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Heart Rate reacts to the Perception of Musical Pulse: A Comparison of High and Low Sensation Seekers

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Abstract: The search for new thrilling experiences is summarized in the concept of „Sensation Seeking", which connects a baseline in arousal with stimulus-dependent changes. The arousing situation is a necessary prerequisite for the physiological reactivity. In connection with music, it is assumed that variations in the rhythmical performance provoke different forms of arousal in „high sensation seekers" (HSS) compared to „low sensation seekers" (LSS). To test this hypothesis, 40 subjects were screened for their level of sensation seeking and grouped into „high", „low", and "Median" sensations seekers. Two versions of Beethoven's „Elise" were presented (one synthesized in absolute regular pulse, the other one with rhythmical variations). Electrocardiogram (ECG) was recorded and analyzed (heart rate [HR]). Connections between rhythmical variations and cardiovascular variables were evaluated using ANOVAs, Pearson correlations, and wavelet-based Semblance analysis. Using the highly sensitive semblance analysis, it can be shown, that low sensation seekers present stimulus-dependent correlations between rhythmic structure and HR changes (r= .5 - .9), whereas high sensation seekers displayed no differences in HR reaction. The correlation between rhythmic changes in the music and HR point out the relevance of the music time domain for eliciting emotions.
Running head: Heart rate, music & sensation seekers
Key words: Heart Rate, Music, Rhythm, Sensation Seeking, Emotion

1. Introduction

The search for alterations and for new thrilling experiences is summarized in the concept of „Sensation Seeking" (Zuckerman, 1994). This trait is based on a psychophysiological mechanism that connects a baseline in arousal with stimulus-dependent changes (Zuckerman, 1990). Hence, the existing situation becomes a necessary prerequisite for the physiological reactivity, resulting in low psychophysiological changes during relaxation within high sensations seekers (HSS) as compared to low sensation seekers (LSS). These different reactions were in accordance with the concept of 'arousability' that proposed orienting reactions for stimuli with low intensity and defensive reactions for stimuli with high intensity (Brocke et al., 2000). Therefore, HSS and LSS persons differ in their physiological reactions like heart rate (HR) to the same stimulus with a given intensity (Sokolov, 1963;1990). E.g. while listening to stimuli with moderate to high intensity HSS' HR is still modulated by orienting reactions whereas LSS showed already defensive reactions. Subsequently LSS are physiologically more sensitive and therefore more responsive to arousal modulating stimuli than HSS persons. The trait SS is linked to activities like adventure sports, illegal behaviors, intake of drugs, eating exotic meals, and so forth, which is attributed to extraverted and impulsive individuals. Eysenck (Eysenck and Eysenck, 1967a;Eysenck and Eysenck, 1967b;Ball and Zuckerman, 1990) included the trait SS as a primary element inherent in extraversion (E). Correlations between E and SS are found in different cultures ranging from .24 to .44 (Zuckerman et al., 1978). In a newer paper Aljua et al. (Aluja et al., 2003) report a close relationship between E and Openness (O) with SS, mainly explained by the subscale E5-Excitement Seeking facet and, secondly, by O4-Actions andO1-Fantasy which can classify85% of HSS and LSS individuals.

Generally, emotional arousal is associated with a predominance of sympatheticautonomous nervous system (ANS) activity, thus leading to an increase in HR, whereas a predominanceof parasympathetic ANS activity leads to a decrease of HR.Music is a powerful stimulus for evoking and modulating emotionalarousal. Recent studies have shown that music is associated with activity changes in brainstructures known to modulate HR, such as amygdala, insular cortex, and orbitofrontal cortex(Koelsch, 2014)Therefore, several studies showed an increasing heart rate due to music with a higher emotional arousal(Iwanaga et al., 1996;Krumhansl, 1997;Iwanaga and Moroki, 1999;Bernardi et al., 2006;Russo et al., 2013). One major source of emotional arousal in music is expectations in harmony melody and rhythm(Narmour, 2000;Krumhansl, 2002;Rohrmeier and Koelsch, 2012). Rhythmic entrainment that modulates a regular beat by accentuating musical issuesto increase tension in musical performance is called 'tempo rubato' (Finck and Paderewski, 1909;Hudson, 1994;Zatorre and Krumhansl, 2002;Koelsch et al., 2008;Mikutta et al., 2013). The application of "Tempo Rubato" results, therefore, in expectation errors and therefore breaches in expectation in the time domain ("temporal expectation"): An expected note can become unexpected when it appears early (anticipation) or late (delay/retardation) (Large and Palmer, 2002;Rohrmeier and Koelsch, 2012). These breaches in temporal expectations are capable of altering HR,and as a result emotional arousal(Mikutta et al., 2013). Since emotional arousal states change rapidly over time during listening to music, a continuous subjective measurement of arousal was frequently used to assess changes in emotional arousal over time (Schubert, 2005;Mikutta et al., 2012). Emotional arousal ratings seem to be independentof consonance or dissonance but strongly connected with music expectation (Huron 2006) and loudness (Schubert, 2005;Mikutta et al., 2014).

Differences in sound and music induced emotional arousal within SS seems to be driven by different occurrences of orientating and defensive reaction. Therefore,compared to HSS-, LSS-persons are more prone to defensive reactions with subsequently more intense emotional arousal and heart rate changes.(Ridgeway and Hare, 1981) as well as (Zuckerman, 1990) showed an orientation reaction (deceleration of HR) in HSS as opposed to a defensive reaction (acceleration of HR) in LSS due to unexpected tones.

In connection with music, it is assumed that certain styles produce different forms of emotional arousal in HSS as compared to LSS (Arnett, 1991;McNamara and Ballard, 1999;Weisskirch and Murphy, 2004;Nater et al., 2005). Based on behavioral data, HSS seem to prefer music with high intensity like hard rock, or high complexity(Litle and Zuckerman, 1986). However, HSS persons show less physiological arousal even during stimulating music than LSS persons (Gerra et al., 1996;Nater et al., 2005).

It was the aim of the presented exploratory study to investigate the influence of SS on rhythmic expectations and complexity in naturalistic music. We use two different versions of a music piece with a regular rhythm (low complexity with no breach of expectations) versus a "Tempo Rubato" shaped (high complexity with high breach of expectations) interpretation. We measured the HR and continuous subjective arousal ratings while the participants listened to the music. First we investigated the connection between subjective arousal ratings, HR and sound intensity by computing the correlations over time of those variables.

Second, for an in depth analysis of the irregular version of the music, we computed the correlations between HR and differences of beat between the rhythmical regular and irregular versions of the music(overall "Tempo Rubato") and the differences within the irregular version (local "Tempo Rubato")using semblance analysis. By that method we were able to analyze the correlationas a function of both scale (or wavelength) and time. Therefore, it is possible to compare the correlation of the rhythmical irregularity and HR within different time segments and frequency domains (Cooper and Cowan, 2008).

We assumed that HSS will result mainly in a orientation response and therefore in less change of HR due to the rhythmic expectancy breaches. Correspondingly LSS will result in a defensive reaction and therefore present more changes in HR due to the music stimulus. Therefore, we hypothesize a positive correlation between the HR and the differences in beat within the LSS group. Furthermore, we assume a neutral to negative correlation within the HSS group.

2. Materials and Methods

2.1 Stimuli

Two different performances of Beethoven's "For Elise" (WoO Nr. 59, a-minor) were used as musical stimuli; this piece was chosen 1) for avoiding a novelty effect 2) its aptness for an interpretation with 'tempo rubato', and 3) its easy harmonic and melodic structure. The two versions can be distinguished on the bases of their temporal progressions and points of dynamic emphasis.

(1) A synthesizer produced the first presentation (regular interpretation [r]) resulting in a regular rhythm and an equalized sound intensity.
(2) The second (irregular interpretation, [ir]) was played by Siang Wong who applied the concept of "Tempo Rubato" in a sophisticated way and used dynamic variations to underline harmonic conditions (Hudson, 1994).

Measured sound intensity (SI) in both interpretations ranged 51–83 dB. The durations of both interpretations were adjusted to 180 s.

2.2 Apparatus

Standardized instructions, musical performances, and temporal linkage to physiological variables were monitored by the PsyScope X experimental software package (Cohen et al., 1993). We used a Technics® SU V-306 M2 amplifier and Technics® headphones. Subjective ratings, SI, electrocardiograms (ECG), and respiration

(RSP) were recorded simultaneously via PowerLab (AdInstruments) and LabChart Software version 7.2.5. Recording frequency was set up at 4 KHz to control for the coordination between channels (music and psychophysiological variables).

2.3. Procedure

During the entire experiment, the participants sat in a comfortable chair in a sound-shielded room. They were asked to listen to the two different versions of Beethoven's "For Elise" carefully without focusing on a particular aspect of the music. Additionally, the participants were asked to rate their subjective levels of tension using a joystick while listening to the music. They were instructed to move the joystick forward when they felt heightened inner tension due to the music, independently of affective valence. When they felt reduced inner tension, they were instructed to move the joystick backward. Three Ag/AgCl electrodes were attached to the chest to measure ECG, and a RSP belt was adjusted around the chest. An adaptation period of approximately 10 min before each session allowed cardiovascular measurements and RSP to stabilize. Time between the first and the second version and the relaxation measurement was 3 min. Throughout the entire sequence (relaxation – Interpretations 1 and 2 randomized – relaxation), psychophysiological variables (ECG and RSP) and subjective ratings were recorded simultaneously.

Before the physiological measurements were collected, each subject participated in a 3-min training session in order to become familiar with the rating instrument; another piece of music was presented during this training. After the experiment, the participants completed a questionnaire containing questions on their age and gender in a 15-minutes session. Furthermore, musical education (training in musical instruments, duration of training), recognition of musical stimuli and overall differences in interpretations, as well as liking vs. disliking for the piece were assessed on a 10-point Likert scale ranging from 1 (maximal dislike) to 10 (maximal like). To collect the trait characteristics of "Sensation Seeking", the German version of the Arnett Inventory of Sensation Seeking (AISS) was used (Roth, 2003b;Roth, 2003a).

2.4 Participants

Forty Caucasian volunteers, 20 men and 20 women, took part in this study. Participants were recruited from December 2012 until March 2013. The exclusion criteria were the presence of central neurological disease, amblyacousia, psychiatric disorders, or current administration of psychotropic medication. Amblyacousia was excluded by testing at the auditory threshold of 5–10 dB at 2000 Hz. Tests were performed using a Diatec screening audiometer (AS-608). Five participants played an instrument, 19 recognized the piece of music as a famous piano piece, and 9 could label the correct title "For Elise". An overall rating shows that all participants perceived a difference between the two interpretations (mainly in respect of rhythm and general interpretation). The mean rating of liking for the presented piece on a 10-point Likert scale (1: maximal dislike; 10: maximal like)was 7.3 (range 3-10, SD=1.94).

The study was approved by the Ethics Committee of the State of Bern and has therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its amendments. All subjects gave their written informed consent prior to their inclusion in the study.

2.5 Groups

For a categorization of the volunteers into groups of high and low sensation seeking (HSS and LSS) the distribution of the summary scores of the Sensation Seeking Questionnaire (AISS) was used. The analysis of the AISS-D revealed total-scores between 41 and 76. The Median was 55 points.

For pointing out and controlling differences in LSS and HSS we built 2 groups:

(1) The HSS and (2) LSS group: Only participants representing the full concept of high and low sensation seeking, were included (AISS scores exceeding the upper (75-100%) for HSS and lower (25-0%) quartile for LSS). This resulted in 22 participants (11 HSS and 11 LSS). The mean age (M) of the whole group was 24.9 years (range: 20–28). The HSS group was comprised of 10 men and 1 woman (M: 25.09, SD: 2.02) while the LSS group was comprised of 10 women and 1 man (M: 24.73, SD: 2.41).

2.6 Preprocessing

The subjective arousal ratings were resampled in a common timescale using spline interpolation. This timescale had 0.1sec intervals, which still allowed capture of the dynamics of the ratings. The means and standard deviations of these interpolated ratings were calculated as individual indices of the mean and variability of the arousal level induced by the music. The sound intensity (SI) variation in the presented interpretations was analyzed by computing the sound pressure level (SPL) of the music as a function of time via the root mean square method. For the analyses of the psychophysiological variables and subjective ratings, the sampling rate is reduced to 400 Hz. By measuring the R-R interval, ECGs were translated into HR data.

2.7 Main data analysis

First, in order to control for possible gender effects in the sensation-seeking concept and HR, we conducted single factor ANCOVAs (df:38) over all participants (HSS-group, LSS-group, groups around median, main factor: gender, covariate: AISS score, dependent variable: mean HR of Beethoven's Elise). To find possible relation between gender and HR, the four parts of "Elise" and a phase of relaxation are analyzed separately. This makes sense because the harmonic and temporal progression is different in the four parts of the piece.

Second, Pearson correlations were computed to detect the global connections between subjective arousal ratings, SI, and HR within and between the interpretations.

Third for investigating the effect of SS on perceiving variations of temporal expectation (i.e. irregularities in rhythm), we compared the rhythmic differences of the (r) and (ir) version by means of the semblance analysis.

Within the semblance analysis (Cooper and Cowan, 2008), two signals can be analyzed as a function of both scale (or wavelength) and time. In such semblance plots, it is possible to compare different time segments (horizontal axis) and frequency domains (vertical axis) of the two signals. Semblance scores range from -1 (strong negative correlation) to 1 (strong positive correlation). Unlike the standard Fourier-transform–based semblance analysis, which is calculated solely as a function of frequency, the continuous wavelet transform (CWT; semblance analysis) is calculated as a function of both scale (or wavelength) and time (or position). This enables the changing phase relationships between the two datasets' HR and changing time (from beat to beat, or differences in beat time between (r) and (ir) interpretation) to be visualized and analyzed (Cooper and Cowan, 2008). The resulting values are ranging between [-1,0, 1]. -1 represents a strong negative correlation, 0 no correlation, and 1 a strong positive correlation. The correlations between the two datasets can be read directly from the colors indicated in Figures 4 and 5; positive, negative, and no correlations are marked in red, blue, and green, respectively.

For defining the difference or regularity of the succeeding beats in the (r) and (ir) versions, we used Audacity 2.0.5 (OSX for Mac, http://audacityteam.org/).Beat onsets are implemented in a separate channel, which can be heard along with the music (channel with beats, which can be edited). Afterwards beats as prominent peeks are measured with the detection of their emergence using a trigger. Based on a time series of beats with its real time in occurrence, differences between beats were calculated. For both versions 123 beats are included in a total time of 175.75 seconds. For (r), these differences are all the same (1.429 seconds). For (ir) differences are ranging from 1.08 to 2.7 seconds (Mean=1.43, Standard Deviation=.29). Three different measures are built: (a). Differences from beat to beat in (r) interpretation, (b) Differences from beat to beat in (ir) interpretation, and (c) Differences beat (r) interpretation – beat (ir) interpretation (cp. Figure 1).

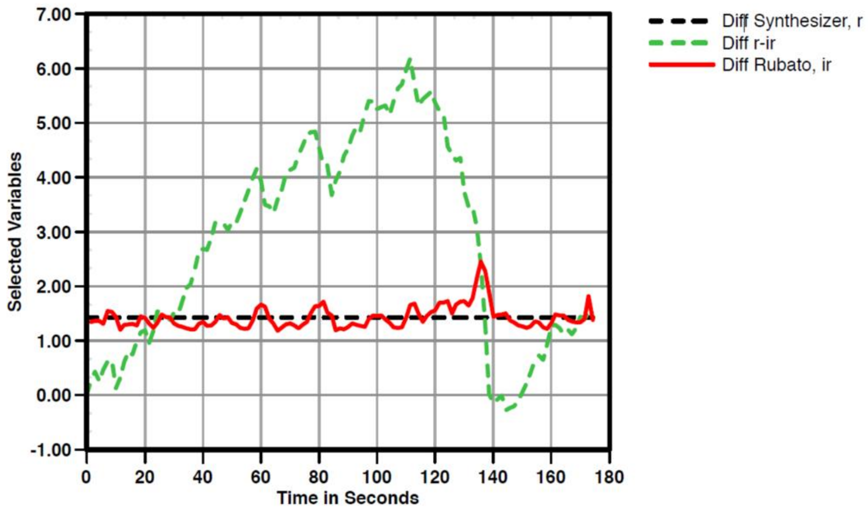

Figure 1

Please note that for the semblance analysis only the irregular HR time series was used. Since we compare how the heart rate reacts to the accelerations and decelerations of the beats.

Therefore,(b) compares the irregularities in beat within the (ir) version, whereas (c) compares the differences in time between (ir) and (r)

A semblance analysis (Cooper and Cowan, 2008;Cooper, 2009) with the factors HR and the measures (b) and (c) was conducted for each individual of the LSS and the HSS group.

For comparing the correlations of (HR) and (differences in beat[b, c]) in LSS and HSS, we computed one-way ANOVAs (df=20) with the factor LLS vs. HSS group. Results were corrected using false discovery rate (FDR)(Benjamini and Hochberg, 1995).

3. Results

3.1 Sensation Seeking and heart rate

Table 1 summarizes the HR values for each group and condition. There were no differences in HR between groups in any condition ($p>0.05$, for all)

Table 1. Mean HR during interpretation of "Elise" (ir), (r), and relaxation, in the threesensations seeking groups (HSS – High Sensation Seeking, LSS Low SensationSeeking, and scores around the median)

	HSS	LSS	Median group
(ir)	70.48 (SD 11.28)	68.88 (SD 9.81)	71.96 (SD 11.51)
(r)	70.93 (SD 10.97)	70.13 (SD 10.69)	74.12 (SD 12.11)
Relaxation	68.13 (SD10.83)	66.38 (SD 9.74)	68.37 (SD 10.98)

3.2 Gender effect of mean HR during "for Elise" and Relaxation

For relaxation (F[1, 38] = .18, p> .5) and during „ for Elise" (F[1, 38] = .68, p = .41) no significant effect of gender is found on mean HR in the ANCOVA. The concept of sensation seeking however is a potent marker to describe the group of women and men of the 40 volunteers into two separate groups (F[1,38] = 170.97, p<.0001). Similar results are found by separating the total group into the HSS and LSS subgroup during r and ir music, as well as over the different parts of Elise. As an example of these analyses plots of the first part of Elise are shown for the r and ir version of Elise and the phase of relaxation (Figure 2, interaction plot of the gender groups with the AISS score).

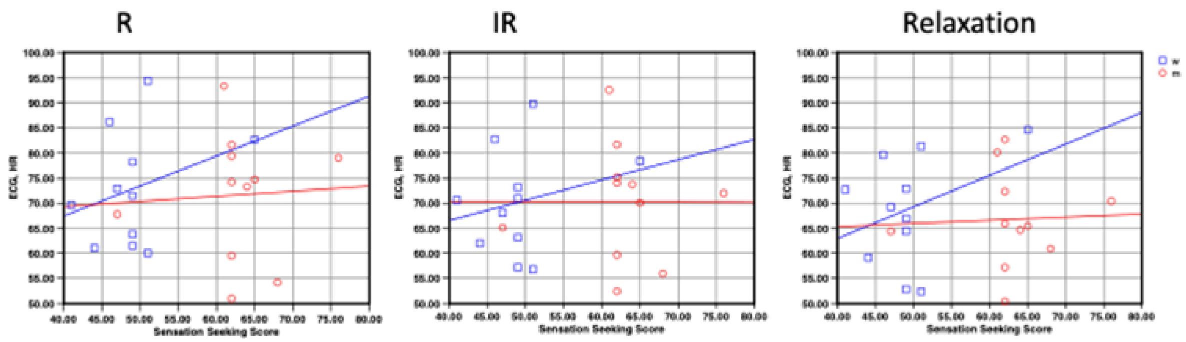

Figure 2

3.3 Correlations between Heart Rate, Subjective Rating of Arousal, and SI in HSS and LSS Persons

The subjective arousal rating within both versions ([r], [ir]) was similar. The Persons'sr between the arousal ratings in the HSS and LSS groups, for both interpretations, are high (r=0.93 respectively 0.83). The Pearsons'sr between the HR of the two groups HSS and LSS was for the (r) version r= 0.64 - for the (ir) version however only r =0.14 was found. During the (r) version the correlations between Ratings, HR data and SI were high in both groups (HSS and LSS) (r=0 .73, r=0.79). In contrast to that, the correlations between SI and HR in both version were negative (r= -.52, r=-.32) meaning that HR decreases while SI increases. In general, correlations during (ir) between HR and the other variables are low (between .29 and -.05). All correlations are summarized in Table 2.

Table 2. Pearson Correlations sound intensity (SI), rating, and heart rate (HR) in HSS and LSSpersons, r = regular interpretation (synthesizer) and ir = irregular interpretation ("Tempo Rubato").

	Rating HSS r	Rating LSS r	ECG HSS r	ECG LSS r	SI r	Rating HSS ir	Rating LSS ir	ECG HSS ir	ECG LSS ir	SI ir
Rating HSS r	1									
p (2-tailed)	-									
N	71935									
Rating LSS r	**0.9345**	1								
p (2-tailed)	< 0.0001									
expl. var.	*87%*									
N	71935	71935								
ECG HSS r	**-0.7027**	**-0.6868**	1							
p (2-tailed)	< 0.0001	< 0.0001								
expl. var.	*49%*	*47%*								
N	71935	71935	71935							
ECG LSS r	-0.3698	-0.3522	**0.6413**	1						
p (2-tailed)	< 0.0001	< 0.0001	< 0.0001							
expl. var.	*14%*	*12%*	*41%*							
N	71935	71935	71935	71935						
SI r	**0.733**	**0.7916**	**-0.5232**	-0.3166	1					
p (2-tailed)	< 0.0001	< 0.0001	< 0.0001	< 0.0001						
expl. var.	*54%*	*63%*	*27%*	*10%*						
N	69435	69435	69435	69435	69435					
Rating HSS ir	**0.8316**	**0.8438**	**-0.7544**	-0.3847	**0.807**	1				
p (2-tailed)	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001					
expl. var.	*69%*	*71%*	*57%*	*15%*	*65%*					
N	71935	71935	71935	71935	69435	71976				
Rating LSS ir	**0.7339**	**0.7224**	**-0.6539**	-0.1987	**0.6862**	**0.8977**	1			
p (2-tailed)	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001				
expl. var.	*54%*	*52%*	*43%*	*4%*	*47%*	*81%*				
N	71935	71935	71935	71935	69435	71976	71976			
ECG HSS ir	-0.305	-0.3047	0.4428	0.379	-0.2975	-0.3334	-0.3094	1		
p (2-tailed)	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001			
expl. var.	*9%*	*9%*	*20%*	*14%*	*9%*	*11%*	*10%*			
N	71935	71935	71935	71935	69435	71976	71976	71976		
ECG LSS ir	0.0598	0.0789	0.189	0.1457	0.2505	0.1424	0.1251	0.1403	1	
p (2-tailed)	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001		
expl. var.	*0%*	*1%*	*4%*	*2%*	*6%*	*2%*	*2%*	*2%*		
N	71935	71935	71935	71935	69435	71976	71976	71976	71976	
SI ir	0.2965	0.2037	-0.0543	0.2814	0.4888	0.4757	**0.5917**	-0.0747	0.4496	1
p (2-tailed)	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	
expl. var.	9%	*4%*	*0%*	*8%*	*24%*	*23%*	*35%*	*1%*	*20%*	
N	71935	71935	71935	71935	69435	71976	71976	71976	71976	71976

Pearson correlation, p (2-tailed), *exp. var (explained variance), N (number of values)*

3.4 Rhythmic Variations in (r) and (ir) Interpretations

In (ir), positive correlations between differences of succeeding beat-times (b) and HR were found in the interval (scale) of 35-50 s in LSS subjects (Figure 4).The one-way ANOVA (df: 2/20) showed significant differences between LSS and HSS in the interval (scale) of 35-50 s (Figure 3) (FDR corrected $p<.007$).

Furthermore, positive correlations between differences between regular and irregular beat-times (c) and HR can be detected in time-intervals (scales) 80-100 s and 40-60 s in LSS subjects (Figure 4). Positive correlations point to an increase of HR during the acceleration in beats. In contrast HSS subjects show negative correlation between both measures of rhythmic variation (b and c) and HR (in time-intervals 40-100 s). Here the one-way ANOVA (df: 2/20) revealed differences within time-intervals (scales) 40-60 s and 10-40 s (FDR corrected, $p<.001$).Therefore, the acceleration in beats is accompanied by a deceleration of HR.

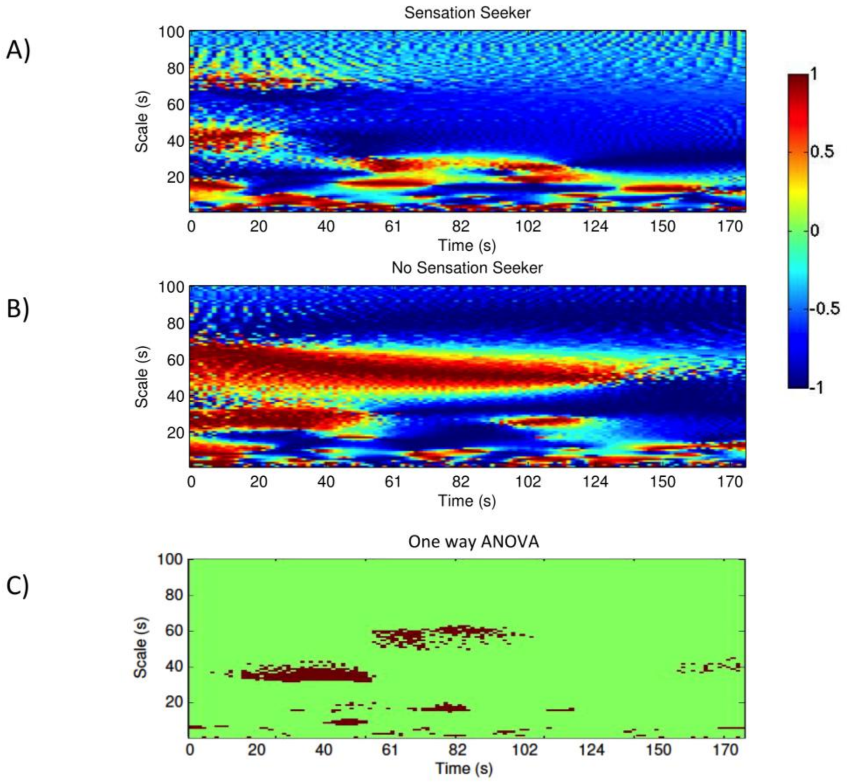

Figure 3

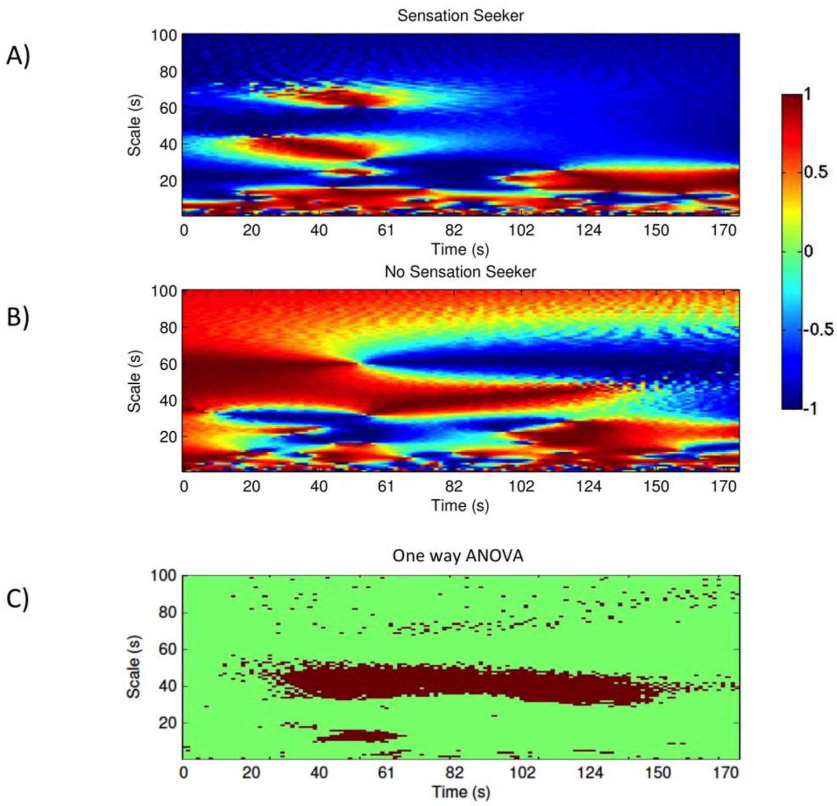

Figure 4

4. Discussion

Heart rate during irregularly (ir) and regularly (r) played interpretations of Ludwig van Beethoven's „ For Elise "showed distinct differences, which may be responsible for the experienced emotional arousal. By quantifying the beat variability of the (ir) and (r) version, we were able to show that temporal expectation violations can cause cardiovascular and therefore - very likely – emotional reactions. Furthermore, we showed that the concept of SS alters physiological reactions to music considerably.

As shown in previous studies with different musical stimuli (Schubert, 2004;Mikutta et al., 2012;Mikutta et al., 2013) SI and subjective ratings were positive correlated. In the present study, this was especially true for the (r) version of "For Elise". However in the (ir) version, the correlation between subjective rating and SI was much lower than in the (r) version, suggesting that in the (ir) version other musical elements besides the SI were responsible for the perceived arousal. There was no difference between HSS and LSS persons concerning their subjective rating in both versions of the musical piece (r=0.93). This finding is in line with (Bhatara et al., 2009), dealing with versions of music performances in which changes in time and intensity were parametrically manipulated, and participants asked to rate the emotional expressivity of those pieces. Emotional judgments monotonically decreased with performance variability. Similar to the findings of the present study time changes were found to explain more variance in reported emotional expressivity than sound intensity.

There was no correlation between SI and HR in both versions. In this respect HSS and LSS persons react in a similar way in the (r) version (correlation .64) and in different way in the (ir) version (correlation .14). These results show that by taking away the rhythmic variability of the music piece, it is lacking important features, which are responsible for the emergence of emotions. However, this global analysis of the course in HR, Subjective Rating, and SI ignores all local connections between these variables.

To focus specifically on music's variations in time, (b) differences between succeeding beats in the (ir) version and (c) differences between the beats in the (r) version and the (ir) version were computed. Both time series were correlated to HR of the HSS and LSS subjects during the (ir) version of "For Elise". The (r) version is used as reference to quantify acceleration (y-axis positive direction in Figure 5) and deceleration (y-axis negative direction in Figure 6) in the (ir) version. Using the semblance analysis (Cooper and Cowan, 2008), it was possible to calculate local correlations that describe HR accelerations coming along with differences between succeeding beats (b). HSS and LSS persons showed similar HR reactions in small scales (Figure 5, Scale 0-30 s), however LSS subjects were influenced by tempo variations in a larger scale Figure 6, Scale 50-60 s) until second 140 of the piece (till the beginning of the reprise). The differences between the beats in the (r) version and der (ir) version (c), showed similar but even more pronounced results. As compared to regular beat, accelerations are accompanied by an increase in HR in LSS persons especially in the long run (Figure 6, Scale 80-100). These positive correlations were not found in HSS persons. The results suggest that LSS is associated with higher physiological effects (in the sense of defensive reactions) (Neary and Zuckerman, 1976;Kimmel et al., 1979;Brocke et al., 2000), as opposed to HSS, which is associated with small physiological reactions (in the sense of orienting reactions). In the present investigation, the musical piece seems to be insufficiently stimulating for HSS subjects whereas LSS subjects were emotionally involved due to their fine vegetative reactivity to variations in time.

The vegetative reactivity in the LSS persons was most likely triggered due to the temporal expectation violations in the (ir) version. Temporal expectation violations are responded behaviorally by adaptation of the period and phase of taps in response to changes in tempo (Large et al., 2002;Repp and Keller, 2004). It has been shown that temporal expectations are not purely periodic. Both musicians' and non-musicians' temporal expectations deviate from periodicity in ways that are related to musical structure and correlate with tempo fluctuations typical of expressive performance (Repp, 2002;2005;Rankin et al., 2009). However, measured fluctuations of temporal expectations are of a smaller magnitude than tempo fluctuations present in performed music (Repp, 1998).Therefore, prediction of tempo fluctuations explains only a portion of the variance in entrainment.

Neural responses to temporal expectation violations have been demonstrated in beta and gamma band oscillations (Snyder and Large, 2005;Zanto et al., 2005;Fujioka et al., 2009). Moreover, it has recently been shown that temporal unpredictability in the auditory domain is sufficient to produce amygdala activation humans (Herry et al., 2007).

Taken together, the physiological evaluation of variations in time presented in the (ir) version of "For Elise" shows different reactions in HSS and LSS subjects. Whereas HSS subjects display a physiological readiness without specific modifications of HR along with accelerations or decelerations of beats, LSS is connected with fine HR changes triggered by succeeding beats and deviations from regular beat. Therefore, only the LSS subjects might be sensible temporal expectation violations in music as postulated by Narmour(Narmour, 1990;1992) and more recently by Krumhansl(Krumhansl, 2000;Krumhansl and Agres, 2008).

Some limitations should be mentioned, which are relevant concerning the external validity of the presented results. First, the concept of SS has an immanent gender bias. In SS men show usually higher scores, and women show usually lower scores. Therefore, the two groups HSS and LSS, which are built using the upper and lower quartile included in the HSS group 10 men and 1 woman and in the LSS group 10 women and 1 man. We controlled this bias by calculating an ANCOVA (cofactors: gender and HR) over all participants. We found no significant effect of the factor gender on HR.

Second, concerning the perception of rhythmic variations in music Habibi et al. (Habibi et al., 2013;2014) showed by using ecological valid musical stimuli, that musicians compared with non-musicians, are significantly better at detecting subtle and unexpected rhythmically deviant notes. Musicians showed enhanced amplitudes of N100 and P200 potentials in the EEG to the delayed note following omissions but did not demonstrate a difference of auditory evoked potentials to the omitted stimuli. These findings suggest that musical training is accompanied by enhanced brain processing of both spectral and temporal aspects of music. In our sample, all participants were non-musicians. However, at least LSS and possibly in a less pronounced way even HSS subjects (perhaps in the sense of an orienting reaction) seem to be sensible listeners, which detect rhythmic variations in the (ir) version of “For Elise”. Third, the subjective arousal ratings of HSS and LSS subjects were highly correlated in both interpretations. Therefore, fundaments for the subjective arousal assessment may be in both versions SI and harmonic features and not irregularities in succeeding beats.

In conclusion we were able to show the effect of temporal expectation violations on heart rate and therefore its relevance for perceived emotions. Further, we were able to show the impact of the personality concept of SS on triggers of emotional arousal in music like temporal expectation violations.

Conflict of Interest Statement

The authors declare no conflicts of interest

Author Contributions

All authors had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. Study concept and design: CM, ADT, AA. Acquisition of data: ADT, CM. Analysis and interpretation of data: AT, CM, AA, WKS, SS. Drafting of the article: CM, AA. Critical revision of the article for important intellectual content: CM, AA. Statistical analysis: ADT, CM, AA, SS. Obtained funding: CM. Administrative, technical, and material support: ADT, SS,. Study supervision: AA.

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