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Emotional and psychophysiological responses to tempo, mode, and percussiveness

Marjolein D. van der Zwaag
Philips Research Laboratories, The Netherlands

Joyce H.D.M. Westerink
Philips Research Laboratories, The Netherlands

Egon L. van den Broek
Human-Centered Computing Consultancy, Austria; Human Media Interaction, University of Twente, The Netherlands; Karakter University Center, Radboud University Medical Center Nijmegen, The Netherlands

Abstract
People often listen to music to influence their emotional state. However, the specific musical characteristics which cause this process are not yet fully understood. We have investigated the influence of the musical characteristics of tempo, mode, and percussiveness on our emotions. In a quest towards ecologically valid results, 32 participants listened to 16 pop and 16 rock songs while conducting an office task. They rated experienced arousal, valence, and tension, while skin conductance and cardiovascular responses were recorded. An increase in tempo was found to lead to an increase in reported arousal and tension and a decrease in heart rate variability. More arousal was reported during minor than major mode songs. Level and frequency of skin conductance responses increased with an increase in percussiveness. Physiological responses revealed patterns that might not have been revealed by self-report. Interaction effects further suggest that musical characteristics interplay in modulating emotions. So, tempo, mode, and percussiveness indeed modulate our emotions and, consequently, can be used to direct emotions. Music presentation revealed subtly different results in a laboratory setting, where music was altered with breaks, from those in a more ecologically valid setting where continuous music was presented. All in all, this enhances our understanding of the influence of music on emotions and creates opportunities seamlessly to tap into listeners' emotional state through their physiological responses.

Keywords
emotion, mode, music, percussiveness, psychophysiology, tempo

Corresponding author:
Marjolein D. van der Zwaag, Philips Research Laboratories Europe, High Tech Campus 34, 5656 AE Eindhoven, The Netherlands
Email: Marjolein.van.der.zwaag@philips.com

Introduction

People listen to music because it can make them feel comfortable, relaxed, or happy (DeNora, 2000; Juslin & Laukka, 2004; Juslin & Sloboda, 2010). In line with this, emotion regulation through music is often considered one of the most important functions of music (Saarikallio & Erkkilä, 2007). One explanation for the impact of music on emotions is that music creates awareness of our current emotional state (Baumgartner, Esslen, & Jancke, 2006; Krumhansl, 1997). Awareness of our emotional state starts when emotion passes an intensity or saliency threshold, and it is recognized that at this point emotion becomes self-regulated (Gendolla, 2000).

Emotions are processes directed towards a specific internal or external event or object, which result in changes in both behaviour and bodily state (i.e., physiological change; Ekman & Davidson, 1994; Scherer, 2004). Emotions provide us with the ability to cope with sudden events in our environment in order to increase our chances of survival (Frijda, 1986). In a positive state, optimistic feelings dominate and cognitive functions (e.g., problem-solving abilities) are improved. In contrast, in negative states, pessimistic feelings dominate, resulting in an underestimation of our capacities and increased analytical thinking (Gendolla, 2000; Isen, 2000). In broad terms, music is thought to evoke emotions via its structural properties (e.g., tempo) or people's associations with music (Juslin & Sloboda, 2010).

One well-grounded way to measure emotion is by means of the valence–arousal model, which gives a dimensional description of emotions (Eerola & Vuoskoski, 2011; Russell, 1980; Russell, 2003; van den Broek, Schut, Westerink, & Tuinenbreijer, 2009; van den Broek & Westerink, 2009). Valence (i.e., overall happiness) and arousal (i.e., excitement or bodily activation) are its two most important dimensions. Together they explain around 80% of the variation of emotion words (e.g., happy, sad). The valence–arousal model is generally accepted as a good model for assessing emotions (Frijda, 1986; Lang, 1995; Russell, 1980; Wilhelm, 2007). In line with the valence–arousal model for emotions, Berlyne (1971) proposed a psychobiological model of arousal that assumes that aesthetic responses to art are determined by the physiological arousal we experience (Berlyne, 1971). The theory was supported by the results of research into music aesthetics that found an inverted U-shape between music preference and the complexity or arousal expressed by the music (North & Hargreaves, 1997), i.e., enjoyment of music is optimal at intermediate arousal levels. Hence, emotions expressed by music can also be captured with the two dimensions of pleasure and arousal (Berlyne, 1971; Hargreaves & North, 2010; North & Hargreaves, 1997).

Even though the valence and arousal dimensions have frequently been adopted, it is still a topic of debate whether other dimensions should be included to capture emotions (Eerola & Vuoskoski, 2011; van den Broek et al., 2009; van den Broek & Westerink, 2009). For example, tension, ranging from restless/under tension to calm/relaxed, has often been proposed as a third dimension (Matthews, Jones, & Chamberlain, 1990; Schimmack & Grob, 2000). Support for this third dimension comes from Wilhelm & Schoebi (2007), who note that although the valence, arousal, and tension dimensions show correlations (i.e., a positive mood mostly coincides with higher levels of positive valence as well as higher energetic arousal) they cannot be reduced to one single dimension as proposed by Thayer (1989) and Watson and Tellegen (1985). Tension is frequently experienced in music (Krumhansl, 1997), which makes it a dimension of interest in music research. For example, dissonance that can occur when an unexpected pitch is included in a chord can cause uncomfortable feelings in the listener, leading to increased perceived tension (Steinbeis, Koelsch, & Sloboda, 2006). Furthermore, music composed for films often uses methods of inducing tension to emphasize feelings of tension in the film (Juslin & Sloboda, 2010).

A further limitation of the valence–arousal model in music research is that some emotions are more profound when elicited with music than otherwise, as well as vice versa. For example, contempt or jealousy are difficult to induce with music (Juslin & Sloboda, 2010), even though these emotions commonly occur in daily life. Furthermore, the extent to which music is able to convey mixed emotions, (e.g., experiencing both happy and sad affect simultaneously) is unclear (Cacioppo & Berntson, 1994; Eerola & Vuoskoski, 2011; Konijn & Hoorn, 2005; Larsen, McGraw, & Cacioppo, 2001; van den Broek et al., 2009; van den Broek & Westerink, 2009). Although a solution for occurrence of mixed feelings is proposed (i.e., two separate unipolar dimensions for positive and negative valence), this method has not yet been widely applied (Cacioppo & Berntson, 1994; van den Broek & Westerink, 2009).

Musical characteristics and emotions

Musical characteristics such as tempo or mode are inherent properties of the structure of music. These characteristics are important, as it has been shown that they influence listeners' emotions (Juslin & Sloboda, 2010). Below we will briefly review the relationship between musical characteristics and emotions.

The relations between a broad variety of these musical characteristics and emotions have been studied (Gabrielsson & Lindström, 2010). We will now briefly describe three such relations by way of illustration. First of all, expectancy violations within the melody of music will induce surprise, and eventually increase arousal when many such expectancy violations occur (Deliège & Sloboda, 1997; Sloboda, 2005; Steinbeis et al., 2006). Second, it has been shown that complex, thick harmonies are appraised with low valence, whereas simple, thin harmonies are associated with higher valence levels (Webster & Weir, 2005). Third, staccato articulated music has been found to induce more fear and anger emotions than legato articulated music, which is more often associated with tenderness or sadness (Juslin, 1997).

The most widely studied musical characteristics are mode and tempo. Tempo is seen as the most important characteristic in modulating affect (Hevner, 1937; Juslin, 1997), in that tempo is assumed to influence a range of emotional expressions: happiness, surprise, pleasantness, anger, and fear; for an overview see Gabrielsson and Lindström (2010). In terms of the valence–arousal model, tempo is associated with the energetic arousal dimension (Gabrielsson & Lindström, 2010). Slow tempos are associated with low-arousal sad music, while fast tempos are associated with high-arousal happy music (Schellenberg, Krysciak, & Campbell, 2000; Webster & Weir, 2005).

In a Western tonal context, musical mode is associated with valence dimension: the minor mode is associated with sadness, whereas music in the major mode induces happiness (Deliège & Sloboda, 1997; Hevner, 1936; Sloboda, 2005; Webster & Weir, 2005). Kastner, Pinchot, and Crowder (1990) have shown that young children correctly mapped major music on the happy scale and minor music on the sad scale, whether innately or as a result of evaluative conditioning through exposure to the music of their native culture (Juslin, 2009). This finding supports the strong relation between (Western tonal) musical mode and valence. In conclusion, tempo is closely related to arousal and mode is closely related to valence, so together they constitute the basis of the valence–arousal model. Thus, despite all the existing interpersonal differences in music appreciation (Hargreaves & North, 2010), the above studies show that at least to some extent, musical characteristics are able to elicit a universal affective reaction pattern to music.

Research into the interaction between the musical characteristics of mode (major/minor) and tempo (slow/fast) provides contradictory evidence (Webster & Weir, 2005). On the one hand, it has been shown that fast-tempo music increases valence and arousal ratings up to a certain degree of happiness (Wilhelm, 1997). On the other hand, it has been found that increases in tempo decrease the effect of increasing happiness appraisal on major phrases and support happiness appraisal on minor phrases (Gagnon & Peretz, 2003). Because tempo also increases arousal, this implies that the valence and arousal axes of the valence–arousal model cannot be manipulated entirely independently of each other by means of music (Makris, 2003; Rigg, 1940; Russell, 1980; Wilhelm, 1997).

Percussiveness of sounds is a less researched musical characteristic that can be considered as a general descriptor for timbre (Skowronek & McKinney, 2007). Percussiveness describes the timbre of arbitrary sound textures without identifying the music instrument itself but by analysing the attack-decay characteristics of the music. Thus, sounds with high-percussiveness do not necessarily incorporate sounds coming from percussion instruments (Skowronek & McKinney, 2007). Instead, percussion in music may be determined by, for example, a cello that is plucked with the fingers. Instruments playing together in harmony can form an even sharper attack-decay characteristic and hence create more percussiveness in the music. Skowronek, McKinney, and van de Par (2006) have proposed that the amount of percussiveness in music indicates the power of the music's impact.

Physiological responses to music

So far, research investigating the effect of music on emotions has primarily focused on self-reports instead of on physiological responses. A disadvantage of self-reports, however, is that people's introspection can be notoriously poor, which makes relying solely on self-reports questionable (Nyklíček, Thayer, & van Doornen, 1997; Spatz & Kardas, 2007). Furthermore, there is a response bias, in that people tend to provide answers in a way they think is best, instead of expressing their own feelings (Nyklíček et al., 1997; Spatz & Kardas, 2007). Physiological measures can tackle this issue in a different way as they reflect unbiased, objective emotional responses to music listening. Another advantage of physiological responses is that they are able to capture changes in emotions that would remain unnoticed when relying solely on self-reports (Cacioppo, Tassinary, & Berntson, 2000). Moreover, physiological measures can be obtained continuously and effortlessly. This makes them particularly suitable for measuring emotions during tasks when one is not able to answer subjective questionnaires because attention is required for the task. Currently, the self-report methodology has also been applied to the temporal domain, by using a slider that can be continuously adjusted over time (Krumhansl, 1997; Schubert, 2001). However, this method requires participants' constant attention to the emotional state and therefore cannot be used next to another task, (e.g., listening to music in the background of office work, while rating emotions continuously).

Current practice requires the use of both subjective questionnaires and physiological measures, as they can cross-validate each other. Therefore, the combination of individual reports and psychophysiological measurements is still common as this can reveal the relation between subjectively perceived emotion and our psychophysiological state. Several reports describe physiological measures such as skin conductance level (SCL) or heart rate variability (HRV) in relation to the impact of music on emotions (Bradley & Lang, 2000; Gomez & Danuser, 2004; Iwanaga, Kobayashi, & Kawasaki, 2005; Krumhansl, 1997; Nater, Abbruzzese, Krebs, & Ehlert, 2006; Nyklíček et al., 1997; Riganello, Candelieri, Quintieri, & Dolce, 2007; Steinbeis, Koelsch, & Sloboda, 2006; see Hodges, 2010 for an overview). However, in none of the studies concerned were musical characteristics used to select the songs.

Skin conductance represents the sympathetic activity of the nervous system, which is directly related to arousal (Boucsein, 1992; Cacioppo et al., 2000; Stern, Ray, & Quigley, 2001; Traxel & Wrede, 1959). Khalfa, Peretz, Blondin, and Manon (2002) studied changes in skin conductance resulting from listening to fearful, happy, sad, and peaceful musical excerpts. Their results showed that higher SCLs and arousal magnitudes were associated with fear and happiness phrases. No differences in valence were found in this study, which underlines that skin conductance is primarily affected by arousal. Other studies revealed an increase in SCL during the presentation of unexpected harmonies (Steinbeis et al., 2006) or a decrease during sad music (Krumhansl, 1997; Salimpoor, Benovoy, Longo, Cooperstock, & Zatorre, 2009). Emotionally powerful music tends to increase skin conductance more than less emotionally powerful music (Rickard, 2004). No studies revealed any changes in the amount of skin conductance responses (SCRs) as a result of music presentation (Boucsein, 1992). However, as in naturally occurring emotions, it may be expected that the amount of SCRs will increase when music with high energy levels is presented (Boucsein, 1992; Cacioppo et al., 2000).

Time-domain HRV has been found to be higher during high positive valences as in relaxation or other non-stressful situations (Cacioppo et al., 2000). This can be explained by the fact that heartbeats follow a stricter pattern during tensed states, leading to decreasing time-domain HRV in such situations (Cacioppo et al., 2000). Influences of music on HRV are rarely reported. Steinbeis et al. (2006) did not find any changes in HRV in response to unexpected harmony changes, known to induce low valence and stress, in the music presented. In contrast, Krumhansl (1997) observed increases in HRV during sad, fearful, and happy music. Regrettably, the precise musical characteristics of the music phrases used were not specified. All in all, we conclude that skin conductance is related to arousal and HRV is related to valence. In line with this conclusion, we employed these physiological signals in our research.

Real-world music listening

In all the research we have discussed so far, the music was presented in controlled laboratory settings. This makes it very hard to generalize the findings to the real world. Several aspects must be taken into account when generalizing results to music-listening situations in everyday life when studying the effect of music on emotions. First, in laboratory studies music is often presented in a discontinuous fashion; that is, music is alternated with silent periods, also referred to as interstimulus time (Webster & Weir, 2005). This guarantees a controlled situation; however, it is not clear to what extent the results can be generalized to continuous music-listening situations. Second, many studies have used tailored music excerpts, composed specifically for the experiment at hand, to test the research question (Hevner, 1937). Such music excerpts are often short, and do not include the broad variety of characteristics that are normally present in music. This limits variability in the interaction between the characteristics, so results should be interpreted carefully, and optimally in a contextual sense (Gabrielsson & Lindström, 2010). Third, only a few studies have considered the notion that music is often listened to in the background while another task is being undertaken (e.g., Cassidy & MacDonald, 2007; Hallam & Prince, 1998; Lesiuk, 2005; Schellenberg, Nakata, Hunter, & Tomota, 2007). In the current study we attempted to overcome these three drawbacks by presenting real music in both a continuous and a discontinuous way, in the background of an office environment, in an attempt to approach a real-world situation.

The aim of our study was to investigate the effects of tempo, mode, and percussiveness on emotions in the context of an office environment setting, where music is listened to in the background. These three characteristics represent the major elements of music: melody, rhythm, and timbre, respectively. Emotions were measured by means of subjective self-reports on valence, arousal, and tension and physiological responses of skin conductance and HRV. We expected that faster tempos would induce higher arousal in the self-reports as well as increase autonomic activity expressed in higher skin conductance levels and the number of skin conductance responses. We also hypothesized that major mode music would induce higher positive valence scores and HRV. Finally, we included percussiveness as an exploratory factor. We expected that highly percussive music would increase the intensities of the emotional responses induced by music in the self-reports as well as in SCRs. In addition, the music in our study was presented continuously and with breaks between songs, to verify the ability to generalize the often-used break condition to everyday-life office environment situations in which music is listened to continuously.

Method

Participants and design

Thirty-two employees at Philips Research, The Netherlands, volunteered for participation (16 men, age: Mean = 26.3, *SD* = 4.03; and 16 women, age: Mean = 24.6, *SD* = 2.22). The participants signed an informed consent form before participating. Participants had no extensive musical knowledge, no hearing impairment, no knowledge of a Slavic language, and did not dislike pop or rock music.

Three musical characteristics were varied as within-subject factors: Tempo (slow/fast), Mode (minor/major), and Percussiveness (low/high). The songs were presented in a within-subject design with two types of music Presentation (continuous/non-continuous) in two consecutive Blocks. The presentation order of the two conditions was counterbalanced across participants.

Materials

Songs. Two songs were selected for each of the 8 combinations of the musical characteristics of Tempo (slow/fast), Mode (minor/major), and Percussiveness (low/high). Each pair of songs with the same characteristics was randomly assigned to one of two groups, resulting in two groups of 8 songs each (see also Tables 1 and 2). The selected songs comprised 9 pop and 7 rock songs. The songs were selected from a music database containing a wide variety of songs, 1800 in total, from which 82 features per song were determined by automatic classification (Skowronek, 2006, 2007; Pauws, 2006; van de Par, McKinney, & Redert, 2006). A conservatory graduate confirmed the automatic classification of the 16 songs. The selected average values of the songs in terms of tempo, mode, and percussiveness, were as follows: Tempo, slow = 80bpm, fast = 139bpm; Mode, minor 88.5% of the song, major 98.5% of the song; and Percussiveness, low = 14.5% percussive sounds, high = 42% percussive sounds (see also Tables 1 and 2). The duration of each song was adjusted to 2 minutes and 30 seconds using Audacity software (Mazzoni & Dannenberg, 1999). Furthermore, the sound intensity of all the songs was equalized. The songs were presented via Sennheiser circum aural, semiopen headphones (HD500 Fusion).

Table 1. The range and mean values of the characteristics of the stimuli within each music group are represented in this table. Tempo is given in beats per minute and mode specifies what percentage of the music is minor or major. Further, percussiveness defines the percentage of percussive sounds occurring in the music stimuli.

	Group 1	Group 2
Tempo		
Slow	80 [74 – 86]	80 [74 – 84]
Fast	142 [129 – 162]	136 [142 – 247]
Mode		
Minor	87 [52 – 100]	90 [76 – 100]
Major	99 [95 – 100]	98 [95 – 100]
Percussiveness		
Low	15 [5 – 19]	14 [7 – 23]
High	46 [29 – 44]	37 [27 – 44]

Table 2. The songs selected for each characteristic combination divided over the two music groups. The precise specification of the music stimuli characteristics, as indicated by the classification algorithms, is given in bpm for Tempo, in % of major/minor mode sounds for Mode and in % of percussive sounds for Percussiveness (Skowronek, 2006; Pauws, 2006; van de Par, McKinney, & Redert, 2006).

Group	Tempo	Mode	Percussiveness	Genre	Artist and title
1	S 75	Minor 100	Low 5	Rock	Evanescence, *Imaginary*
1	S 86	Minor 52	High 29	Pop	Lenny Kravitz, *Heaven Help*
1	S 74	Major 100	Low 19	Pop	The Beatles, *Hey Jude*
1	S 84	Major 100	High 35	Pop	Oates, *Rich Girl*
1	F 136	Minor 96	Low 18	Pop	Geri Halliwell, *It's Raining men*
1	F 129	Minor 100	High 34	Rock	Lenny Kravitz, *Are You Gonna Go my Way*
1	F 141	Major 100	Low 17	Rock	The Eagles, *James Dean*
1	F 161	Major 95	High 43	Pop	Atomic Kitten, *If You Come to Me*
2	S 74	Minor 76	Low 23	Pop	The Eagles, *Hotel California*
2	S 84	Minor 100	High 43	Rock	Beyoncé, *Me, Myself and I*
2	S 82	Major 100	Low 7	Rock	Electric Light Orchestra, *Can't Get it Out of My Head*
2	S 80	Major 95	High 27	Pop	Roxette, *It Must Have Been Love*
2	F 147	Minor 85	Low 9	Rock	Radiohead, *The Trickster*
2	F 136	Minor 100	High 44	Pop	Seal, *Crazy*
2	F 126	Major 100	Low 18	Pop	Abba, *The Winner Takes it All*
2	F 136	Major 97	High 36	Rock	Rolling Stones, *Satisfaction*

Experimental task. During the experiment the participants conducted a task in order to mimic a normal office task with music presented in the background. The task was copying text – a very simple, repetitive typing activity that nevertheless demanded constant concentration (Pashler, 1998). A Latin Serbian translation of the original French children's book *Le Petit Prince* by De Saint-Exupéry (1943) was used to prevent the risk of the emotional content of the text influencing the results. All typically Serbian letter additions were removed (e.g., 'č' was changed into a 'c'), and all end-of-sentence punctuation marks were replaced by a period. The text and the text-editing screen were presented horizontally aligned on a monitor as illustrated in Figure 1.

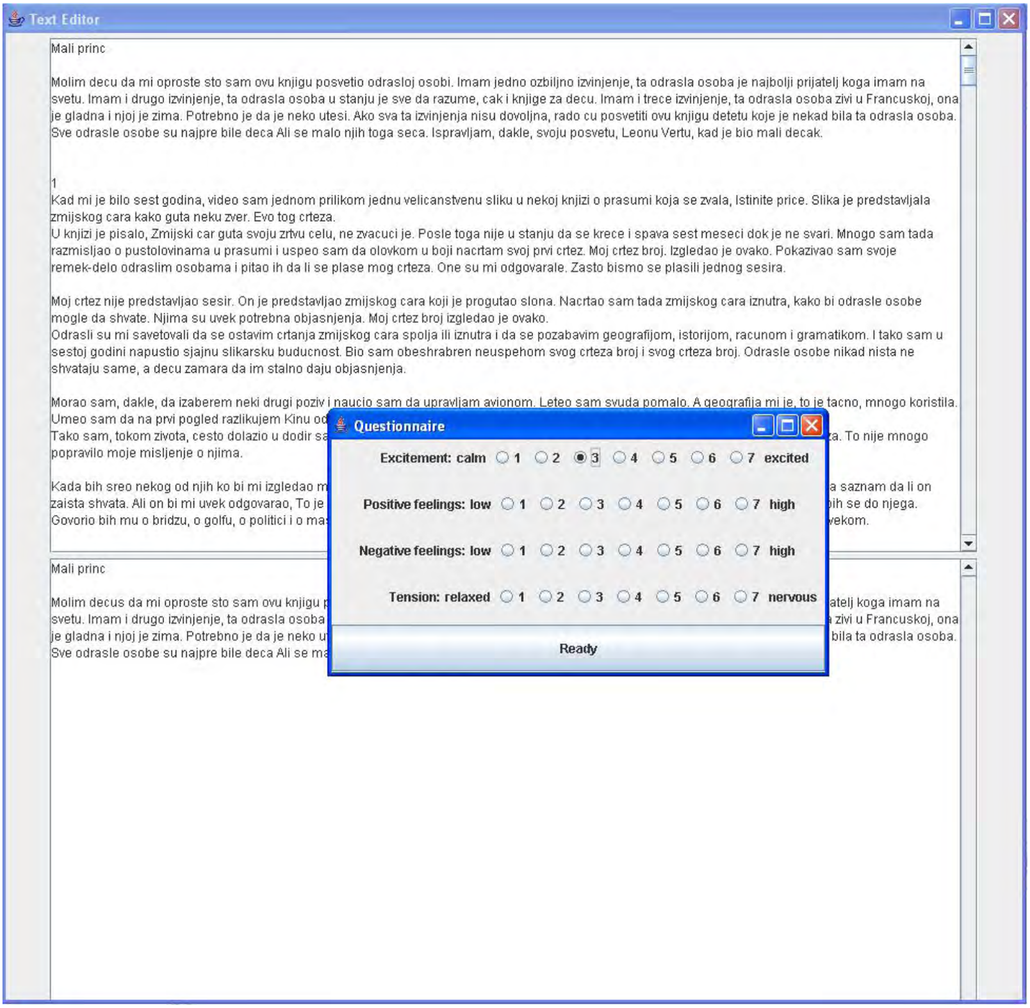

Figure 1. The text editing pane with and the subjective questionnaire. The upper pane shows the text to be copied, and the lower pane shows the text editing field.

Subjective questionnaires. Subjective ratings of emotions were given regarding arousal (calm to energetic), positive feelings (low to high), negative feelings (low to high), and tension (relaxed to nervous), using 7-point interval Likert scales (Lang, 1995; Morris, 1995). For each of these dimensions, participants were asked to indicate how they felt at the current moment. Participants were asked to respond with the first thought that came to mind, to provide the most accurate reflection of their affective state (Spatz & Kardas, 2007). The two valence questions were presented in order to allow the presence of mixed feelings (Cacioppo & Berntson, 1994; Larsen et al., 2001; Konijn & Hoorn, 2005).

Physiological recordings. Physiological recordings of electrocardiography (ECG) and skin conductance were taken with a Nexus-10 apparatus and its accompanying sensors (Mind Media B.V., The Netherlands). These signals were continuously recorded throughout the experiment. The skin conductance measurements were performed using dry Ag/AgCl electrodes, which were attached with Velcro to the upper phalanx of the index and middle finger of the non-dominant hand with Velcro. The signal was sampled with a frequency of 32 Hz.

The ECG was recorded via the standard Lead II placement with a sample frequency of 1024 Hz (Stern, Ray, & Quigley, 2001). The negative and ground electrodes were therefore placed right and left below the collarbones respectively. The positive electrode was placed lateral anterior on the left chest, right between the lowest two ribs. The ECG measurements were conducted using Ag/AgCl disposable sensors, type H124SG, containing a solid gel.

Procedure

When participants entered the room, the physiological sensors were attached and the PC monitor and chair height were adjusted to a comfortable position, as the whole experiment was computerized. Subsequently, participants were told that their main task would be to copy a Serbian text presented on the monitor into a second window (Figure 1). They were also told that music would be present in the background during parts of the experiment. Participants were asked to complete the subjective questionnaires and were told that unfamiliar items would be explained for the first time. When participants had no further questions about the experiment, they were asked to relax and a two-minute ECG and skin conductance baseline measurement was recorded. After the baseline measurement, the experiment started.

The experiment consisted of two blocks, one in which music stimuli were presented to the participants continuously and one in which each music stimulus was alternated with a silent period: the continuous (or loop) block and the discontinuous (or break) block, respectively. The silent periods between the music stimuli were intended to allow any physiological changes to return to the baseline values and to guarantee regularity in the presentation of the stimuli. The order of the music stimuli within the music blocks was also counterbalanced among participants using a multiple 8x8 digram-balanced Latin square design (Gomes et al., 2004; Wagenaar, 1969).

Each block started and ended with 2.5 minutes of silence, in which the questionnaire on the emotional state was presented. Within each block, the questionnaire was provided after 120 seconds of each stimulus (i.e., a song or a silent period) presentation. This presentation time was chosen in such a way that the response actions would not interfere with the next song or silent period. The questionnaires were presented on the monitor, blocking the text-editing field and forcing the participants to fill in the questionnaire immediately. Between the two blocks, a five minute break was presented, in which the experimenter had a short conversation with the participants.

After the second block, the sensors were disconnected and participants were thanked for their participation. The total time required for the continuous loop condition was 25 minutes, consisting of (2 silent periods + 8 music periods) x 2.5 minutes per stimuli and silent period. The discontinuous break condition had a duration of 42.5 minutes, consisting of (9 silent periods + 8 music periods) x 2.5 minutes. The total duration of the experiment was 72.5 minutes, including a 5-minute break.

Data preprocessing and analysis

The skin conductance signal was preprocessed by minimizing small artifacts applying a low pass Butterworth filter (0.5Hz). Large motion artifacts were removed by setting a maximum amplitude per participant (Cacioppo et al., 2000; Kohlisch, 1992). Normalization was conducted per participant using SCL – SCLmin/SCLmax – SCLmin, with SCLmin being the minimum and SCLmax the maximum SCL of the participant responses in the full trace. SCL was calculated by taking the mean of the normalized signal over each song or silent period. The SCRs were obtained after down sampling (2Hz) and cubic spline interpolation of the raw SCL signal. Subsequently, the SCRGauge algorithm of Kohlisch (1992) was used to extract the SCRs.

The R-peaks of the ECG signal were detected using ANSLAB 4.0 software, above a fiducial point that was set manually (Wilhelm & Peyk, 2006). R-peaks that were not correctly assigned by the software were manually corrected and missing R-peaks were interpolated by taking the mean distance between the surrounding R-peaks of the last 10 peaks. The interval between each successive heartbeat, Inter Beat Interval (IBI), was derived successively. The Root Mean Square Successive Differences (RMSSD) was calculated from the IBIs as a time-domain Heart Rate Variability (HRV) measure, which is known to be the best predictor of short term HRV (Berntson, 1997; Malik et al., 1996).

Missing responses on the subjective data occurred in the case of two songs for two participants. In the case of missing values or outliers (i.e., values that deviated more than 2.5 standard deviations from the group mean; Acock, 2005; Fidell & Tabacknik, 2005), the data for the song concerned was excluded from the analysis of that participant's results. Two participants were excluded from further ECG analysis because of abnormalities in their ECG (i.e., frequently occurring ectopic beats; Malik et al., 1996). From the skin conductance data, two participants were excluded from further analysis because they were found to be skin conductance non-responders, having little to no SCR (Boucsein, 1992). In the following analyses, Bonferroni corrections were used for post hoc testing. Two-tailed Pearson product moment correlations (r) were used for the correlations.

Results

Subjective responses

The following analyses were performed to investigate the effect of the musical characteristics tempo, mode, and percussiveness on the subjective affective state.

A multivariate repeated measures analysis of variance (MANOVA) was performed with Music Presentation (loop/break), Tempo (slow/fast), Mode (minor/major), and Percussiveness (low/high) as within-subject factors on the subjective measures of arousal, positive feelings, negative feelings, and tension. The means and standard errors of the results of this analysis can be found in Tables 3 and 4. Due to the many interactions, non-significant effects will not be mentioned.

A significant multivariate effect of tempo was found ($F(4,28) = 7.22$, $p < .001$, $\eta^2 = .51$). Univariate tests revealed a main effect of tempo on both arousal ($F(1,31) = 29.11$, $p = .001$, $\eta^2 = .48$) and tension ($F(1,31) = 13.93$, $p = .001$, $\eta^2 = .31$). As can be seen in Table 3, fast tempo music generated higher levels of arousal and tension than slow tempo music. Furthermore, higher arousal ratings were given during minor mode music than during major mode music ($F(1,31) = 8.04$, $p < .001$, $\eta^2 = .21$). A two-way interaction of tempo with percussiveness was observed at the level of positive valence ($F(1,31) = 5.98$, $p = .020$, $\eta^2 = .16$). During fast tempo music, higher levels of positive valence were reported in combination with high compared to low-percussive songs ($p = .009$), see Table 2. The amount of percussiveness did not change the intensity of positive feelings during slow tempo music. In addition, the level of positive valence was significantly higher in the case of high-percussive fast tempo than in case of high-percussive slow tempo music ($p = .014$), see also Table 2. A two-way mode with

Table 3. The Means (*M*) and Standard Errors (*SE*) of the subjective responses to songs varying in tempo, mode, and percussiveness, $N = 32$.

		Arousal		Tension		Positive valence		Negative valence	
		M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Tempo									
slow		2.91	0.17	2.77	0.16	4.41	0.17	2.57	0.16
fast		3.35	0.19	2.96	0.17	4.51	0.18	2.49	0.16
Mode									
minor		3.24	0.19	2.92	0.17	4.49	0.18	2.52	0.17
major		3.02	0.16	2.81	0.16	4.42	0.17	2.54	0.15
Percussiveness									
low		3.15	0.18	2.88	0.17	4.41	0.16	2.57	0.16
high		3.11	0.17	2.86	0.16	4.51	0.19	2.50	0.16
Tempo × mode									
slow	minor	2.99	0.19	2.83	0.18	4.41	0.18	2.59	0.17
slow	major	2.84	0.16	2.71	0.15	4.41	0.17	2.55	0.15
fast	minor	3.48	0.20	3.02	0.17	4.58	0.20	2.45	0.18
fast	major	3.21	0.18	2.91	0.17	4.44	0.18	2.53	0.16
Tempo × percussiveness									
slow	low	2.97	0.19	2.75	0.18	4.43	0.16	2.58	0.17
slow	high	2.86	0.16	2.79	0.16	4.38	0.18	2.56	0.16
fast	low	3.33	0.18	3.00	0.17	4.38	0.18	2.55	0.17
fast	high	3.37	0.20	2.93	0.18	4.64	0.20	2.43	0.17
Mode × percussiveness									
minor	low	3.33	0.20	2.91	0.18	4.53	0.18	2.51	0.17
minor	high	3.15	0.19	2.93	0.18	4.45	0.20	2.54	0.18
major	low	2.97	0.17	2.84	0.17	4.28	0.16	2.63	0.16
major	high	3.08	0.17	2.79	0.16	4.57	0.19	2.46	0.15

percussiveness interaction was observed for arousal ($F(1,31) = 6.25$, $p = .020$, $\eta^2 = .17$) and positive feelings ($F(1,31) = 6,86$, $p = .020$, $\eta\eta^2 = .18$). Subsequent post hoc tests showed that minor mode low-percussive music yielded higher arousal levels ($p = .037$) than minor mode high-percussive music. Major mode music evoked more intense positive feelings in combination with high- compared to low-percussive music ($p = .003$). In addition, the levels of arousal ($p = .001$) and positive feelings ($p = .025$) were higher during low-percussive minor mode than during low-percussive major mode music.

Physiological responses

A MANOVA was performed with Music Presentation (loop/break), Tempo (slow/fast), Mode (minor/major), and Percussiveness (low/high) as within-subject factors on the two skin conductance measures of SCL and SCR. A significant multivariate effect of percussiveness was found for the skin conductance measures ($F(2,28) = 4,15$, $p = .026$, $\eta^2 = .23$). As can be seen in Table 3, both the amount of SCRs ($F(1,29) = 4.36$, $p = .046$, $\eta^2 = .13$) and the SCL ($F(1,19) = 5.54$, $p = .026$, $\eta^2 = .16$) were higher during high-percussive music than during low-percussive music; see also Table 4. The tempo with percussiveness interaction showed a

Table 4. The Means (*M*) and Standard Errors (*SE*) of the physiological responses to songs varying in tempo, mode, and percussiveness, $N = 30$.

	HRV		SCL		SCR	
	M	*SE*	*M*	*SE*	*M*	*SE*
Tempo						
slow	40.77	2.56	0.63	0.02	16.17	1.09
fast	39.82	2.43	0.63	0.02	16.27	1.16
Mode						
minor	40.17	2.37	0.63	0.02	16.09	1.12
major	40.42	2.62	0.62	0.02	16.35	1.13
Percussiveness						
low	40.33	2.46	0.62	0.02	15.98	1.14
fast	40.26	2.54	0.63	0.02	16.46	1.10

significant multivariate effect ($F(2,28) = 3.75$, $p = .036$, $\eta^2 = .21$). This two-way interaction between tempo and percussiveness was found for the amount of SCRs ($F(1,29) = 7.77$, $p = .009$, $\eta^2 = .21$). During fast tempo music more SCRs were observed during high-percussive than during low-percussive music ($p = .008$; fast tempo low-percussiveness Mean (*SE*) 15.63(1.16), fast tempo high-percussiveness 16.91(1.19), slow tempo low-percussiveness 16.33(1.16), slow tempo high-percussiveness 16.01(1.04)). Furthermore, the amount of SCR was higher during fast tempo high-percussive music than during slow tempo high-percussive music ($p = .048$).

The results of an ANOVA with Music Presentation (loop/break), Tempo (slow/fast), Mode (minor/major), and Percussiveness (low/high) as within-subject factors on HRV showed a significant main effect of tempo on HRV ($F(1,29) = 4.26$, $p =.048$, $\eta^2 = .13$); no other significant effects were found. HRV was higher during slow tempo music than during fast tempo music, see also Table 4. Furthermore, a significant two-way interaction was observed between HRV and Music Presentation ($F(1,28) = 5.57$, $p =.026$, $\eta^2 = .17$). During the loop condition, HRV was higher during high-percussive music than during low-percussive music. This effect was reversed in the break condition, in which a higher level of HRV was observed during low-percussive music than during high-percussive music.

Correlations between subjective and physiological values

Correlations between the subjective and physiological measures were calculated to determine possible redundancies in the affective terms. To compensate for within-subject dependability the Pearson correlations were first calculated per participant. These correlations were normalized using a Fisher transformation, and entered into a one-sample *t*-test to test for significance ($N = 31$). The mean values from the test were re-transformed using a reverse Fisher transformation to obtain average Pearson correlations. The results show that arousal is strongly positively correlated with both tension ($r = .45$, $p < .001$) and positive valence ($r = .17$, $p = .02$). While arousal and tension ratings are strongly positively correlated with each other, their relation with positive valence follows an opposite direction: arousal is positively related with positive valence, whereas positive valence is negatively related with tension ($r = -.13$, $p = .05$). Furthermore, the level of negative valence showed a positive correlation with the amount of tension ($r = .37$, $p < .001$). In addition, there was a negative correlation between positive valence and negative valence ($r = -.50$, $p < .001$).

The physiological measures indicated significant correlations with the subjective responses. The amount of SCRs showed a positive relationship with both the arousal ($r = .10$, $p < .09$) and the tension ratings ($r = .08$, $p < .01$). Furthermore, the HRV measure was negatively related with arousal ($r = -.06$, $p < .01$), the level of negative feelings ($r = -.08$, $p < .01$), and the amount of tension ($r = -.05$, $p < .01$). Finally, SCR and SCL were strongly positively correlated ($r = .35$, $p < .001$).

Discussion

In this study we have investigated the influence of the musical characteristics of tempo, mode, and percussiveness on emotions in a controlled but ecologically valid manner. In addition to participants' subjective ratings, physiological measures were included to demonstrate their ability to reflect musically induced emotions. The three musical characteristics explain at least some of the influence of music on emotions, as is apparent from both participants' subjective ratings and their physiological responses.

In line with both our hypothesis and previous research, fast tempo music is found to increase experienced arousal and tension (Husain, Thomson, & Schellenberg, 2002). In addition, HRV is lower during fast tempo music than during slow tempo music. This objective physiological finding corresponds with the subjective tension experienced during fast tempo music, as time-domain HRV is naturally lower during high-stress situations (Haag, Goronzy, Schaich, & Williams, 2003).

Our results show that minor mode music evoked higher arousal ratings than major mode music. This conflicts with both our expectations and previous research, which revealed a relation between mode and valence (Juslin & Sloboda, 2010; Kastner et al., 1990). This discrepancy may be attributed to the music selected and the situations in which they were listened to. That is, in our study real songs were presented in the background of an office task. The relation between mode and valence may not have been perceived so strongly in these real songs, because pop and rock music generally do not have strong negative valence, whereas some other genres do. This interpretation is supported by the fact that no effects on perception were observed from the subjective ratings of negative valence.

The SCL and amount of SCR were found to be sensitive to percussive music; higher reactions were observed in the case of high-percussive music. This finding confirms our hypothesis that SCL increases with higher percussiveness, as skin conductance is a direct reflection of the sympathetic nervous system, which is positively related to energetic as well as tensed arousal (Boucsein, 1992; Cacioppo et al., 2000). Several other researchers have also demonstrated the relation between arousal in the music and SCL responses (Lundqvist, Carlsson, Hilmersson, & Juslin, 2009; Salimpoor et al., 2009; Witvliet & Vrana, 2007). The fact that percussiveness nevertheless does not influence subjectively experienced arousal most probably indicates a higher sensitivity of skin conductance measures to different levels of percussiveness in music. This finding emphasizes the value of physiological responses in measuring the influence of music on emotions.

The two-way interactions found between the musical characteristics and emotions indicate a complex interdependency of musical characteristics in modulating emotions. This is most prominent in the responses to percussiveness. Percussiveness seems to act as a mediator in strengthening the influence of either mode or tempo on the intensity of positive feelings. Fast tempo music and major mode music are both experienced more positively in combination with high-percussive music than with low-percussive music. This pattern was confirmed by the physiological responses; a higher intensity of SCR was observed during high-percussive music in combination with fast tempo music than with slow tempo music.

Objective and subjective measurement methods; theoretical implications

The subjective questions used to assess the influence of musical characteristics on emotions revealed two redundancies. First, these results confirm our hypothesis that tension and arousal ratings show high correlations. The main difference between the two is that arousal shows a positive relationship with positive valence, while tension shows a negative relationship with positive valence. This implies that as long as positive valence is included, arousal or tension ratings will be redundant. Second, positive and negative experienced valence show a strong inverse relationship with each other. Thus, no mixed feelings on these valence scales were found in this study, implying that there may be no need to split the valence dimension into two unipolar scales for music and affect research. In summary, confirming previous research, the most widely used bipolar valence and energetic arousal dimensions prove to be sufficient to capture the experienced influence of musical characteristics on affect (Berlyne, 1971; Frijda, 1986; Lang, 1995; North & Hargreaves, 1997; Russell, 1980; Wilhelm, 1997).

Physiological responses can sometimes reveal patterns uncovered by self-report. The current results show this in the effect of percussiveness on skin conductance, which was not reflected in any of the self-report measures. This phenomenon might be taken to indicate that physiological changes can occur before subjective experiences of emotions have reached a threshold at which they are sufficiently intense and salient for the subject to become consciously aware of them (Gendolla, 2000; Gendolla & Krüsken, 2002). This mechanism suggests that musical characteristics that may be considered less profound (e.g., percussiveness) can reach this threshold later than other characteristics (e.g., tempo). Future research should investigate the existence and specifics of such temporal aspects of music emotions and mood induction, for example, by presenting music with certain characteristics for longer time periods when music listening is a primary task as well as when music is presented in the background.

The results further support an emotivist position in that music is shown to induce emotions in listeners even when it is presented in the background (Kivy, 1989, 1990). This is in line with literature that shows that psychophysiological changes relate to musically induced emotions (Baumgartner, 2006; Nater et al., 2006; Nyklíček et al., 1997; Witvliet & Vrana, 2007). The current study strengthens support for this emotivist approach in that different musical characteristics conveyed physiological responses even though participants were distracted from the emotion induction with music, as music was presented in the background and the importance of task performance was emphasized to participants.

This study shows the usefulness of physiological measures in research into the relation between music and emotions. In particular, patterns of the influence of music on emotion that might otherwise remain unnoticed, and therefore unreported by participants may still influence the physiological state and more unconscious states such as mood. Another advantage of physiological measures such as those used here is that subjective reports may be influenced by confirmation bias (Nyklíčzek et al., 1997). In such cases, the affect *expressed* by music is rated, instead of the affect *induced* by music (Kivy, 1990). Physiological measures can overcome this by reflecting the emotions induced by music. In any case, physiological responses can add information complementary to self-reports, and thus disentangle the influence of music on emotions, since they effortlessly provide continuous information on body state.

Listening in a simulated office setting

The present study investigated the emotional impact of listening to music while doing a typical office task. For this reason, we chose to limit ourselves to songs from the often listened-to and closely related genres of pop and rock. While we did observe effects in this limited subset, the impact of musical characteristics on emotions may actually be greater when different genres are included, as the degree of variation between characteristics would be assumed to be greater among different genres.

The presentation of the music, as either continuous or with breaks, did not influence subjectively experienced affect, but did however influence HRV. HRV was higher during high-percussive music in the loop condition, but not in the break condition. This implies that there was less physical stress during high-percussive music in the continuous presentation than in the discontinuous presentation. Again, this example illustrates that physiological measures may be more sensitive to certain aspects that cannot be measured with subjective reports. This finding also implies that care should be taken when generalizing the result of studies in which music is presented in a discontinuous way to everyday music listening, as our results show that they do not provide entirely identical results.

Limitations and future research

One of the most important limitations of this study's design is that the music songs were selected by the experimenter instead of by the participants themselves. This meant that appreciation of and familiarity with the music were not controlled. Nevertheless, even if the participants did not like the songs or were not very familiar with them, some convincing results in line with the current body of literature have been obtained. This suggests that even more convincing results may be obtained when participants bring their own selected songs (van der Zwaag & Westerink, 2010), as would be the normal case in a real office environment. Future research should further investigate the impact of musical characteristics on affect using personally selected music. Another limitation of the study is that particular combinations of musical characteristics in the employed songs are less typical in real music than others. This may have influenced our findings in that more common combinations will be more familiar to people, and further research should therefore replicate this study with songs having features that are equally present in real songs. In line with this limitation, the current study only varied three musical characteristics, whereas there were several others that remained uncontrolled (e.g., harmony, pitch, and lyrics). Lyrics can carry emotional content; however, these do not necessarily influence the emotions of the listeners (Ali & Peynircioglu, 2006). Therefore, and because in the current study the music was listened to as background to another task, the influence of lyrics on emotions was expected to be marginal. Nevertheless, future research should try to address the interaction of various other musical characteristics on induced emotions to complement our results and to gain a better understanding of how music influences emotions.

The effect size of individual differences to emotional reactions to music listening is not yet known. Previous studies have already shown that the influence of music listening on emotions can vary due to differences in sex (Nater et al., 2006), musical experience (Kreutz, Bongard, & Von Jussis, 2002), and pain perception (Roy, Peretz, & Rainville, 2008). Our study found some patterns in line with existing results, for example, SCL was generally higher during high arousal than low arousal states. Nevertheless, the precise impact of numerous individual differences on this influence is not fully understood. A possible way to reveal these underlying mechanisms that constitute how music influences emotions is to adapt triangulation or a multivariate approach (Levenson, 2003; van den Broek, Janssen, Westerink, & Healey, 2009): these approaches suggest integrating various measures in order to be able to build a theoretical model of how these measures relate, in this case how music influences emotions. Measures to incorporate this could involve several physiological responses or response from the systems proposed by Juslin and Västfjäll (2008); the brain stem, evaluative conditioning, emotional contagion, mental imagery, episodic memory, and musical expectancy (see also Lundqvist et al., 2009).

The importance of a theoretical foundation for understanding the underlying mechanisms of musically induced emotions is becoming increasingly apparent (Juslin & Västfjäll, 2008). First of all, some studies that included physiological measures did not find the hypothesized effects. For example, Etzel, Johnsen, Dickerson, Tranel, and Adolphs (2006) had difficulty in detecting psychophysiological correlates of mood induction. Because the underlying mechanism of music mood or emotion induction remains unknown, the exact reason for this lack of significant findings is also unknown. As a second example, Grewe, Nagel, Kopiez, and Altenmüller (2007) did not regularly find events occurring in physiological, motor responses, and subjective responses to music stimuli. Therefore, in contrast with our conclusion, Grewe et al. (2007) adapted a cognitivist position and questioned the emotivist view that musical patterns can induce emotions. However, to be able to provide a definite proof of the emotivist or cognitivist position on musically induced emotions, it requires knowledge of the underlying mechanisms. In order to acquire this we need to overcome methodological shortcomings (e.g., recognizing the difference between emotions and mood) in study designs that now support either position (Konečni, 2008; Scherer, 2004). Further research should address this point and continue the current line of enquiry, consequently further exploring the mechanisms that constitute musically induced emotions.

In summary, listening to music is often used to regulate affect in everyday life. Therefore, a better understanding of how to select music to direct emotions to a desired state would be useful. The present study has yielded insights into how musical characteristics can modulate affect which may allow guidelines to be formulated to facilitate the selection of music for the purpose of guiding emotions to a preferred state.

Our results show that the three musical characteristics of tempo, mode, and percussiveness interplay with each other in evoking experienced emotions. The physiological measures are correlated with these subjective measures and show changes in affect which are not captured by subjective measures.

To assess the influence of music on emotions in everyday music listening, it is important to record physiological responses, as they can measure emotions in an unbiased, rather unobtrusive way, and can reveal much more subtle emotional responses than subjective ratings ever can. This study has shown that fast tempo music can be presented to boost arousal levels. However, when fast tempo or major mode is combined with high-percussion levels, a more positive valence will be evoked. Furthermore, this study shows that music presentation in laboratory settings can yield different responses than in more ecologically valid settings. This illustrates the importance of understanding music in everyday-life settings, which include all the interacting music characteristics within real music, when aiming to understand the mechanisms by which music influences our emotions.

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