Short Title: The impact of music and music tempo on human heart rate

Adopting a music-to-heart rate alignment strategy to measure the impact of music and music tempo on human heart rate

Edith Van Dyck[1*], Joren Six[1], Esin Soyer[1], Marlies Denys[1], Ilka Bardijn[1], and Marc Leman[1]

[1] Ghent University, Faculty of Arts and Philosophy, Department of Arts, Music and Theatre Sciences, Institute for Psychoacoustics and Electronic Music (IPEM), Technicum Blok 2, Sint-Pietersnieuwstraat 41, 9000 Ghent, Belgium

[*] Corresponding Author

E-mail: edith.vandyck@ugent.be (EVD)

Address: IPEM, Ghent University, Technicum Blok 2, Sint-Pietersnieuwstraat 41, 9000 Ghent, Belgium.

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Abstract

Music is frequently used as a means of relaxation. Conversely, it is used as a means of arousal in sports and exercise contexts. Previous research suggests that tempo is one of the most significant determinants of music-related arousal and relaxation effects. Here we investigate the specific effect of music tempo, but also more generally, the influence of music on human heart rate. We took the pulses of 32 participants in silence, and then we played them non-vocal, ambient music at a tempo corresponding to their heart rates. Finally, we played the same music again, either with the tempo increased or decreased by a factor of 45%, 30%, or 15%; or maintaining the same tempo as in the first playing. Mixed-design ANOVA tests revealed a significant increase in heart rate while listening to the music as compared with silence ($p < .05$). Besides, substantial decreases in tempo (-45% or -30%) could account for smaller subsequent heart rate reductions ($p < .05$). We neither found links between increases in tempo (+15%, +30%, and +45%) and heart rate change, nor small decreases (-15%). In addition, neither effects of gender, music training, nor of musical preference were found. This indicates that during passive music listening, music exerts a general arousal effect on human heart rate, which might be regulated by tempo. These results are a major contribution to the way in which music may be used in everyday activities.

How is music related to human heart rate? Particularly in music therapy, but also in sports and exercise contexts, this question has puzzled many due to the implications of the answer. For instance, the use of music has long been considered effective for enhancing exercise (Karageorghis & Terry, 1997). Music reflects participants' physiological arousal level (Berlyne, 1971; North & Hargreaves, 1997), and it was established that, in everyday settings, people prefer to listen to auditory stimuli with tempi in the range of the normal heart rate (i.e., 70–100 BPM) (Iwanaga, 1995a, 1995b). In moderate to high-intensity exercise, however, there is a preference for medium- and fast-paced music (Karageorghis, Jones, & Low, 2006).

Listening to certain types of musical stimuli has also been shown to attenuate heart rate after stressful tasks (Knight & Rickard, 2001). Slow music, for example classical or meditative music, has often been demonstrated to initiate reductions in heart rate, resulting in greater relaxation (Bernardi, Porta, & Sleight, 2006; Chlan, 1998; Hilz et al., 2014; Krumhansl, 1997; Nomura, Yoshimura, & Kurosawa, 2003). Combined with evidence of decreases in blood pressure, respiratory rate, and subjective anxiety levels (Knight & Rickard, 2001; Hilz et al., 2014; Möckel et al., 1994), such findings support the claim that listening to certain music could serve as an effective anxiolytic treatment, reducing stress levels and inducing relaxation. Based on such results, it is apprehensible that the common use of music in therapeutic situations (White, 2000), cardiac care (Nilsson, 2011), and pre-surgical settings (Lee, Chao, Yiin, Hsieh, Dai, &

Chao, 2012; Miluk-Kolasa, Matejek, & Stupnicki, 1996) is effectively a non-invasive relaxation technique. Similarly, in the sports and exercise domain, music is often employed for its relaxing properties, after intense bouts of exercise, expediting recovery and preventing injuries and cardiac complications (Karageorghis, 2015). Conversely, regarding arousal effects, research has also shown links between the perception of certain aspects of musical stimuli and increases in cardiovascular parameters (e.g., Lingham & Theorell, 2009). For instance, heart rate has been shown to increase in association with *crescendi* and simple rhythmic structures (Bernardi, Porta, & Sleight, 2006; Bernardi et al., 2009; Iwanaga, Kobayashi, & Kawasaki, 2005). Findings such as these are in line with entrainment theory, substantiating the propensity of bodily pulses to entrain to musical rhythms without conscious effort (Thaut, 2008). Besides the effects of music itself, the introduction of pauses between musical excerpts has been shown to exert an influence on human heart rate: sudden silences demonstrably result in decreased pulse (Bernardi, Porta, & Sleight, 2006).

Tempo has often been considered to be one of the most significant determinants of audio-related effects on human heart rate (Bernardi, Porta, & Sleight, 2006; da Silva et al., 2014; Iwanaga, Kobayashi, & Kawasaki, 2005; Steelman, 1991; White & Shaw, 1991). Using audible clicks generated in a loudspeaker, Bason and Celler (1972) indicated that the heart behaves as an oscillator whose period can be varied over a certain range. Previous research also indicates that passive listening to music accelerates heart rate in proportion to the tempo of the rhythm (Bernardi, Porta, & Sleight, 2006; Bernardi et al., 2009; Chlan, 1998; Iwanaga, Kobayashi, & Kawasaki, 2005; Krumhansl, 1997; Nomura, Yoshimura, & Kurosawa, 2003). However, in the literature on human heart rate, the effect of musical tempo has rarely been a specific focus for rigorous study. Some previous studies used only a single musical stimulus (Knight & Rickard, 2001), thus preventing comparison between different tempi. Other studies have used arrays of musical excerpts: the effects of stimuli with different tempi have been compared across a range of music styles (such as raga, classical, dodecaphonic, rap, and techno (Bernardi, Porta, & Sleight, 2006); or classical, New Age, country western, religious, and easy listening (Chlan, 1998)); and across different emotional loadings, for instance sad, fearful, happy, and tense (Krumhansl, 1997), sedative versus excitative (Iwanaga, Kobayashi, & Kawasaki, 2005) or relaxing and aggressive (Hilz et al., 2014). In previous research, tempi have not usually been varied systematically, and musical stimuli have either been compared with each other or with a silent condition. In the present study, the tempo was modified while other parameters remained constant. As such, although earlier studies provide valuable indications regarding the topic at hand, they do not discriminate between the effects of musical style, tempo, other musical features, or merely the introduction of the musical stimulus itself.

In the current study, the aim is to investigate the link between musical tempo and human heart rate, adopting an experimental design that offers tight control over the relevant variables, in order to enable better-substantiated conclusions. In addition, musical tempo is not selected at random, but is manipulated in order to distinguish experimental conditions. By comparison as compared with stimuli with fixed slow or fast tempi, previous research shows greater cardiac response to auditory stimuli that were initially entrained with participants' heart rates and subsequently played one beat per minute slower (Saperston, 1995). A comparable approach was employed in a pilot study with six male participants by Nomura, Yoshimura, and Kurosawa (2003),. Initially, music was played three times as fast as the subjects’ heart rates, which had been measured prior to the start of the music; after this the music was repeated, either 10% faster or slower than previously. Results indicated significantly higher average heart rates in the fast condition than in the slow. Similarly, in the current study, the starting tempo of the music is derived from the heart rate of the participants themselves, reflecting their physiological arousal levels, and as such enabling the investigation of possible entrainment effects. Taking the participants' heart rate as 100%, tempi were adjusted systematically (by 15%, 30%, or 45%) enabling comparison of the impact of different extents of increase and decrease.

Possible confounding effects of: familiarity with the stimuli (Fontaine & Schwalm, 1979), music preference (Bunt, 1994; Davis & Thaut, 1989), music training (Bernardi, Porta, & Sleight, 2006), music style (Bernardi, Porta, & Sleight, 2006; Chlan, 1998), spectral features (Gingras, Marin, & Fitch, 2014), age of the participants (Hilz et al., 2014), time of day (Piccione, Giannetto, Assenza, Casella, & Caola, 2009), and use of chemical substances such as coffee, cigarettes, and alcohol (Mahmud & Feely, 2003; Whitsett, Manion, & Christensen, 1984) were controlled for and/or tested. Although gender was not expected to have an influence on the relationship between heart rate and musical tempo (Knight & Rickard, 2001), its possible effects were examined, because some entrainment studies reported superior music-to-movement coordination results for females than for males (Priest, Karageorghis, & Sharp, 2004; Van Dyck et al., 2015).

Adopting the methodology described above, the goal for this study is to identify possible arousal or relaxation effects of music tempo on human heart rate in a passive listening condition. Alongside this, the holistic impact of music is investigated: participants' pulses are taken during a period of quiet rest after which non-vocal, ambient music with a steady beat is played at tempi corresponding to the their heart rate. In subsequent iterations of the stimulus, the initial tempo is decreased, increased, or maintained. In the context of earlier research, it is hypothesized (*i*) that by comparison with silence, there is an increase in heart rate in music listening conditions, and (*ii*) that passive listening to music influences heart rate in proportion to musical tempo; slow tempi lead to decreases of heart rate, while fast tempi lead to increases.

Method

Power analysis

To establish the proper sample size, a power analysis was conducted using G*Power 3.1.9.2 (Faul, Erdfelder, Lang, & Buchner, 2007). With an α level of .05 and a power of $1-\beta = .80$ to protect beta at four times the level of alpha (Cohen, 1988), based on an estimated low to moderate effect size, it was indicated that around 30 participants would be required.

Participants

Thirty-two healthy participants (16 males), with an average age of 23.59 years (*SD* = 2.73), ranging from 19 to 31 years of age, took part in the experiment. Roughly half of the participants (53.13%) had received music training (Pearson's chi-square test revealed no significant association between gender and music training, $\chi^2(1) = 0.13$, $p = .72$). Subjects were asked not to smoke on the morning of the study, and to avoid the consumption of caffeine and alcohol, in order to control for possible confounding effects on heart rate (Mahmud & Feely, 2003; Whitsett, Manion, & Christensen, 1984). All participants signed a form to declare that they participated voluntarily; that they had received sufficient information regarding the tasks, the procedures, and the technologies used; that they had had the opportunity to ask questions; and that they were aware of the fact that heart rate was measured, for scientific and educational purposes only. The study was approved by the Ethics of the Faculty of Arts and Philosophy of Ghent University, Belgium, and all procedures followed were in accordance with the statements of the Declaration of Helsinki.

Experimental procedure

First, participants filled out a general questionnaire to assess gender, age, and musical training. They were also asked if they had smoked or used caffeine or alcohol before the start of the experiment. None of them reported to have used either of these substances. Participants were seated comfortably in a soundproof, secluded room and were equipped with Sennheiser HD60 headphones and a pulse sensor attached to their right index finger. A preferred volume level was selected which could not be modified by the participants during the further course of the experiment. They were instructed to "relax and listen to the music". Prior to starting, the researcher left the demarcated room, dimmed the lights, and began the experiment. All experiments took place between 9.00 and 11.00 am in order to standardize the protocol.

The experiment began with 9 minutes of silence to enable the stabilisation of the heart rate (HR). Next, the first condition was introduced. In this condition, no music was played for 60 seconds (silent condition). In the last 45 seconds of the condition, the participant's mean HR (interbeat intervals or RRI, converted to BPM) was calculated and taken as a reference for the tempo of the 60 seconds of music in the subsequent 'heart rate-based music' (HRBM) condition. Finally, in the altered tempo (AT) condition the same musical stimulus was played, either with the tempo modified, being increased or decreased by 45%, 30%, or 15%; or at the same speed as in the HRBM condition. These three conditions were repeated seven times to ensure that all levels of tempo modification would occur (see Figure 1). In total, the data collection phase of the experiment had a duration of 30 minutes.

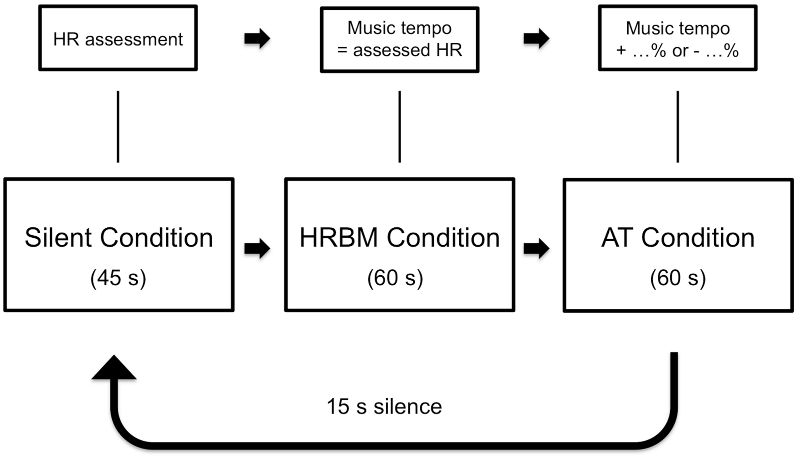

Figure 1. Experimental loop.

The order of the tempo modifications was randomized for each participant, ensuring that no order occurred more than once. At the end of the experiment, participants were asked to rate their familiarity with and preference for the stimuli.

Heart rate measurements

A photoplethysmograph (PPG) was used to measure heart rate. A PPG consists of an optical device that measures change in volume of arterial blood, generating a periodic voltage from which the RR intervals (RRI) can be derived (Shelley & Shelley, 2001).

During the experiment a Pulse Sensor Amped was employed (http://pulsesensor.com). The sensor was attached to the right index finger of each participant and an Arduino Uno microcontroller processed the resulting signal. The software running on the Arduino, provided with the sensor, was also used to determine RRI. Subsequently, the raw data and the RRI were sent from the Arduino to a Macbook over a serial-USB connection. On the laptop, the signal was visualized and the instantaneous HR, calculated from the RR intervals, was stored. Since the optical device was prone to motion artefacts, the participants were instructed to remain relatively still. Should a participant move to the extent that an increase in HR was discovered, that participant's condition was removed for further analysis. The signal was monitored continuously during the experiment, to prevent aberrations.

Music database and selection

A normal human adult HR at rest ranges from 60-85 BPM (Palatini, 1999), so a music database was created (see Table S1 in the Supplemental Material Online section), primarily consisting of stimuli with tempi lying within that range. However, extra stimuli were added, enabling the inclusion of participants with slightly higher or lower heart rates (e.g., trained athletes). All the stimuli consisted of non-vocal, ambient music with a binary rhythmical structure and were purchased from iTunes. They were chosen according to the following criteria: first, the music was required to have a steady beat, which was verified using BeatRoot (Dixon, 2007). Second, the tempi of the stimuli needs must be adjustable to increases and decreases up to 45% without quality loss. Third, in order to control for familiarity, only stimuli that had made few or no appearances in popular music charts were selected. Familiarity was also checked in a post-test showing that participants were unfamiliar with 94% of the music. A different stimulus was selected for each of the seven adaptation levels,. Audition was used to cut off intros or outros in case of the detection of unstable tempi in these sections of the music and ReplayGain was used to normalize perceived loudness and minimize possible imbalances in sound pressure level (SPL).

To automate the experimental procedure, a script was developed using the Ruby programming language (Flanagan & Matsumoto, 2008). It controlled (*i*) the transition from one condition to another, (*ii*) the presentation of the stimuli, (*iii*) the registration of HR measurements, and (*iv*) the logging of events and data. For both the HRBM and the AT condition, the participant was presented with time-stretched music. A time-stretching algorithm enabled tempo modification without affecting the pitch of the stimuli. Each stimulus was played for 60 seconds. Therefore each audio excerpt had a required duration of at least 87 seconds (= 60 s+45%), to enable the 45% tempo increase condition. The time stretching itself was performed in the two-second pause in between conditions with the command-line version of the Rubber Band time stretcher. This time stretcher separates onsets from harmonic content in the spectral domain in order to minimize audible artefacts (which is especially required for time-stretch factors of more than 15%). Time-stretch factors were minimized, as in each HRBM condition a musical excerpt was selected with an initial tempo as close as possible to the detected HR. To regulate the number of occurrences for each AT condition, a permutation of conditions was determined beforehand and followed by the experimenter.

Results

Effect of music

To check for differences in heart rate (HR) between the silent condition and the heart rate based music (HRBM) condition, a 2 × 2 × 2 mixed-design ANOVA with the condition (silent, HRBM) as within-subjects factor and gender (male, female) and music training (no training, training) as between-subjects factors was performed. The analysis revealed a significant main effect of the condition, $F(1, 22) = 8.44$, $p = .01$, $r = .53$[1], showing that participants' HR (BPM) was significantly higher in the HRBM condition ($M = 68.26$, $SE = 1.53$) compared to the silent condition ($M = 65.45$, $SE = 1.09$). There was neither a significant main effect of gender, $F(1, 22) = 0.31$, $p = .59$, $r = .12$, nor of musical training, $F(1, 22) = 2.00$, $p = .17$, $r = .29$. No interaction effect was found between the condition and gender (see Figure 2), $F(2, 44) = 3.01$, $p = .10$, $r = .35$, the

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[1] To indicate effect size, r is provided (instead of η^2) since Field (2009) advises reporting this indicator of effect size for mixed-design ANOVA tests. It is calculated as $r = \frac{\sqrt{F(1,\ df_R)}}{\sqrt{F(1,\ df_R) + df_r}}$ and benchmarks for small, medium and large effect sizes remain as usual (.10, .30, .50).

condition and musical training, *F*(2, 44) = 0.52, *p* = .48, *r* = .15, or between the condition, gender, and musical training, *F*(2, 44) = 0.50, *p* = .49, *r* = .15.

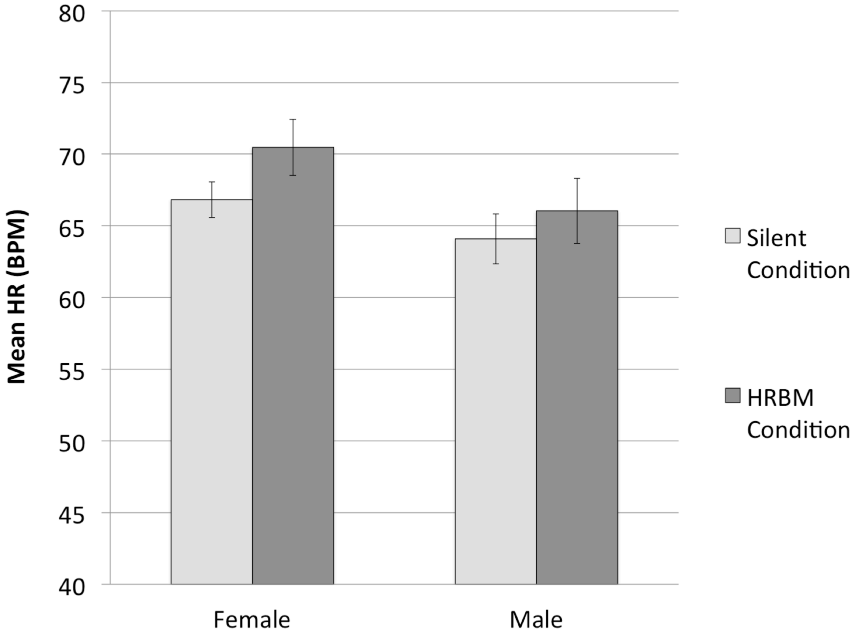

Figure 2. A comparison of the HR during the silent vs. HRBM condition for females and males. Data presented are mean ± *SE* (*N* = 32).

Effect of music tempo

Next, the effect of the different tempo modifications on participants' HR was checked, by comparison between the HRBM condition and the altered tempo (AT) condition. For each adaptation level, a 2 × 2 × 2 mixed-design ANOVA with the condition (HRBM, AT) as within-subjects factor and gender (male, female) and musical training (no training, training) as between-subjects factors was performed. Only for adaptations of -45% and -30%, was a significant main effect of the condition found (see Table 1 and Figure 3).

Table 1. Results of the main effect of condition for each tempo adaptation level. Mean HR values and standard errors (*M* (*SE*)) are reported, as well as test statistics (*F*), significance values (*p*) (* significant main effect), and effect sizes (*r*).

	HRBM condition	AT condition	*F*	*p*	*r*
Condition					
-45%	67.95 (1.59)	66.70 (1.55)	5.45	.03*	.41
-30%	67.26 (1.55)	65.23 (1.46)	6.26	.02*	.46
-15%	69.10 (1.58)	68.32 (1.49)	1.56	.22	.24
0%	66.53 (1.18)	66.87 (1.39)	0.51	.48	.16
+15%	66.95 (1.33)	67.25 (1.79)	0.09	.77	.05
+30%	67.07 (1.50)	67.69 (1.53)	0.73	.40	.18
+45%	67.91 (1.85)	68.73 (1.80)	0.32	.57	.11

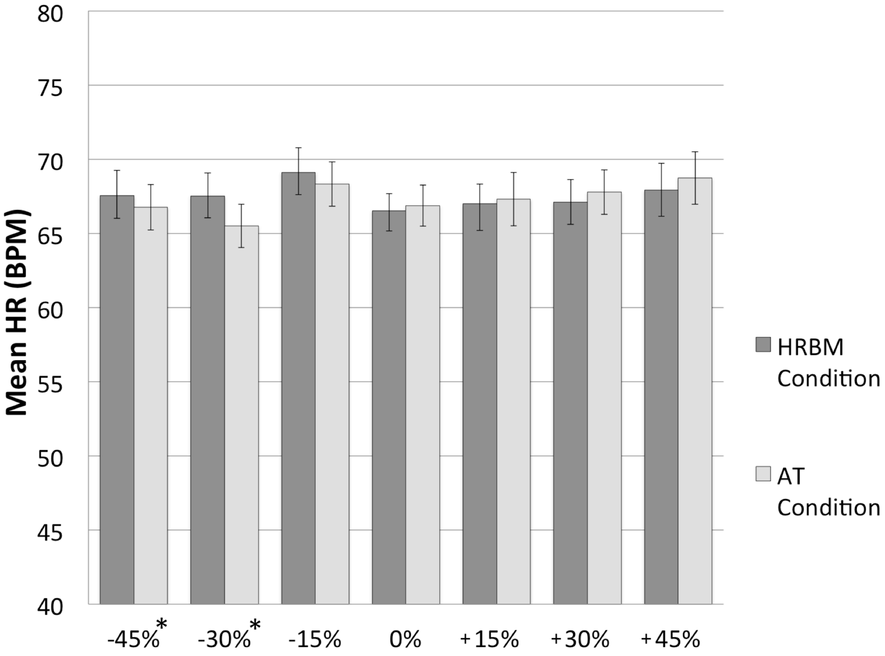

Figure 3. A comparison of HR during the HRBM condition vs. AT condition for all adaptation levels. Data presented are mean ± *SE* (*N* = 32) (* significant main effect).

There was no main effect for gender or musical training at any of the adaptation levels, nor were there any interaction effects between the condition and gender, between the condition and music training, or between the condition, gender, and music training (see Table 2).

Table 2. Results of main (gender, musical background) and interaction (condition, gender, musical background) effects. Test statistics (*F*), significance values (*p*), and effect sizes (*r*) are reported.

	-45%	-30%	-15%	0%	+15%	+30%	+45%
Gender							
F	1.92	1.58	0.83	1.58	0.92	1.11	3.12

p (r)	.18 (.26)	.22 (.25)	.37 (.18)	.22 (.27)	.35 (.18)	.30 (.21)	.09 (.32)
Condition x gender							
F							
p (r)	0.26	0.10	0.62	0.04	0.18	2.59	0.53
	.61 (.10)	.76 (.06)	.44 (.16)	.84 (.05)	.68 (.08)	.12 (.32)	.47 (.14)
Music training							
F	0.96	2.02	1.50	2.60	3.02	1.27	1.90
p (r)	.34 (.19)	.22 (.28)	.23 (.24)	.12 (.34)	.09 (.32)	.30 (.27)	.18 (.25)
Condition x music training							
F	0.0004	0.13	0.22	1.26	1.88	0.41	1.00
p (r)	.95 (.01)	.73 (.07)	.65 (.09)	.28 (.24)	.18 (.25)	.53 (.13)	.33 (.19)
Condition x gender x music training							
F	0.91	0.53	3.71	0.99	1.17	0.41	0.37
p (r)	.35 (.18)	.47 (.15)	.07 (.36)	.33 (.22)	.29 (.20)	.53 (.13)	.55 (.11)

Effect of music preference

Regarding music preference, 26.34% of the stimuli received low ratings, 18.75% were given medium ones, and 54.91% was regarded as highly preferred. To check for a possible effect of preference, mean HR in the HRBM condition for music with low, medium, and high preference scores were compared. A repeated-measures ANOVA revealed no significant effect of music preference on HR, *F*(2, 24) = 2.047, *p* = .151, *r* = .38.

Discussion

Here we investigated the effect of music tempo on human heart rate during a controlled passive music listening task. Additionally, the effect of listening to music (by comparison to silence) on heart rate was examined. With heart rate measurements of 32 participants, the experiment showed that pulses increased significantly in the music condition compared to the silent one. By comparison with the initial (HRBM) music condition, it was also shown that substantial decreases of tempo (-45% and -30%) significantly reduced participants' heart rates. However, heart rate did not respond to less considerable drops (-15%) or increases (+15%, +30%, +45%) in the tempo of the non-vocal, ambient stimuli. Factors such as gender, musical preference or training did not have significance for the results of the experiment.

Thus, overall, we observed an arousal effect caused by the music. In addition, a regulating effect of music tempo was identified: slower tempi induced lower heart rates, but never dropping below the initial heart rate, which was measured in silence. Our results concerning the arousal effect of music as opposed to silence correspond with previous research. Bernardi et al. (2006), for instance, found more evidence of relaxation during intermissions or pauses than in musical conditions. In a study by Lingham and Theorell (2009), it was shown that self-selected stimulating music resulted in heart rate increases (and increased emotional arousal), but also that self-selected relaxing music induced small but nonetheless significant increases in heart rate (alongside emotional arousal and calm).

It has been speculated that passive music listening induces arousal resulting from focused attention, similar to the effect of reading silently (Bernardi et al., 2000; Haas, Distenfeld, & Axen, 1986). In the case of silence, arousal is released and the subject is left in a state of relaxation. Also, in neuroscientific research it has been suggested that the initial autonomic and cardiovascular responses to music reflect an arousal response. fMRI and PET studies have demonstrated activation or deactivation of multiple brain regions during music stimulation, including areas of central autonomic control (Spyer, 1999), such as the ventral medial prefrontal cortex, anterior cingulate cortex, insula, and amygdala, depending on the level of arousal, which is in turn associated with a music excerpt (Altenmuller, Schurmann, Lim, & Parlitz; Blood & Zatorre, 2001; Koelsch, Fritz, Cramon, Müller, & Friederici, 2006).

There was no additional arousal effect of increased music tempo, and only a regulatory effect of substantial tempo decreases was found, whereas previous research has often indicated that passive listening to music could modify heart rate proportionally to the tempo of the stimuli (Bernardi et al., 2009; Bernardi, Porta, & Sleight, 2006; Chlan, 1998; Iwanaga, Kobayashi, & Kawasaki, 2005; Krumhansl, 1997). This is likely due to the methodological choices made in this particular study compared to those made in past investigations. Previously, the impact of different musical stimuli was examined in contrast to silence and to stimuli with unsystematically reduced or elevated tempo ranges, simultaneously encompassing different music styles

(Bernardi, Porta, & Sleight, 2006; Chlan, 1998; Hilz et al., 2014; Iwanaga, Kobayashi, & Kawasaki, 2005; Krumhansl, 1997). In another example of previous research, tempo changes (increases/decreases of 10%) and music stimuli were controlled, although without reference to the initial heart rate (Nomura, Yoshimura, & Kurosawa, 2003). Thus in that study it remained unclear whether arousal or relaxation mechanisms (or both) were responsible for the obtained effects

By presenting a music stimulus only after a period of silence, and subsequently repeating the very same music at adjusted tempi, we applied a novel approach here. Consequently, within a given pair of stimuli all of the musical parameters remained constant: the tempo alone was varied systematically, allowing us to draw conclusions about it exclusively. Most preceding research has regarded only up to two conditions (silence and music or slow and fast music) instead of three (silence, music, and music with an increased or decreased tempo), as was the case here. Besides, since the current study confirmed that music listening induces arousal in and of itself, likely to a greater extent than the arousal effect of tempo change. Therefore, rather than being caused by the tempo of the music, it seems plausible that the arousal effects of fast music (as observed by others), could be largely or even exclusively put down to the mere introduction of a music stimulus after a period of silence (Roy, Mailhot, Gosselin, Paquette, & Peretz, 2009); or to the regulatory effects of the contrast between fast and slow musical stimuli.

Thus, our results seem to contradict the idea of the relaxing influence of music listening on heart rate. Although previous research has often supported this notion (e.g., Bernardi, Porta, & Sleight, 2006; Bernardi et al., 2009; Chlan, 1998; Iwanaga, Kobayashi, & Kawasaki; 2005; Nomura, Yoshimura, & Kurosawa, 2003; Saperston, 1995) others have disputed such an effect. Research by Zimny and Weidenfeller (1969) did not detect any change in heart rate following listening to calm music, whereas Lingham and Theorell (2009) revealed that not only listening to self-selected stimulating music can increase heart rate , but that also the same applies to self-selected calm music. As discussed above, that our results concerning the effects of music tempo on heart rate are inconsistent with a number of previous studies can largely be traced back to methodological issues, such as the disentangling of music and music tempo while controlling for other musical parameters. However, they do not necessarily contradict the general belief that certain music can lessen stress and anxiety (Lee, Henderson, & Shum, 2004; Szmedra & Bacharach, 1998; Trappe, 2012; White, 1999, 2000).

In therapeutic settings, music intervention is often employed to maximize the attempt to promote comfort and relaxation, as well as to reduce or control distress. It should be noted that relaxation might also concern other psychophysiological parameters; slow music, for instance, has been shown to lead to decreases in blood pressure and respiratory rate (Hilz et al., 2014; Knight & Rickard, 2001; Möckel et al., 1994). Besides, our findings apply to a passive listening setting, during which the participants were already in a relaxed state. Other contexts, where psychophysiological properties are might be measured in more active situations (e.g., during exercise or sports activities), might imply quite a different relationship between music and heart rate. For instance, at any given level of physical exercise, music (particularly at faster tempi) has been shown to lower the heart rate, as well as the perceived level of exertion, through its distracting effect (Szabo, Small, & Leigh, 1999). Also in other contexts where the initial heart rate is substantially higher than when at rest (e.g., in a stressful situation), one might expect the relaxing effects of music to be more pronounced.

Although we did not discover any relaxation effect of decreased tempo, we did find that substantial decreases in tempo regulated the arousal effect of the music. As described above, previous research indicated that slow music might induce relaxation in situations where the initial measured heart rate is higher than in rest. Therefore, it is plausible that any effects observed in a passive listening situation are comparatively reduced, because in rest, heart rates tend to be low and therefore less susceptible to further decreases. As musical tempo has been shown to affect respiratory rate, which could also be related to heart rate (Hilz et al., 2014; Knight & Rickard, 2001; Möckel et al., 1994), the regulatory effect of reductions in tempo might also be a function of lower respiration rates linked with heart rate decreases. In addition, since passive music listening is believed to induce arousal on account of the focused attention that it inheres

(Bernardi et al., 2000; Haas, Distenfeld, & Axen, 1986), music with a substantially slow tempo might be rather uninteresting to listen to. As such, the focus of listeners' attention might have drifted away from the stimuli, resulting in a discontinuation of any implicit arousal effects.

The results of this study only apply to a certain tempo spectrum (tempo of heart rate in rest -/+45%). However, deviation from this spectrum (especially when further increasing music tempo, since larger decreases would generally result in rather unnatural sounding stimuli) might yield different results. In order to test this in future research, different methodological choices should be made, because there is a limit to the extent to which an audio excerpt can be time stretched without adversely affecting the perceptible quality of the recording. In this study, the quality of the musical stimuli was controlled to ensure that they were perceived to 'sound natural', even after the implementation of large tempo decreases/increases. However, in most cases, it is clear that excessive time stretching can pose a threat to ecological validity. Beyond time stretching, other methodological choices might also differ in future research. However, in controlling for other musical parameters, a notable advantage of this approach is that tonal frequency is kept constant as the tempo increases/decreases. As such, the total energy level is affected as little as possible. In order to further expand the tempo spectrum available to experimenters, whilst maintaining control over all of the musical parameters, electronically produced music tailored to the experiment would probably be most suitable, as it can tolerate substantial time stretching.

In this particular study, a music-to-heart rate alignment strategy was implemented as a baseline; individuals' heart rates were taken in silence, and used as a reference for selecting the tempo of the music in the first condition (Bason & Celler, 1972; Nomura, Yoshimura, & Kurosawa, 2003; Saperston, 1995). As such, music tempo reflected their personal physiological arousal levels, and this has been shown to be preferable to participants in other studies (Iwanaga, 1995a, 1995b; Karageorghis, Jones, & Low, 2006). This alignment strategy is rooted in entrainment theory (Thaut, 2008), but it also diverts from it: heart rate and music tempo can be regarded as interacting oscillating systems, set off with the same period, but unveiling a unidirectional propensity of one of these systems to re-entrain to bidirectional deviations of the other. It should be noted that this alignment strategy was only implemented at the start of the experiment in order to select the tempo of the initial musical stimuli. Besides, since heart rate increased significantly after the introduction of these stimuli, no heart rate-to-music alignment was uncovered, indicating that human heart rates do not entrain to musical beats.

Neither musical preference nor training was proven to impact participants' heart rate, a finding that is in line with previous cardiovascular research on music (Bernardi, Porta, & Sleight, 2006). Also, the gender of the participants did not have a significant main effect. Yet, there was some indication that arousal effects of music were more pronounced for female participants than for male subjects. It has been suggested that gender-based differences in psychophysiological responses to music could be influenced by hormonal status (Nater, Abbruzzese, Krebs, & Ehlert, 2006). However, since our results regarding this effect were not significant, and as there is very little in the literature to describe gender differences between women and men regarding cardiac autonomic responses to music, this is a matter of some speculation, which would benefit from further study.

That heart rates did not respond to smaller drops in tempo might be put down to the relatively high initial heart rate in the -15% adaptation level, as compared to that of other levels. However, this is debatable, and was probably caused by chance (especially given the randomisation of the order in which excerpts were played). Conversely however, this raises the question of whether a lower starting heart rate (such as those in the silent condition of the other adaptation levels), might have been significantly impacted by tempo decreases of -15% as well, Now, the majority of the participants were presented with a -15% modification at a point where their initial heart rate was relatively high, which was therefore succeeded by corresponding high tempi, and thus conceivably increasing heart rate as well. As such, possible effects of -15% tempo drops might have been cancelled out. This issue could be further elaborated on in future research.

Furthermore, it would be interesting to know whether the observed effect is maintained over longer time spans and if it can be replicated in older age groups. In the current study, the test group consisted of healthy young adults. However, as arousal responses may change with age (Tsai, Levenson, & Carstensen, 2000), different autonomic cardiovascular responses in young and older healthy persons could occur (Hilz et al., 2014). Another point that would be interesting to pursue further is whether different music styles (with fixed tempi) impact heart rate differently. Here, a homogeneous dataset of ambient, non-vocal musical stimuli with low to no appearances in popular music charts was employed in order to control for spectral features (Gingras, Marin, & Fitch, 2014), music style (Bernardi, Porta, & Sleight, 2006; Chlan, 1998), and familiarity (Fontaine & Schwalm, 1979). Yet, it should be taken into account that some of these items have been shown to influence arousal ratings, and thus might also affect heart rate (e.g., spectral flux, spectral entropy), while for others, a more direct link has already been demonstrated (e.g., familiar music and heart rate increases).

Conclusion

We presented evidence that when people listen passively to non-vocal, ambient music, their heart rate increases, while subsequently slowing down music could regulate the arousal effect of listening to music. In contrast to what has been suggested previously, musical tempo did not enhance heart rate. These findings contribute to thinking about how we can use music in everyday activities, demonstrating an arousal effect of music and a regulatory effect of music tempo. They also further expand the discussion concerning the therapeutic power of music. Furthermore, these results are also valuable in the sports and exercise domain, as the ergogenic and regulatory effects of music are exploited not only during, but also before and even after exercise.

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