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The Influence of Unwanted Entrainment with Low Frequencies in Techno Music on Performance and Mental Exhaustion.

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Abstract

To better understand the characteristics and reported mental exhaustion of individuals who live near a festival terrain, we investigated how low frequencies in techno music influence performance and mental exhaustion. As techno music has become one of the most beloved forms of music for young individuals, sound pollution of this music is a prominent problem in society. This study elaborates upon the concept of entrainment and focused on both low-demand and high-demand cognitive tasks. We hypothesized that (a) listening to music would affect performance on cognitive tasks, (b) listening to a dominant pulse would affect performing on cognitive tasks more than listening to music without a dominant pulse, and (c) that trying to suppress entrainment to music with a dominant pulse would elicit more mental exhaustion than suppressing music without a dominant pulse. Cognitive performance was measured with the Stroop Task and Modular Arithmetic Task. Entrainment was measured with the Mental Entrainment Questionnaire (MEQ) and heart rate (HR). Mental exhaustion was measured with the Multidimensional Fatigue Inventory (MFI). Participants (N=36) were each tested two times on the cognitive tasks, once without music and once while listening to techno music. The musical stimuli were manipulated to create three distinct musical conditions (I) Bass only (i.e., pulse condition), (II) Beat only (i.e., no pulse), (III) Normal (i.e., combined pulse and beat elements). RT and accuracy on the different tasks were compared for the different musical conditions. Strong effects of entrainment and mental exhaustion were found in the conditions with a dominant pulse. These findings indicate an effect of suppressing unwanted entrainment on both low-demand and high-demand cognitive performance and mental exhaustion. Implication of this study points to a need for a reduction of low-frequencies at techno festivals as individuals living in the vicinity of a festival, are negatively impacted by unwanted entrainment.

Keywords: Entrainment, Mental exhaustion, Stroop Task, Modular Arithmetic Task, Techno, Pulse, Beat, Heart rate, low-demand, high-demand.

1. Introduction

In western society, techno music at dance festivals is one of the most beloved forms of music for young individuals. Techno is a form of music that emerged in the United States during the mid-to-late 1980s. This form of music is typically characterized by repetitive instrumental music in common time (4/4), with a mark of a bass drum on each quarter note, a backbeat on the second or fourth beat, and an open hi-hat sounding every second eight note (Hopkins, 1996). The low frequencies by the bass drum are usually dominant and prominent in techno music and elicit a trance feeling. Thanks to these traits, and combined to the looping rhythm, young individuals are invited and activated to dance. People attend these festivals for pleasure and relaxation, and this may be due to the effects of techno music on the brain. To understand these effects on the brain, we must first understand the different ways in which sound can affect humans.

Most of the sounds we hear in our daily life are accidental, and often unpleasant (e.g., traffic noise). We stand on street corners shouting and talking over noise and pretending that the noise isn't there. As sounds surround us all the time, this has resulted in us becoming habituated to suppressing these sounds. The habit of suppressing these unwanted and unpleasant sounds has caused our relationship to it to become largely unconscious (Treasure, 2017). There are four different ways in which sound is affecting us all the time. Firstly, sound affects us physiologically. The ringing of an alarm bell can affect hormones secretion, breathing, and heart rate by activating flight-fight systems. However, not only unpleasant sounds can affect an individual physiologically. The sounds of an ocean (which has a frequency of roughly twelve cycles a minute) can have a soothing and relaxing effect due to it being around the same frequency as breathing of a resting human, and its association with being at rest. Secondly, sound affects us psychologically. Music is the most powerful form of sound that affects our emotional state. For example, previous research has shown that major mode music can induce happiness in individuals, and minor mode music can induce sadness (Yaheda, 2011). However, natural sounds can also affect us on psychological level. For instance, bird song makes us feel relaxed and gives us a feeling of safety. Evolution has taught us that when birds are singing, we are safe (Treasure, 2017). The moment the birds stop singing, is the moment something bad is about to happen. Thirdly, sound can affect us cognitively. An individual's performance is dependent on the surrounding sounds. It's impossible to understand two people talking at the same time. Humans have a small bandwidth for processing auditory input, so it is very difficult to be maximally productive when you are in a noisy environment (e.g., a workplace). Also, traffic noise for instance can cause people to appraise soundscapes as more chaotic and can induce feelings of unrest (Bosch & Andringa, 2014). Lastly, sound can affect us behaviorally. Individuals tend to move away from unpleasant sounds, and gravitate towards pleasant sounds. Research has shown that drivers who listen to fast paced music while driving, are more likely to exceed the speed limitations on the road (Brodksy, 2001). If someone were to put an unpleasant sound like a jackhammer on and leave it on for a couple of hours, windows would be closed and most people in the vicinity would be gone. At the basic level, we will move away from unpleasant sounds when we can. This principle can also be seen in many retail stores with loud, pumping, irrelevant, or inappropriate music (e.g., clothing stores or sneaker stores) (Treasure, 2013). Most of us will probably know an example from personal experience.

With the effects of sound on individuals stated above in mind, it’s clear that techno music influences the brain. Listening to techno-music induces changes in neurotransmitters, peptides and hormonal reactions, related to mental state and emotional involvement (Gerra et al., 1998). Previous research has shown that major music (e.g. Mozart’s Allegro con spirit, K448, which induces happiness) reduces stress and cortisol levels more than minor music (e.g. Beethoven’s für Elise, which induces sadness (Yaheda, 2011)). Furthermore, it was found that up-tempo techno music increases stress hormones including cortisol, while lower tempo music like classical music reduces the cortisol level of individuals (Gerra et al., 1998; Suda et al., 2007). There seems to be a contradiction here, because why would people attend festivals for pleasure and relaxation, while stress hormones like cortisol increase? This contradiction might be explained by personal affection to the type of music, and the context of listening to music. However, another explanation to this incongruence could be the concept of entrainment.

Entrainment refers to the synchronization of organisms to an external perceived rhythm, such as foot tapping in human music, but can also be more discreetly like two persons walking next to each other in synchronization (Clayton, Sager, & Will, 2005). Entrainment is a good thing when it happens at the appropriate time. Dance clubs have become a significant part of the lives of individuals due to the common practice of having enhanced music with loud low-frequency beats (e.g. the so-called bass drum), that encourages individuals to move on the beat and synchronize with the audience. It is suggested that besides sound, physically feeling the bass, elicits entrainment. Furthermore, low frequencies may affect the vestibular system, sense of motion, and engages motor areas in the brain (Chen, Penhune & Zatorre, 2008). It has been suggested by Burger, Thomspon, Saarikallio, Luck and Toiviainen (2010), that music with a clear rhythmical structure in the low frequency range encourages participants to move and frequencies which are not so clear tend to prompt locomotion. It could be argued that individuals at music festivals want to achieve a form of entrainment with the music, and with the other people attending. We suggest that individuals living near a festival terrain however, are pulled in an unwanted form of entrainment and have feelings of exhaustion and stress, caused by the mental effort of blocking the unwanted sounds. The strong effects of entrainment in techno music could be a possible explanation for rising levels of stress hormones for people who are not fond of this kind of music and want to suppress the effects of entrainment (Gerra et al., 1998).

While research suggests that lower frequency sounds (i.e., the bass in music) encourage participants to move, most research did not focus on these low frequencies, but focused on other components of music such as major and minor modes, or made use of classic musical stimuli instead (Khalfa, Roy, Rainville, Dalla Bella & Peretz, 2008). Music is a complex sound structure and has a lot of difficult components to grasp, so one must try to break the concept of music in smaller components to use it in research. While previous research focused on tempo, or rhythm, as one construct in entrainment research, this research argues for a clear distinction between the concepts of *pulse* and *beat* in tempo and rhythm. Beat and pulse structures can be regarded as the basic metrical structure in music from which more complex structures, such as rhythm, emerge (Burger et al., 2010). A beat in musical context is a unit of time with the same sounds for each of the beats. A good example would be ticking on a table with each beat the same as the beat before. Finding the first beat when all the beats sound the same is a very difficult task. In contrast, the pulse gives life to a beat and music as a whole. By accenting a note and making a difference between strong and weak beats, a new rhythmical pattern is made, which gives music the feeling of wanting to move. In most music, the pulse is given by the lower frequency sounds (i.e. bass drum, lower percussion and bass) while the higher frequency sounds give music the beat (i.e. hi-hat of a drumkit and guitars) (Hove, Marie, Bruce, & Trainor, 2014). The frequently heard terms in music like ‘Soul’, ‘Groove’, ‘Locking’, or ‘In the Pocket’, are all referring to this pulse and how the pulse gives life to music and sound (i.e. the feeling of entrainment). Elaborating on the subjects mentioned above, one would expect the lower frequencies to elicit entrainment due to it distributing a clear pulse. In contrast, music without a pulse would not elicit a strong form of entrainment.

This study intended to verify whether the pulse indeed elicits entrainment and mental exhaustion when an individual tries to suppress unwanted entrainment, while the absence of a clear pulse would not elicit entrainment and exhaustion. Therefore, we examined the differences of entrainment, performance and exhaustion for pulse and beat in techno music to replicate the previously stated scenario of individuals who live near a festival terrain and are pulled in an unwanted form of entrainment by music while doing other tasks (e.g., working, reading, watching tv, etc.). We wanted to make a distinction between unwanted entrainment during low-demand cognitive tasks and high-demand cognitive tasks to research if there would be differences in performance, or if both low and high-demand tasks would be inhibited.

Elaborating on the above, this study intended to research if suppressing unwanted entrainment with low frequencies elicits mental exhaustion and influences performance on cognitive tasks. We expected that (a) participants would have an overall lower performance while performing on cognitive tasks while hearing music, and (b) we also expected individuals to have a higher decline in performance when they were performing while hearing a dominant pulse in contrary to performing while hearing no dominant musical pulse. Lastly, it was expected (c) that suppressing entrainment to music with a dominant pulse would cost more cognitive capacity of the individual and thus elicit more mental exhaustion than suppressing music without a dominant pulse.

2. Methods

2.1 Participants and design

Thirty-six participants (15 women, and 21 men; age = 23.8), took part in this experiment. Participants were randomly assigned to one of the three musical conditions and were asked about possible colorblindness before starting the experiment to make sure this could not influence the Stroop task results. No participants were excluded from the analyses. The experiment was performed in one of the drum basements of Parnassos, the culture center of Utrecht University. A mixed design was used in which differences (within-subjects) in performance on the modular arithmetic task and Stroop test between the counterbalanced *block I* (no musical stimuli) and experimental *block II* were compared for each individual, and the performance scores between the three musical conditions were compared (between-subjects).

2.2 Materials

An external speaker setup (*Logitech X-530 5.1 Speaker System*) was used for the musical stimuli. The song “One” by Swedish House Mafia (in the rendition of Pete Thong and the

Heritage Orchestra) was used and manipulated in *Audacity* (*ver. 2.2.0*). This rendition has a fixed tempo of 126 beats per minute, and was manipulated to a perfect continuous loop of a rhythmical structure. Following the creation of this perfect loop, three different musical stimuli were created. Firstly, the Bass-only stimuli was created by cutting off all higher frequencies and boosting the lower frequencies. This condition only consisted of pulse characteristics. Secondly, the Beat-only condition was created by cutting off all lower frequencies, and turning off the subwoofer during testing. This condition only consisted of beat characteristics. Finally, the Normal condition, was not manipulated so it could feature both the pulse and beat elements.

Heart rate (HR) was measured by using a *Fitbit Charge 2+*. By creating an app for heart measurement, HR data for each participant during the experiment was collected on a server and coded for time. By using a *R* script, it was possible to collect the data during the two parts of the experiment for each individual participant and compare those to the HR of other participants in the other conditions (*Appendix*).

2.1 Procedure

The participants were asked to perform different mental tasks while being exposed to the different sound conditions. Upon arrival, participants were asked to wear the Fitbit to make sure the HR would drop to a resting state. After being seated, participants were asked to fill in some demographics questions after which the first experiment block could start. Depending on their number, participants started with the musical stimuli, or would start without music. This was done for counterbalancing the experimental design. In an experiment designed in *Open Sesame (version 3.1.9.)*, participants started with the Stroop Task. After the practice trails, the experiment began with 96 Stroop trials. Following this task, participants got instructions for the Modular Arithmetic Task, and had to perform on 36 trials variating on difficulty level. After finishing the last trial, the participants were asked to fill in the Mental Entrainment Questionnaire (MEQ). After performing on the tasks with a musical stimulus present, participants were also asked to fill in the Multidimensional Fatigue Inventory (MFI). After a short resting period, participants continued with the second part of the experiment. This second part consisted of the same tasks and number of trials, only the presence of the musical stimuli would differ (i.e. If a participant started with a musical stimulus, the second part was without music). After the second block, participants were asked to score the MEQ for a second time. Finally, they were asked to answer questions about the musical stimulus and were debriefed about the experiment.

2.2 Task

The Stroop task consists of two blocks of 96 trials. Participants had to name the color of the presented word, while ignoring the actual meaning of the words. The task consists of congruent, incongruent and neutral combinations of colors and meaning. The colors yellow, blue and red were used for this task and corresponded with the 'n', 'b' and 'v' keys respectively. The Dutch letter combinations for 'red', 'blue', 'yellow' and a neutral 'xxxx' were used for the words. Participants were asked to maximize both speed and accuracy on the trials. During this task, both accuracy and reaction times (RT) on performance were measured.

The modular Arithmetic task consists of two blocks of 36 modular arithmetic problems, such as 34≡18 [mod 4]. Before starting the task, participants were explained how to solve the trials. By subtracting the second number from the first (34-18 = 16), and dividing the difference by the third 'mod' number (16/4 = 4). If this division resulted in a whole number (in this case 4), the statement is considered *true*; otherwise, *false*. It was up to the participants to indicate whether the statements were true or false, by pressing the 'W' or 'O' keys. The participants were instructed to maximize speed and accuracy. The mathematical problems variated on three difficulty levels, low, medium and high in working memory demands. These levels of difficulty were created by manipulating whether solving the problems required a single-digit no-borrow subtraction operation (low-demand; e.g., 9≡2 [mod 7]), a double-digit no-borrow subtraction operation (medium-demand; e.g., 47≡15 [mod 7]), or a double-digit borrow subtraction operation (high-demand; e.g., 55≡27 [mod 9]). Every block included 12 low-demand problems, 12 medium-demand problems, and 12 high-demand problems. The statements within each block were presented in random order, and each *true* statement had a *false* counterpart within the same block (created by only changing the 'mod' number) (Beilock et al., 2004; Boere et al., 2016). On each trial, both accuracy and RT were measured.

To measure reported Entrainment during the presence of the musical stimuli, participants were asked to fill out the Musical Entrainment Questionnaire (MEQ). This questionnaire consists of 20 items (Labbé & Grandjean, 2014) scaled from 0 to 100. The MEQ has items regarding the listener's inclination to move, the extent to which a listener is aroused by the music, and the extent to which a listener can feel his own body autonomic activity change. Examples for these items are *'To what extent did you feel like beating time, tempo or rhythm'* and '*To what extent did you feel your own bodily rhythms change'*.

Finally, the Multidimensional Fatigue Inventory (MFI) was used. The MFI is a 20-item self-report inventory designed and validated by Smets et al., 1996, and measures five different dimensions of fatigue: general fatigue (e.g., *'I feel tired')*, mental fatigue (e.g., '*When I am doing something, I can keep my thoughts on it'*), physical fatigue (e.g., '*Physically I can take on a lot'*), reduced activity (e.g., *'I feel very active*'), and reduced motivation (e.g., '*I feel like doing all sort of nice things*'. Each dimension consists of four items. The score on each item ranges from 1 (no fatigue) to 5 (very fatigued). The score in each dimension ranges from 4 (best) to 20 (worst) (Lou, Kearns, Oken, Sexton & Nutt, 2001).

3. Data Analysis

As previously stated, we expected that (a) participants would have an overall lower performance while performing on cognitive tasks while hearing music, (b) Individuals who performed while hearing a dominant pulse would have a higher decline in performance compared to individuals who perform without a dominant pulse. Lastly, we expected (c) that suppressing entrainment to music with a dominant pulse would cost more cognitive capacity of the individual and thus elicit more mental exhaustion than suppressing music without a dominant pulse.

After extracting the HR data of the *Fitbit Charge 2+* from the application with the *R* script (as described in the *Appendix)*, the data was coded and sorted for each participant and added to the performance data of each block. No outliers were found or had to be removed.

We first examined the effect of the different musical conditions on HR both within subject (music: absent vs music present), as between subjects of the different conditions (condition: Bass vs. Normal vs. Beat). These analyses determined whether the presence of music influenced the HR of individuals while performing, and was used as an indicator of entrainment.

Next, following literature for RT analyses (Whelan, 2008), outliers were removed from the performance data. Only the RT's for the correctly answered trials in the Stroop Task and Modular Arithmetic Task (MA) were used, and RT's that deviated more than 3 standard deviations from the mean were considered outliers and were discarded along with their corresponding accuracy scores. This resulted in a removal of 349 trials (5.05% of total) for the Stroop Task, and a removal of 52 trials (2.01% of total) for the MA. To examine if there were differences in performance between the conditions and if there were differences for presence of musical stimuli, RT and accuracy were compared for the Stroop Task, and RT on the different difficulty levels were compared for the MA. As the RT on the Stroop Task was not normally distributed, nonparametric analysis methods had to be used.

The MEQ scores for self-reported entrainment were only compared between the different musical conditions (Bass vs Normal vs Beat). As expected, participants did not report any feelings of entrainment when the musical stimulus was absent, so these MEQ scores were not needed for analyses and were only used in this experiment for control of entrainment. The MEQ analysis tested if the reported entrainment was higher in the pulse conditions compared to the beat condition. Finally, after the scores of on the MFI were rescored and sorted by dimension following the procedure suggested by Smets and colleagues (1994), the analysis tested whether there were differences between the musical conditions for mental exhaustion after performing on the cognitive tasks, and if reported mental exhaustion was higher for the pulse conditions.

4. Results

4.1 Heart rate

To examine the effect of the musical stimuli on the HR of participants during the two parts of the experiment, a paired *t*-test was conducted (music: present vs. music absent). The paired *t*-test was used to compare the average HR during the presence of a musical stimulus (*M* = 79.93, *SD* = 8.23) to the average HR while the musical stimulus was absent (*M* = 75.81, *SD* = 6.78). On average the HR of participants was 4.12 beats per minute higher when performing while being subjected to the musical stimuli. This difference was statistically significant, *t(*35) = 4.296, *p*< .001. Cohen's *d* for this test was .55, which can be described as a large effect.

Since the *t*-test for (music: present vs. absent) revealed a main effect of music, a one-way between group ANOVA (condition: Bass vs. Normal vs. Beat) was used to investigate the effects of the three different musical stimuli on HR. However, no significant differences were found, *F*(2, 33) = .135, *p* =.87, indicating that although performing while hearing music can have an effect on the HR of an individual, no significant differences were found between the three music conditions.

4.2 Stroop Task

To test for a within-subject effect of music on Stroop RT performance, a Wilcoxen Signed Rank test was performed (music: present vs. absent). This analysis indicated that music had a significantly negative effect on the RT performance of participants, *T*=541.0, *z*=3.268 (corrected for ties), *N*-Ties = 36, *p*=.001, two tailed. Twenty-six participants had a significantly higher RT during the experiment with musical stimuli (Sum of Ranks = 541.0), whilst only ten participants were ranked with lower RT's (Sum of Ranks = 125.0). No ties were excluded from the analyses. This effect can be considered large, *r*=.54

A Kruskal Wallis ANOVA (condition: Bass vs. Normal vs. Beat) indicated that there was a statistically significant difference of RT between the Normal (*Mean Rank* = 19.25), the Bass (*Mean Rank* = 23.58) and the Beat (*Mean Rank* = 12.67) conditions, (corrected for ties) = 6.53, *df* = 2, *N* = 36, *p* = .038, η^2 = .19. A Mann-Whitney *U* test comparing the Bass condition to the Beat condition, indicated that only participants in the Bass condition (*Mean Rank* = 16.33, *n* = 12) had significantly higher RT's than those in the Beat condition (*Mean Rank* = 8,67, *n* = 12), *U* = 26.0, *z* = -2.656 (corrected for ties), *p*=.007, for a corrected Bonferroni alpha. This effect is considered large, *r=.54.* No significant differences for RT were found between the other conditions.

Next, to test for within-subjects effect of type of music on RT performance, Wilcoxen Signed Rank tests were performed for each of the conditions (music absent vs. Bass condition, music absent vs. Normal, and music absent vs. Beat condition). A significant difference was found for the Bass condition (i.e., compared to the without music RT scores of the corresponding participants), *T*=6.0, *z*=2.559(corrected for ties), *N*-Ties= 36, *p*=.010, two tailed. A significant difference was also found for the Normal condition compared to the without music RT scores of the corresponding participants, *T*=9.0, *z*=2.538 (corrected for ties), *N*-Ties=36, *p*=.019, two tailed. No significant differences were found for the Beat condition, indicating that participants had a significantly lower performance on the RT of the Stroop task while performing during music with the low frequency pulse.

To test for a difference on accuracy on the Stroop Task, a paired *t*-test (music: present vs. absent) was used to test for a difference on accuracy for performing while listening to the musical stimuli ($M = 91.94$, $SD = 2.64$), and accuracy without musical stimuli ($M = 93.86$, $SD = 1.68$). On average the accuracy score was 1.92 points lower for performance while listening to music. While this difference seems small, it was significant, $t(35) = 4.37$, $p < .001$. Cohen’s for this test was .89, which can be described as a large effect.

Since the *t*-test for (music: present vs. absent) revealed a main effect of music, a one-way between group ANOVA was used to investigate the effects of the three different musical stimuli on the accuracy score for the Stroop Task (condition: Bass vs. Normal vs. Beat). Only a significant difference was found between the Beat and Normal music conditions, $F(2, 33) = 11.48$, $p < .001$, indicating a decline in accuracy performance while hearing music with the combination of both pulse and beat. No significant differences were found between the other conditions. Post hoc analyses with Tukey’s HSD (using an α of .05) revealed that participants who performed while hearing the Normal stimulus ($M = 89.92$, $SD = 2.35$) scored significantly lower on accuracy than participants from the Beat condition ($M = 94.00$, $SD = 1.65$). However, no significant differences were found for the Bass condition compared to the Normal and Beat conditions ($M = 91.92$, $SD = 2.19$).

Finally, we tested for within-subject differences on accuracy on the Stroop Task for each of the conditions compared to the accuracy during absence of a musical stimulus (music absent vs. Bass condition, music absent vs. Normal, and music absent vs. Beat condition). A significant difference was found between the Normal (M=89.9, SD=2.35) and without music (M=93.5, SD=1.68), $t(11) = 3.46$, p=.001. A significant difference was also found between the Bass (M=91.9, SD=2.19) compared to the without music condition (M=94.1, SD=1.44), $t(11)$ =3.46, p=.005. No significant differences for accuracy were found for the Beat condition compared to the without music condition.

4.3 Modular Arithmetic Task

To test for a within-subject effect of music on the RT of the MA, a 2(music: present vs. absent) x 3(difficulty: low-demand vs. medium demand vs. high-demand) two-way analysis of variance

(ANOVA) was used to compare the RT's for each difficulty in presence of a musical stimulus, and in absence of a musical stimulus. Mauchly's test indicated that the sphericity assumption was violated. Consequently, the Greenhouse-Geisser correction was employed. The two-way ANOVA revealed a main effect of music, *F*(1,35)=25.55, *p*<.001, partial η^2 =.42, indicating there was a significant difference in performance when music was present compared to when music was absent. The ANOVA revealed a main effect of difficulty, *F*(1.34, 47.02)=384.36, *p*<.001, partial η^2 =.92, indicating participants had a higher RT on the high-demand tasks, compared to the medium- and low-demand tasks. An interaction effect was found for music x difficulty, *F*(1.52, 53.08)=11.73, *p*<.001, partial η^2 =.25. Pairwise comparisons corrected with Bonferroni revealed a significant difference for medium-demand tasks. On average participants had a higher RT when exposed to a musical stimulus (*M* = 4648.82, *SD* = 1313.58) compared to the testing without a musical stimulus (*M* = 3797.28, *SD* = 807.48), *t(*35) =3.49, *p*=.001. A significant difference was also found for high-demand tasks. On average participants had a higher RT when exposed to a musical stimulus (*M* = 7669.16, *SD* = 2044.07) compared to the testing without a musical stimulus (*M* = 6019.82, *SD* = 1469.77), *t(*35) = 4.65, *p*< .001. Effect sizes for these comparisons were *d*=.80 and *d*=.93 respectively. Both effects can be interpreted as large effects. No significant differences were found for the low-demand tasks.

A 3(difficulty: low-demand vs. medium demand vs. high-demand) x 3(condition: Bass vs. Beat vs. Normal) repeated measures analysis of variance (ANOVA) was used to compare the RT's for difficulty and condition. Mauchly's test indicated that the sphericity assumption was violated. Consequently, the Greenhouse-Geisser correction was employed. The repeated ANOVA revealed a main effect of difficulty, *F*(1.55, 51.22)=215.16, *p*<.001, partial η^2 =.87, indicating that as expected people were faster on low-demand problems when compared to medium-demand or high-demand problems. A main effect was found for condition, *F*(2,33)=5.90, *p*=.006, partial η^2 =.26, indicating that people in the conditions performed significantly different on the task. Pairwise comparisons corrected with Bonferroni revealed significant differences between the Bass (*M* = 2306.48, *SD* = 509.81) and Beat (*M*=1832.50, *SD*=282.53) conditions for low-demand tasks, *F*(2, 33) = 4.132, *p* =.036. Secondly, it revealed a significant difference between the Bass (*M* = 5167.31, *SD* = 1166.15) and Beat (*M*=3846.11, *SD*=1537.85) conditions on medium-demand tasks, *F*(2, 33) = 4.057, *p* =.035. Lastly, it revealed a significant difference between the Bass (*M* = 8534.19, *SD* = 2264.55) and Beat (*M*=6507.38, *SD*=1998.82) conditions on high-demand tasks, *F*(2, 33)= 3.607, *p*=.041. Effect sizes for these comparisons were *d*=.93 for low-demand, *d*=.93 for medium-demand and *d*=.91 respectively. All three effect sizes can be interpreted as large effects. No interaction effect for difficulty x condition was found and no significant differences were found for the other musical stimuli combinations. An overview of the pairwise comparisons between the conditions is given in *Figure 1.*

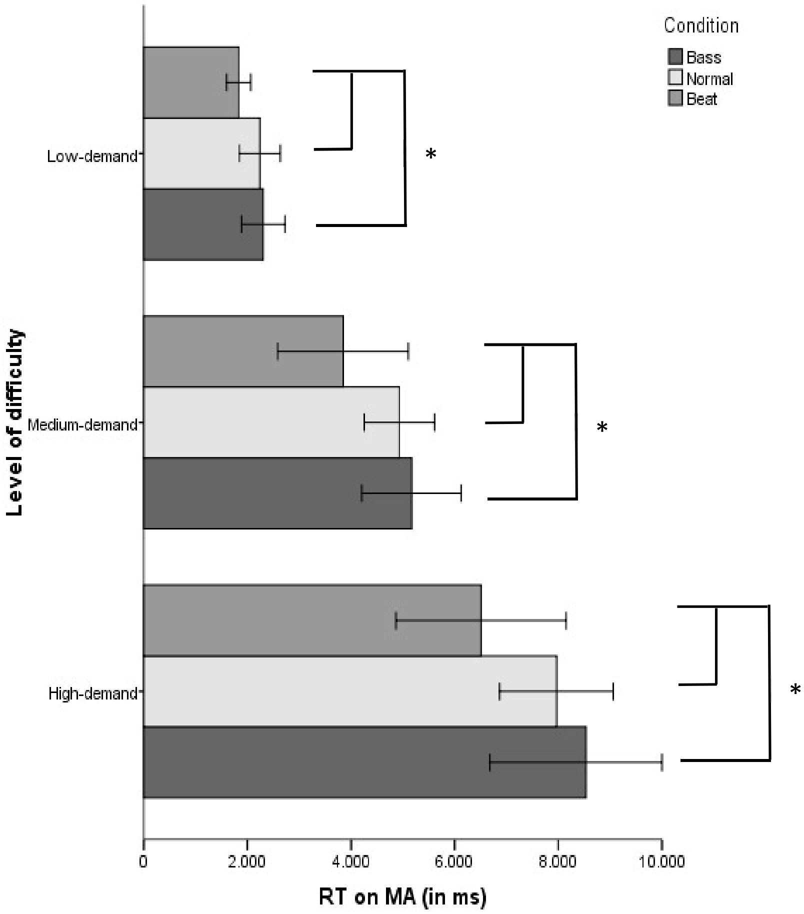

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Fig. 1. Overview of RT results Bass vs. Normal vs. Beat for each of the difficulty levels. * = *p*<.05.

4.4 MEQ and MFI

Finally, we were interested to explore (a) whether there were differences in self-reported feelings of entrainment between the different music conditions and (b) whether there were differences in feelings of mental exhaustion between the different music conditions. To test for differences by *pulse* induced entrainment, an ANOVA was conducted to compare the MEQ scores on each item for the Normal vs Bass vs Beat conditions. Results showed significant differences between the Normal and Beat condition, and the Bass and Beat condition. An overview of the results after Bonferroni correction is given in *Table 1*. The reported entrainment in the Normal condition was significant higher for each of the items compared to the Beat condition (i.e., the condition without a pulse). The reported entrainment in the Bass condition was also significant higher for each item compared to the Beat condition, except for item 6 (i.e., felt animated) and item 7 (i.e., felt physically excited). As expected participants did not report feelings of entrainment during the part of the experiment where they had to perform without any form of music.

Table.1. Average Entrainment scores (MEQ) of the Normal and Bass conditions compared to the Beat condition per item.

Entrainment items	Normal	Bass	Beat
Entrain1 - felt physically stimulated	72.42*	71.42*	58.5
Entrain 2 - felt like dancing	83.76*	76.92*	56.17
Entrain3 - felt entrained/driven	89.00*	87.42*	70.00
Entrain4 - felt energized	88.50*	87.58*	63.33
Entrain5 -felt like moving	92.67*	87.75*	56.00
Entrain6 - felt animated	82.58*	73.33	60.00
Entrain7 - felt physically excited	81.33*	69.08	52.67
Entrain8 - felt the rhythm in own body	93.00*	92.42*	65.75
Entrain9 - felt bodily agitated	90.08*	89.83*	65.75
Entrain10 - felt like beating time, tempo, or rhythm	90.58*	85.83*	57.25
Entrain11 - felt own body rhythms change	87.08*	80.75*	57.58
Entrain12 - felt own body resonate with the music	87.58*	80.92*	42.17

*Note. Bonferroni corrected values were used. *p<.05*

To explore differences of reported mental exhaustion by the participants in the different conditions, the scores on the different items were rescored and sorted by dimension following the procedure suggested by Smets and colleagues (1994). We conducted a between-subjects ANOVA to compare the scores on the five different dimensions for the three different music conditions. Results showed significant differences after Bonferroni adjustment between the Normal and Beat conditions, and the Bass and Beat conditions for all five dimensions. An overview of the results is given in *Table 2*.

Table.2 MFI Dimension scores for the Normal and Bass conditions compared to the Beat condition.

Dimensions	Normal	Bass	Beat
General fatigue	15.00*	16.33*	6.92
Physical fatigue	11.00*	11.42*	7.50
Mental fatigue	12.83*	13.42*	8.00
Reduced activity	10.17*	9.83*	7.58
Reduced motivation	11.00*	12.25*	7.50

*Note. Bonferroni corrected values were used. *p<.05*

5. Discussion

In this research, we set out to investigate whether (a) listening to music would affect performance on cognitive tasks, (b) whether listening to a dominant pulse would affect performing on cognitive tasks more than listening to music without a dominant pulse, and (c) whether trying to suppress entrainment to music with a dominant pulse would elicit more mental exhaustion than suppressing music without a dominant pulse (i.e., low frequency bass sounds).

First, we examined how performance was affected by music. During exposure to music people performed worse on the cognitive tasks than they did without music. Music induced drops in performance occurred on math problems that required double-digit carry operations (i.e., medium-demand and high-demand problems), but not on low-demand problems. People had a lower performance on the Stroop task for both accuracy and RT when listening to music compared to performing without music. Performing while listening to music seemed to have an effect on HR of people, showing a higher HR when performing on cognitive tasks during music. This is in line with previous research suggesting that music can alter brainwaves of individuals (Yehuda, 2011). Studies have found that alpha and theta brain waves increase while listening to relaxation music (Jacobs & Friedman, 2004), and that high arousal music may deter performance due to competition for limited processing space in the cortex (Dalton, 2017). People have a limited bandwidth for audio perception and processing, which makes it understandable that high arousal music (i.e., in this case 126 bpm), disrupts the cognitive performance of individuals (Treasure, 2017; North & Hargreaves, 1999). Analyses demonstrated that HR increased during exposure to techno music. Whereas a 5.4. % increase in heart rate might not be considered to be substantial, it can be an indication of the increased effect of sound on the sympathic nervous system. It is known that musical beats resemble the rhythms of the respiratory system and heart (Dalton, 2017; Yehuda, 2011). The music induced increase in HR may depend upon the amplitude, tempo and rhythm of the musical stimuli. This seems to imply that entrainment influences heart rate by activating an arousing response.

Second, we examined (b) whether there were differences between the effects of pulse compared to beat on performance of individuals. As expected, we found significant differences in the MEQ for reported entrainment between the conditions. The conditions with a pulse (i.e., the Bass only and the non-manipulated Normal conditions) scored significantly higher on each of the items compared to the beat condition. While not significantly different from the Bass condition, the results show the strongest effect of entrainment in the Normal condition (i.e., when pulse and beat are combined in the music). No significant differences for HR were found when comparing the Bass and Normal conditions to the Beat condition. It is possible that participants in the Beat condition experienced stress during the experiment, which also affects HR. A lack of low frequencies makes a musical stimulus less dimensional and less pleasing to listen to, activating stress. Another possible factor could be that even though entrainment is significantly higher while hearing a pulse, entrainment is still influencing individuals because of there still being a rhythmical component in the musical stimulus (i.e., the beat). This could explain why the music-induced increase in HR is the same for all three of the conditions. As expected, this study found a lower performance in the pulse conditions, compared to the beat condition. Performance on the Stroop task was significantly lower for the Bass condition compared to the Beat condition, and performance on the MA task was significantly lower for the Normal condition compared to the Beat condition. These results suggest a negative role of pulse on performance.

Third, we examined (c) whether trying to suppress entrainment to music with a dominant pulse would elicit more mental exhaustion than suppressing music without a dominant pulse. Individuals in the Bass and Normal conditions reported significantly more mental exhaustion than individuals in the Beat condition. The findings of this experiment support the hypothesis of an effect of unwanted entrainment on mental exhaustion. Especially the scores on the general fatigue dimension (i.e., scores on items like 'I feel tired') are considered high following the suggestions of Smets and colleagues (1994). This seems to suggest that participants who tried to focus on the mental tasks during the experiment were inhibited strongly in their performance by the pulse of the techno music and experienced a higher decrease in energy compared to the participants who performed without a pulse. As previously stated, the pulse and beat are differentiated by the low frequencies which not only has a sound component, but also a physical component. Low frequencies can be felt in one's body and affects the vestibular system, sense of motion and engages motor areas in the brain (Chen et al., 2008). An explanation of the difference in mental exhaustion can be found in how entrainment is not solely a sound principle, but a physics principle. The reason people who live near a festival terrain report feeling mentally exhausted, is probably linked to this physics principle.

One should take in account that although above reported results seem conclusive of an effect of unwanted entrainment, music preference is also of importance. *"… no music has power in itself. Music has no consequences for social action unless it can be related to a coherent set of ideas and bodily feelings"* (Blacking, 1974). The reason techno music has a different effect on individuals who attend festivals, compared to people who live near a festival terrain, is not only subject of entrainment, but is also subject of musical preference and context. Previous studies have found that when participants were allowed to choose a preferred type of music, stress and anxiety would decrease significantly compared to chosen relaxing music (Bernardi, Porta & Sleight, 2006). However, when individuals are not able to choose their preferred type of music, stress and anxiety will possibly increase. After the experiment, many participants remarked that they found the music intense, and that they did not like this song (i.e., 'One' by Swedish House Mafia) during the task. However, participants noted that they often listen to music during study or work. It's possible that musical preference influenced the results of performance in this experiment. A follow-up study should take these effects on mental exhaustion in account. It's not expected that music preference is of significance on performance. Studies have shown that in contrary to popular believes, listening to music always decreases performance on cognitive tasks compared to silence (Cassidy & McDonald, 2007). It takes longer to perform the same amount of work when listening to music because of divided attention. Results of this current research confirm this decrease in performance (i.e., higher RT) during cognitive tasks.

6. Conclusion

Elaborating on the results of this study, a link should be made to the previously mentioned statements of Julian Treasure (2017). This experiment is an illustration of the four different ways in which sounds affect us as an individual. We found effects on a physiological level (i.e., effects on heart rate), psychological level (i.e., feelings of exhaustion), cognitive level (i.e., effects on performance), and lastly on behavioral level (i.e., the effects of entrainment). This study examined the notion that suppressing unwanted entrainment affects performance and elicits mental exhaustion. The results of this present study indicate a strong effect of entrainment in music with a dominant pulse on performance and mental exhaustion, and illustrate how pulse and beat differ. Effects of pulse driven music and beat-only music work through different routes, because entrainment is not solely an auditory phenomenon. However, as this research is pioneering in examining the effects of entrainment with pulse driven bass sounds in techno music, more research on this subject matter is needed. New studies should take note of possible influences of context and musical preference on mental exhaustion.

7. References

Andringa, T. C., & Lanser, J. J. L. (2013). How pleasant sounds promote and annoying sounds impede health: A cognitive approach. *International journal of environmental research and public health*, *10, 4,* 1439-1461.

Beilock, S. L., Kulp, C. A., Holt, L. E., & Carr, T. H. (2004). More on the fragility of performance: choking under pressure in mathematical problem solving. *Journal of Experimental Psychology: General*, *133*(4), 584.

Bernardi, L., Porta, C., & Sleight, P. (2006). Cardiovascular, cerebrovascular, and respiratory changes induced by different types of music in musicians and non-musicians: The importance of silence. *Heart, 92*, 445–452.

Blacking, J. (1974). How musical is man? Seattle, WA: University of Washington Press.

Boere, J. J., Fellinger, L., Huizinga, D. J., Wong, S. F., & Bijleveld, E. (2016). Performance pressure and caffeine both affect cognitive performance, but likely through independent mechanisms. *Brain and cognition*, *102*, 26-32.

Bosch, K. A., & Andringa, T. C. (2014). The effect of sound sources on soundscape appraisal. In *Proc. 11th International Congress on Noise as a Public Health Problem*.

Burger, B., Thompson, M. R., Luck, G., Saarikallio, S., & Toiviainen, P. (2013). Influences of rhythm-and timbre-related musical features on characteristics of music-induced movement. *Frontiers in psychology*, *4*, 183.

Brodsky, W. (2001). The effects of music tempo on simulated driving performance and vehicular control. *Transportation research part F: traffic psychology and behaviour*, *4, 4,* 219-241.

Cassidy, G., & MacDonald, R. A. (2007). The effect of background music and background noise on the task performance of introverts and extraverts. *Psychology of Music*, *35*,*3,* 517-537.

Chen, J. L., Penhune, V. B., & Zatorre, R. J. (2008). Listening to musical rhythms recruits motor regions of the brain. *Cerebral cortex*, *18, 12,* 2844-2854.

Clayton, M., Sager, R., & Will, U. (2005). In time with the music: the concept of entrainment and its significance for ethnomusicology. In *European meetings in ethnomusicology. 11,* 1-82.

Dalton, B. H., Behm, D. G., & Kibele, A. (2007). Effects of sound types and volumes on simulated driving, vigilance tasks and heart rate. *Occupational Ergonomics*, *7, 3,* 153-168.

Hopkins, S. (1996). Synthetic ecstacy: the youth culture of techno music. *Youth Studies Australia*, *15*, *2*, 1-12.

Hove, M. J., Marie, C., Bruce, I. C., & Trainor, L. J. (2014). Superior time perception for lower musical pitch explains why bass-ranged instruments lay down musical rhythms. *Proceedings of the National Academy of Sciences*, *111, 28,* 10383-10388.

Gerra, G., Zaimovic, A., Franchini, D., Palladino, M., Giucastro, G., Reali, N., ... & Brambilla, F.

(1998). Neuroendocrine responses of healthy volunteers to techno-music': relationships with personality traits and emotional state. *International journal of psychophysiology*, *28, 1,* 99-111.

Jacobs, G. D., & Friedman, R. (2004). EEG spectral analysis of relaxation techniques. *Applied Psychophysiological Biofeedback*, *29*, 245–254.

Khalfa, S., Roy, M., Rainville, P., Dalla Bella, S., & Peretz, I. (2008). Role of tempo entrainment in psychophysiological differentiation of happy and sad music? *International Journal of Psychophysiology*, *68*, *1*, 17-26.

Labbé, C., & Grandjean, D. (2014). Musical emotions predicted by feelings of entrainment. *Music Perception: An Interdisciplinary Journal*, *32*, *2,* 170-185.

Lou, J. S., Kearns, G., Oken, B., Sexton, G., & Nutt, J. (2001). Exacerbated physical fatigue and mental fatigue in Parkinson's disease. *Movement disorders*, *16*, *2,* 190-196.

North, C., & Hargreaves, D.J. (1999). Music and driving game performance, *Scandinavian Journal of Psychology*, *40*, 285–292.

Lou, J. S., Kearns, G., Oken, B., Sexton, G., & Nutt, J. (2001). Exacerbated physical fatigue and mental fatigue in Parkinson's disease. *Movement disorders*, *16*, *2,* 190-196.

Smets, E. M. A., Garssen, B., Bonke, B. D., & De Haes, J. C. J. M. (1995). The Multidimensional Fatigue Inventory (MFI) psychometric qualities of an instrument to assess fatigue. *Journal of psychosomatic research*, *39, 3,* 315-325.

Treasure, J. (2013). Conscious Listening. Annual Meeting Proceedings. Million Dollar Round Table, 93-103.

Treasure, J. (2017). How to be Heard: Secrets for Powerful Speaking and Listening. Miami: Mango Media.

Van Dyck, E., Moelants, D., Demey, M., Deweppe, A., Coussement, P., & Leman, M. (2013). The impact of the bass drum on human dance movement. *Music Perception: An Interdisciplinary Journal*, *30, 4,* 349-359.

Whelan, R. (2008). Effective Analysis of Reaction Time Data. *The Psychological Record, 58*, 475-482.

Yang, W., & Kang, J. (2005). Soundscape and sound preferences in urban squares: a case study in Sheffield. *Journal of urban design*, *10, 1,* 61-80.

Yehuda, N. (2011). Music and stress. *Journal of Adult Development*, *18*, *2*, 85-94.

Appendix

R-script for downloading HR data from Fitbit Charge 2+.

An application was created and registered at the Fitbit developer website.

For this print ‘x’ is used as substitution for personal data.

The following script was used to extract the HR data from the application.

```
##PARAMETERS###

#remove -1 for today, or enter date as "YYYY-MM-DD" (with quotes) for any other day

date_to_download <- as.character(Sys.Date()-1)

##enter your personal key and secret here, leave them in quotes!
##example -- change to:  client_id <- "123ABC"

client_id <- "xxxxxxx"
secret <- "xxxxxxxx"

###path to save CSV and plot
### example -- change to: outpath <- "C:/Users/xxxxx/xxxxxx/Fitbit/xxxxx/"

outpath <- "path"
```

```
#install.packages("ggplot2")
#install.packages("jsonlite")
#install.packages("httr")
#install.packages("plyr")
library(jsonlite)
library(httr)
library(ggplot2)
library(plyr)


##Authentication with Fitbit website

dir.create(file.path(outpath, "plot"))
dir.create(file.path(outpath, "data"))
fbr <- oauth_app('FitteR',client_id,secret)
accessTokenURL <-  'https://api.fitbit.com/oauth2/token'
authorizeURL <- 'https://www.fitbit.com/oauth2/authorize'
```

```
fitbit <- oauth_endpoint(authorize = authorizeURL, access = accessTokenURL)
token <- oauth2.0_token(fitbit,fbr, scope=c("activity", "heartrate", "sleep"),
   use_basic_auth = TRUE, cache=FALSE)

#Get data
conf <- config(token = token)
resp <- GET(paste0(
   "https://api.fitbit.com/1/user/-/activities/heart/date/",
   date_to_download,
   "/1d/1sec/time/00:00/23:59.json"),
   config=conf)
cont <- content(resp, "text")
data <- fromJSON(cont)
hr <- data$"activities-heart-intraday"$dataset
names(hr)[[2]] <- "heart_rate_bpm"
hr$date <- date_to_download
tz <- Sys.timezone()
hr$datetime <- as.POSIXct(paste(hr$date,hr$time),tz=tz)

#plot
#define u/l limits for plot
hr_upper_limit <- round_any(max(hr$heart_rate_bpm, na.rm = TRUE),
   10, f = ceiling)
hr_lower_limit <-  round_any(min(hr$heart_rate_bpm, na.rm=TRUE),
   10, f = floor)

hrplot <- ggplot(hr, aes(x=datetime, y=heart_rate_bpm, color=heart_rate_bpm))+
geom_line() + geom_point(size=0.8)+

            scale_y_continuous(limits=c(hr_lower_limit,hr_upper_limit),breaks=seq(hr_lower_
limit,hr_upper_limit,10))+
                        scale_color_gradient(name="heart rate (bpm)",low="green",
high="red",breaks=seq(hr_lower_limit,hr_upper_limit,20),
limits=c(hr_lower_limit,hr_upper_limit))+
                        xlab("Date & Time") + ylab("heart rate (bpm)")

#save results

write.csv(hr,paste0(outpath,"data/heartrate_",date_to_download,".csv"),
row.names=FALSE)
ggsave(hrplot, file=paste0(outpath,"plot/heartrate_",date_to_download,".png"), width=11,
height=8.5, units="in")
```