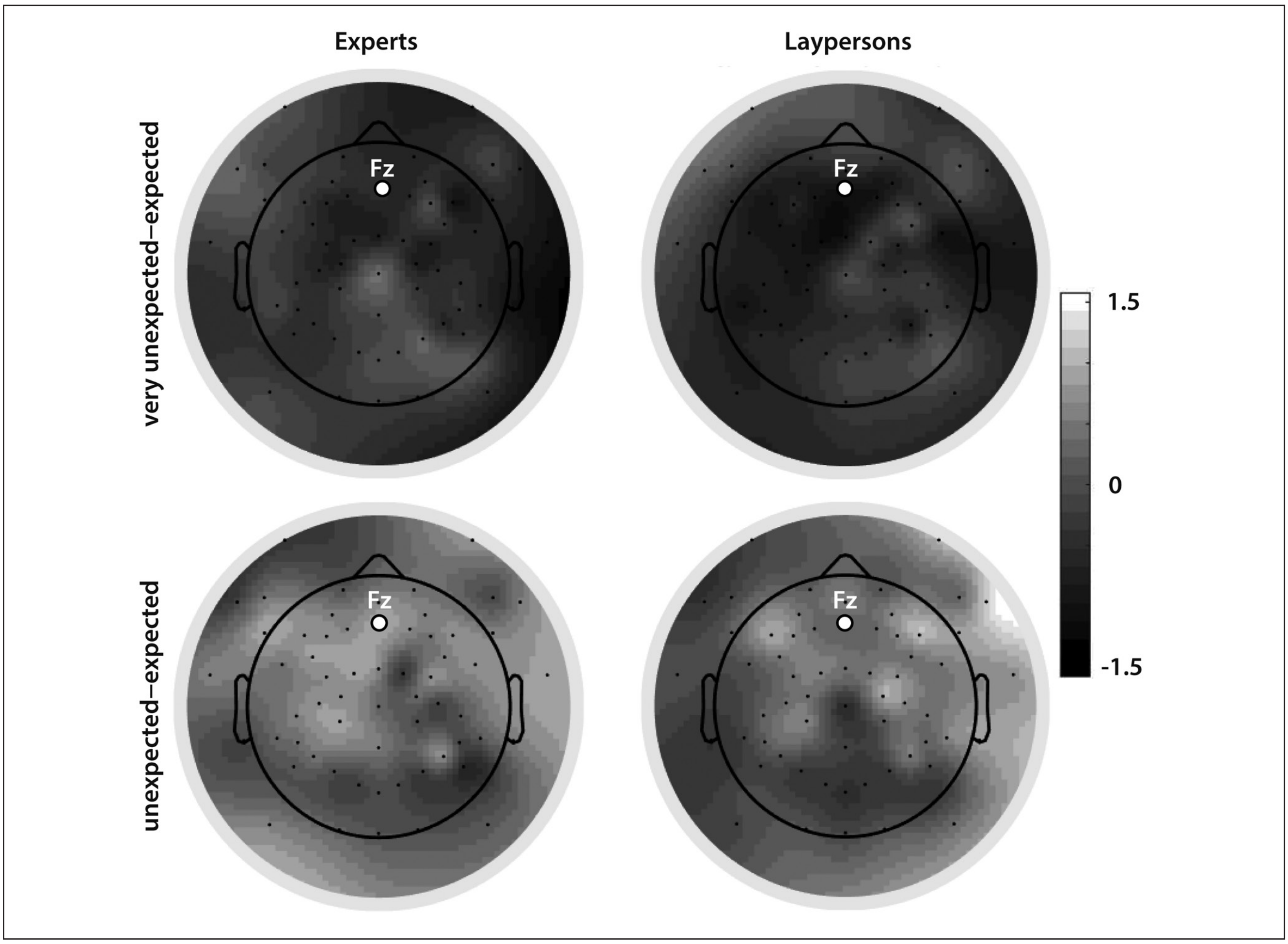

Fig. 4. Scalp maps of voltage distribution of difference between expected and very unexpected chords and between expected and unexpected chords for experts (left panel) and laypersons (right panel) in 160–240 ms time window.

Late Positive Potential

Analysis of variance (ANOVA) was conducted to assess differences in LPP. The dependent variable was average wave amplitude in the 500–650 ms time window with Chord Type (expected; unexpected; very unexpected), Task (judging beauty; judging correctness), Side (right [F4, C4, P4, O2], middle [FZ, CZ, PZ, OZ], left [F3, C3, P3, O1]), Area (frontal [F3, FZ, F4], central [C3, CZ, C4], parietal [P3, PZ, P4], occipital [O1, OZ, O2]) as within-subjects factors and Group (layperson; expert) as between-subjects factor.

Analysis showed a main effect of Chord Type ($F_{2, 50}$=4.62, P<0.014, η^2=0.16). The highest mean amplitudes reported for very unexpected, unexpected and expected chords were 1.16 μV, 0.22 μV and 0.66 μV accordingly (Fig. 5A). There was also an Area effect ($F_{1.54, 75}$=34.75, P<0.001, η^2=0.58, ε=0.52); the highest positive amplitude was recorded on the parietal electrodes (1.89 μV). The Side effect ($F_{2, 50}$=4.16, P<0.05, η^2=0.14) reflected that the highest amplitudes were recorded at central electrode sites (0.82 μV). There was also a main effect of Task ($F_{1, 25}$=5.58, P<0.05, η^2=0.18), with the mean amplitudes being higher for judgment of correctness (0.93 μV) than beauty (0.43 μV). There was no Group effect ($F_{1, 25}$=1.56, P=0.224), however there was an interaction between Group and Task ($F_{1, 25}$=7.25, P<0.05, η^2=0.23).

The analysis also revealed interactions between Chord Type and Side ($F_{4, 100}$=4.60, P<0.002, η^2=0.16), Chord Type and Area ($F_{2.95, 150}$=9.77, P<0.001, η^2=0.28, ε=0.49) and Side and Area ($F_{6, 150}$=7.67, P<0.001, η^2=0.24). These interactions reflected higher mean amplitudes at posterior and central electrode sites.

In a separate ANOVA on data from posterior sites main effects of Chord Type ($F_{1.46, 50}$=22.58, P<0.001, η^2=0.48, ε=0.73), Area ($F_{1, 25}$=32.34, P<0.001, η^2=0.56) and Side ($F_{2, 50}$=7.06, P<0.05, η^2=0.22) remained. There were no main effects of Task ($F_{1, 25}$=3.09, P=0.091) or Group ($F_{1, 25}$=1.54, P=0.227) but there was a Task by Group interaction ($F_{1, 25}$=4.95, P<0.05, η^2=0.17). This interaction effect indicating that there were task differences in mean amplitude only in the expert group. Separate ANOVAs on the lay and expert groups revealed a main effect of Task in the expert group ($F_{1, 13}$=10.57, P<0.05, η^2=0.45) but not the lay group ($F_{1, 12}$=0.07, P=0.792) (Fig. 5).

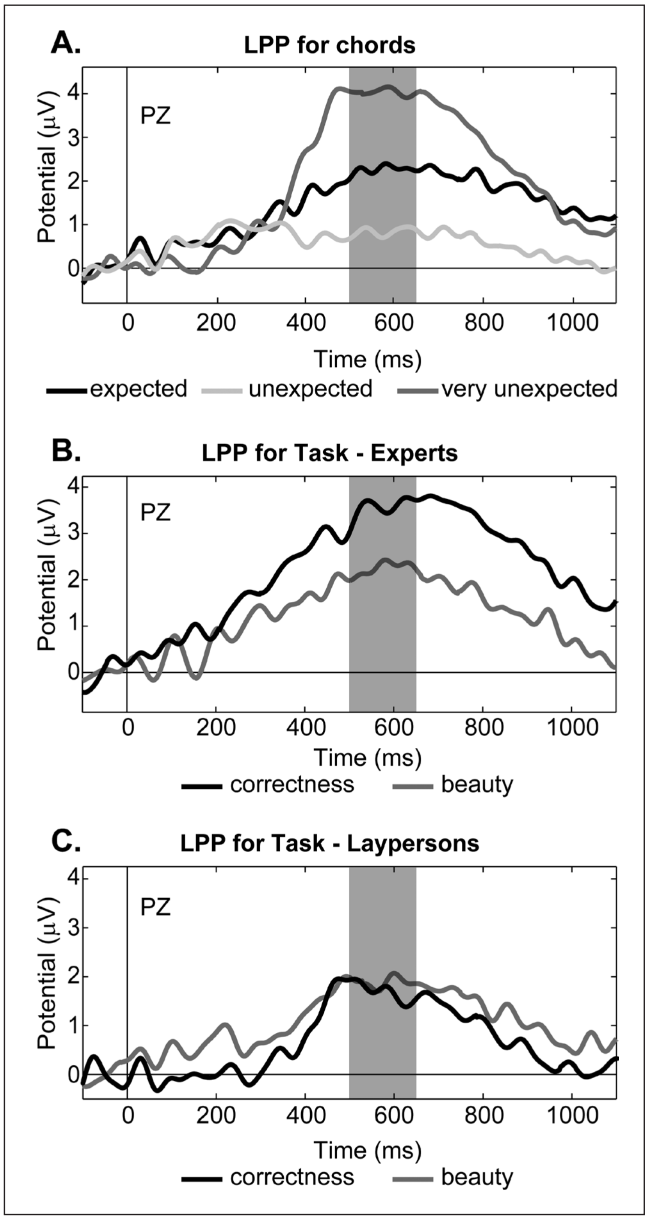

Fig. 5. Grand averages of ERPs recorded at PZ during presentation of experimental chords for the various chord types (A) and for judgments of beauty and correctness in separate voltage-time diagrams for experts (B) and laypersons (C). The time window (500 to 650 ms) for quantification of the effects is marked in light gray.

DISCUSSION

The aim of our study was to investigate the influence of violation of harmonic expectancy and musical expertise on LPP amplitude. We investigated whether chords which violated harmonic expectation evoked larger LPPs than chords which did not. We also analyzed differences in LPP amplitude between musical experts and laypersons judging the beauty or correctness of a musical excerpt.

As well as analyzing LPP effects we were interested in differences in ERAN amplitude associated with (1) violation of harmonic expectation or (2) musical expertise. We observed a right frontal early negativity in response to very unexpected chords which can be defined as ERAN for very unexpected chords. We did not observe an ERAN for unexpected chord but the significant difference between amplitudes for expected and unexpected chords gave a positive deflection. This effect will be discussed below.

Despite observation of ERAN for very unexpected chords our results did not confirm earlier findings relating ERAN amplitude to musical expertise. The effect was similar for experts and laypersons. Müller and others (2010) also found no significant differences between experts and laypersons with respect to chords that strongly violate harmonic principles. The strong violation of harmonic rules is unexpected for laypersons and musicians at the same level. This supports the hypothesis that musical syntax processing is connected not only with musical education but also with everyday experience of exposure to music (see also: Koelsch 2013).

Despite the differences between the responses to expected and unexpected (Bach's original) chords in relation to harmonic context, this cannot be described as an ERAN effect for unexpected chords. ERAN is characterized by negative deflection of difference wave between unexpected and expected chords (more negative amplitudes for unexpected than expected chords). Observed effect is characterized by more positive amplitudes for unexpected than expected chords. Although no ERAN is observed for Bach's original chords, the differences between expected and unexpected chords are still statistically significant. This early positivity is reminiscent to P3a component and may reflect attentional processes elicited by the Bach's original chords (Näätänen 1992, Ritter and Ruchkin 1992). This is an unexpected finding because the number of presentation of each chord type was the same for expected, unexpected (Bach's original) and very unexpected chords. Exploring the extent to which such unexpected harmonic structures are incorporated to the harmonical context of a piece and how this process is modified by attention needs further investigation.

Our results failed to confirm Müller's and colleagues' (2010) finding that experts and laypersons differ with respect to aesthetic judgments of music. Experts and laypersons had similar levels of arousal during appraisals of beauty, but differences were noted during judgments of harmonic correctness. Musical experts had larger LPPs to experimental chords when judging correctness rather than beauty – judging correctness triggers a stronger emotional reaction in experts than judging beauty. Laypersons showed LPPs of similar amplitude on the two tasks.

Hajcak and others (2006) showed that where the LPP is sensitive to the type of task performed, it may be due to an interaction between cognitive and emotional processes. Experts in music can recognize musical sounds and chords, refer to them using the correct musical terms and divide musical phrases or compose new ones on the basis of the rules of music (Brattico et al. 2013). When they are processing music, experts focus on regularities and other descriptive features. If these musical features are of particular interest, it is not surprising that experts' level of engagement is high when they are judging the correctness of a piece of music, a task which requires analytical processing. Experts may have found the correctness judgment task more stimulating and more motivating than the beauty judgment task, thereby resulting in a greater LLP effect. Laypersons, however, may find judging the beauty and correctness of complex musical pieces equally difficult and hence less engaging, both cognitively and emotionally.

Behavioral results did not show any significant differences between experts and laypersons in their ratings of correctness and beauty of presented stimuli. The lack of differences between groups in behavioral results with simultaneous differences in LPP amplitudes shows that the effect of music experience on affective aspects of judgments of music can be seen only on physiological level. LPP is an indicator of emotional arousal for both negative and positive stimuli. Higher amplitudes of LPP shows higher arousal in response to the stimuli. Perhaps this measure is not related to behavioral ratings. Judgments of beauty and correctness of stimuli do not show if the stimuli is perceived with high or low arousal. The musical excerpt can be judged as correct and simultaneously be perceived as very or not negative/positive one. Future investigation should measure also the rating of arousal elicited by stimuli in order to check the link between LPP potential and behavioral results.

Regardless of the group stimuli were judged as correct more often than as beautiful. This pattern of results was shown in previous studies but only for laypersons; for experts there was no difference for two type of tasks (correctness and beauty judgments) (Müller et al. 2010). We suggest that because of using complex stimuli in our study the difference between experts and laypersons was obiletareted. For complex stimuli (as in our study) experts could have less difficulty with differentiate between two types of tasks.

We showed that very unexpected chords (Neapolitan) elicited larger LPPs than expected (tonic) or unexpected (Bach's original) chords. LPP amplitude may be considered an indicator of emotional arousal, which was increased by serious harmonic violations. This interpretation is consistent with studies in which a higher LPP amplitude was recorded in response to visual arousal stimuli (Cuthbert et al. 2000, Foti et al. 2009, Schupp et al. 2004). The late positivity from our study, just like measures used in Steinbeis colleagues' (2006) study, proved to be sensitive to strong violation of harmonic expectation. The judgments of correctness and beauty of presented excerpts shows no differences in these two ratings for stimuli with very unexpected chord. For both: ratings of beauty and ratings of correctness very unexpected chords were perceived rather in negative way (as no beautiful and incorrect) indicating negative emotional arousal, which is consistent with high amplitude of LPP for very unexpected chords. Expected and unexpected chords were judged as correct more often than beautiful which indicated that participants perceived them as congruous with music harmonics.

Unexpected chords elicited smaller LPPs than expected or very unexpected chords. Previous studies concluded that neutral stimuli elicited a much lower positive amplitude response than pleasant or unpleasant stimuli (Cuthbert et al. 2000, Foti et al. 2009, Schupp et al. 2004). Unexpected chords (Bach's original) might be viewed as emotionally neutral stimuli relative to the expected and very unexpected chords.

Perhaps violation of the principles of harmony in music should not be interpreted as a measure of the arousing properties of a stimulus. Berlyne (1971) distinguished four collative variables which characterize all stimuli: complexity, novelty, uncertainty and conflict. A stimulus which has high or low levels of these collative variables elicits high arousal. Applied to our study this implies that expected and very unexpected chords are characterized by either high or low levels of Berlyne's collative variables whereas Bach's chords have a moderate levels and therefore do not induce strong arousal, which is reflected in the reduced LPP.

It is possible that Bach's original chords did not evoke high positive LPPs because unexpected harmonic structures are more familiar to contemporary listeners than chords which follow traditional harmonic principles (expected chords). Undoubtedly, the harmonic combinations used by Bach have spread to contemporary popular music.

It should also be noted that the LPP effect in our study in the 500–650 ms time window (which was particularly marked in response to very unexpected chords) is reminiscent of the P600 response elicited by irregular chords (Patel et al. 1998) and the LPC response elicited by irregular melodic tones (Besson and Faita 1995). P600/LPC response reflect structural reintegration and/or reanalysis during the processing of rule-governed sequences in music (Koelsch 2011) and is elicited by violation of music syntax (Patel 1998, 2008). The stimuli in this study were sequences which included violations of harmonic expectation. Such violations can be defined as violations of musical syntax (Koelsch 2011). Furthermore, P600/LPC responses were also observed after eliciting ERANs (Koelsch et al. 2005, Koelsch and Mulder 2002). In our study the ERAN to very unexpected chords was similarly followed by a late positivity. The ERAN, reflecting processes of detection of harmonic violation, was followed by late positivity which could reflect later processes of structural reanalysis (Koelsch 2011). Eliciting of these two effects simultaneously for very unexpected chords can provide a strong violation of syntax processing. Such violation of the process resulted not only in detection of incongruous chord but also attempt of integration of this chord into musical context.

The relationship between P600/LPC and task relevance is not clear. Koelsch (2011) argued that this positive potential is elicited by tasks which require conscious detection of musical structural incongruities i.e. when harmony is task-relevant (Koelsch 2011). In our study, participants were not asked to detect violations of musical syntax, but to judge the correctness or beauty of musical excerpts, so harmonic violation was task-irrelevant. However, P600/LPC components have also been observed in studies where task was not relevant to detection of violations of harmonic expectation (Koelsch et al. 2005). Further research into the relationship between detection of violations of harmonic expectation and the P600/LPC is needed.

The results of our studies, as well as the studies conducted by Müller et al. (2010), indicate that the complexity of musical stimuli may influence affective aspects of aesthetic judgments and correctness judgments, in both musical experts and laypersons. Due to the fact that we did not include simple stimuli in our studies, this aspect needs further investigation. Additionally, the results show that processing of musical syntax (both earlier and later processes) is influenced by complexity of stimuli and type of task required from participants. It gives a new look to research of brain activity during syntax processing showing that later stages of syntax processing could be independent of task relevance.

REFERENCES

Berlyne DE (1971) Aesthetics and psychobiology. NY: Appleton-Century--Crofts, New York, USA.

Besson M, Faita F (1995) An event-related potential (ERP) study of musical expectancy: Comparison of musicians with nonmusicians. J Exp Psychol Hum Percept Perform 21(6): 1278–1296.

Brattico E, Bogert B, Jacobsen T (2013) Toward a neural chronometry for the aesthetic experience of music. Front Psychol 4: 1–21.

Cuthbert BN, Schupp HT, Bradley MM, Birbaumer N, Lang PJ (2000) Brain potentials in affective picture processing: Covariation with autonomic arousal and affective report. Biol Psychol 52: 95–111.

Ferree TC, Luu P, Russell GS, Tucker DM (2001) Scalp electrode impedance, infection risk, and EEG data quality. Clin Neurophysiol 112: 536–544.

Foti D, Hajcak G (2008) Deconstructing reappriasal: Descriptions preceding arousing pictures modulate the subsequent neural response. J Cogn Neurosci 20: 977–988.

Foti D, Hajcak G, Dien J (2009) Differentiating neural responses to emotional Picture: evidence from temporal-spatial PCA. Psychophysiology 46: 521–530.

Hajcak G, Moser JS, Simons RF (2006) Attending to affect: appraisal strategies modulate the elctrocortical response to arousing pictures. Emotion 6: 517–522.

Hajcak G, Nieuwenhuis S (2006) Reappraisal modulates the electrocortical response to negative pictures. Cogn Affect Behav Neurosci 6: 291–297.

Istók E, Brattico E, Jacobsen T, Krohn K, Müller M, Tervaniemi M (2009) Aesthetic responses to music: a questionnaire study. Music Sci 13: 183–206.

Jaśkiewicz M, Francuz P, Zabielska-Mendyk E, Zapała D, Augustynowicz P (2014) The effect of music harmonics and level of expertise on aesthetic judgment of music: an ERP study. In: Advances in Science, Technology, Higher Education and Society in the Conceptual Age: STHESCA (Marek T, Ed.). AHFE Conference, USA. p. 109–113.

Koelsch S (2011) Toward a neural basis of music perception–a review and updated model. Front Psychol 2: 110.

Koelsch S (2013) Brain and music. John Wiley & Sons, New Jersey, USA.

Koelsch S, Gunter T, Friederici AD, Schröger E (2000) Brain indices of musical processing: "nonmusicans" are musical. J Cogn Neurosci 12: 520–541.

Koelsch S, Gunter TC, Wittfoth M, Sammler D (2005) Interaction between syntax processing in language and in music: an ERP study. J Cogn Neurosci 17(10): 1565–1577.

Koelsch S, Jentschke S (2008) Short-term effects of processing musical syntax: an ERP study. Brain Res 1212: 55–62.

Koelsch S, Mulder J (2002). Electric brain responses to inappropriate harmonies during listening to expressive music. Clin Neurophysiol 113(6): 862–869.

Koelsch S, Schmidt BH, Kansok J (2002) Effects of musical expertise on the early anterior negativity: an event-related brain potential study. Psychophysiology 39: 657–663.

Konečni VJ (2008) Does music induce emotion? A theoretical and methodological analysis. Psychol Aesthet Creat Arts 2: 115–129.

Maidhof C, Koelsch S (2011) Effects of Selective Attention on Syntax Processing in Music and Language. J Cogn Neurosci 23(9): 2252–2267.

Meyer LB (1956) Emotion and Meaning in Music. The University of Chicago Press Books, Chicago, USA.

Moser JS, Hajcak G, Bukay E, Simons RF (2006) Intentional modulation of emotional responding to unpleasant pictures: an ERP study. Psychophysiology 43: 292–296.

Müller M, Hofel L, Brattico E, Jacobsen T (2010) Aesthetic judgments of music in experts and laypersons – An ERP study. Int J Psychophysiol 76: 40–51.

Näätänen R (1992) Attention and Brain Function. Psychology Press, New Jersey, USA.

Patel A (1998) Syntactic processing in language and music: different cognitive operations, similar neural resources?. Music Percept: 27–42.

Patel A (2008) Music, Language, and the Brain. NY: Oxford University Press, New York, USA.

Patel A, Gibson E, Ratner J, Besson M, Holcomb P (1998) Processing syntactic relations in language and music: An event-related potential study. J Cogn Neurosci 10(6): 717–733.

Riemenschneider A (1941) 371 Harmonized Chorales and 69 Chorale Melodies with figured bass by Johann Sebastian Bach. G. Schirmer, New York, USA.

Ritter W, Ruchkin DS (1992) A review of event-related potential components discovered in the context of studying P3a. Ann N Y Acad Sci 658(1): 1–32.

Schupp HT, Junghofer M, Weike AI, Hamm AO (2004) The selective processing of briefly presented affective pictures: an ERP analysis. Psychophysiology 41: 441–449.

Steinbeis N, Koelsch S, Sloboda JA (2006) The role of harmonic expectancy violations in musical emotions: evidence from subjective, physiological, and neural responses. J Cogn Neurosci 18: 1380–1393.

Tucker DM (1993) Spatial sampling of head electrical fields: the geodesic sensor net. Electroencephalogr Clin Neurophysiol 87: 154–163.