Abstract

The experience of pain is thought to involve sensory (sensation) and emotional (affective-motivational) components. The current work examined the extent to which music may be able to alleviate the sorts of negative feelings and emotions that tend to be associated with the experience of pain. Over two experiments, we examined the influence of music type (relaxing and non-relaxing) and familiarity (familiar and non-familiar), on the behavioural, physiological and neural correlates of negative emotional responses (stress/anxiety) and examined the role that visual imagery may play as a potential mechanism underlying the reduction of these responses.

In Experiment 1, patients underwent three experimental blocks: each comprised of a 5-min stress/anxiety task that induced a negative emotional state, and a 15-min listening experience. In Experiment 2, they only took part in the listening experience but were exposed to music of varying familiarity. In both experiments, participants were fitted with an electroencephalography (EEG) cap and skin conductance (SC) sensors and were regularly probed about their emotional state and any visual imagery they were experiencing. Our results showed a significant reduction in negative affective state levels (anxiety) after exposure to all listening tracks and showed the extent of this drop to be related to the degree of visual imagery experienced while listening. Critically, however, the reduction in negative affective state levels (reflected in both subjective ratings and SC) was particularly pronounced in conditions involving the Ambient MassiveMusic track, both when it was played in isolation and as part of a longer compilation of several relaxing musical tracks. We propose that the more pronounced effects found with the MM track may result from a combination of its musico-acoustic features (which may facilitate feelings of relaxation in a listener), and its higher tendency to encourage visual imagery experiences (a purported mechanism by which music may modulate emotional states).

Benefits of Music Listening on the Reduction of Pain-Related Negative Affect: Exploring Subjective and Objective Signatures and the Role of Visual Imagery as an Underlying Mechanism

MassiveMusic Collaboration: Results Summary

Introduction

As far back as 1986, The International Association for the Study of Pain (1986) stated while pain “is unquestionably a sensation in a part or parts of the body” ... “it is also always unpleasant and therefore also an emotional experience". Today, it remains widely accepted that pain has two components – a bodily sensation and an aversive affective experience. Specifically, while bodily sensations are characterised by tissue damage and underlying bodily receptors (e.g., for temperature, pressure), the affective/emotional aspect is characterised by arousal and specific negative emotions (e.g., distress, anxiety; see, Fernandez & Turk, 1992). Studies have demonstrated the separability of the two components of pain by showing that while the neural substrates of the sensory-discriminative/sensation component of pain occurs in the somatosensory thalamus, primary somatosensory cortex (S1), and secondary somatosensory cortex (S2), the affective-motivational aspects of pain are localised to medial thalamus, amygdala, and limbic cortex (e.g., Casey et al., 2001; Kulkarni et al., 2005). Finally, the separability of the two aspects of pain have been further demonstrated by showing how they can be manipulated independently. For example, in Rainville et al.’s (1997) work, the affective component of pain was subject to modulation by hypnosis with relevant brain areas also showing changes in activation.

Critically, a large body of work has specifically emphasized the existence of a bi-directional relationship of pain with anxiety, an emotional trait and state characterised by feelings of tension and worry (Fernandez & Turk, 1992). On the one hand, state anxiety is held to be a symptom associated with the aversive emotional component of pain (e.g., Derogatis et al., 1983; Zwart et al., 2003). On the other hand, feelings of high anxiety are reliable predictors of enhancements in the perception of pain (Rhudy & Meagher, 2000; Tang & Gibson, 2005); indeed, preoperative anxiety in the context of medical procedures has been shown to both negatively impact recovery and exacerbate the unpleasant experience of pain (Ploghaus et al., 2001). Importantly, a number of non-pharmaceutical techniques for reducing anxiety seem to be able to alleviate experiences of pain in medical contexts (Suls & Wan, 1989). Taken together, techniques that can diminish negative affect (in the form of anxiety) seem to have special relevance for the goal of improving the experience of those in, or those about to experience, pain.

Music has been explored as one such technique for reducing anxiety related to pain. Indeed, a large body of research has shown that music holds a profound ability to modulate emotional state and mood (Rickard, 2004), and to modulate the perception of pain intensity (Lee, 2016). Interestingly, music's effectiveness in reducing negative emotional responses (i.e., negative affect) would seem to be genre-dependent (Chafin et al., 2004). Music's use as a strategy for alleviating pain and reducing distress (Yehuda, 2011) seems to be driven in large part by listeners' recognition of the inherently relaxing qualities of certain features of music that may be found to different extents in different genres (Baltazar et al., 2019). Specifically, when using music to destress or reduce anxious feelings, listeners are usually drawn towards specific parameters in music that are thought to be relaxing, such as slow tempo, limited dynamic variation, and rhythmic simplicity (Tan et al., 2012).

To test the efficacy of certain features of an auditory environment over others in reducing the stress and anxiety (negative affect) generally associated with pain, the current research compares MassiveMusic's ambient music track to both an upbeat music track (musical control track) and a podcast listening experience (non-musical control track). Given evidence of the separability of the sensation and affective-motivational aspects of pain, and to circumvent the ethical considerations involved in physical pain stimulation in the lab, we induced solely the negative anxiety-related aspects of pain in our lab setting by using an adapted version of the 4-component Mannheim Multicomponent Stress Test (MMST; Reinhardt et al., 2012). In turn, we measured subjective experience using a reliable tool for measuring subjective anxiety response (the State-Trait Anxiety Inventory; STAI-6; Tluczek et al., 2009).

Last but not least, the current research also examined the potential role of visual imagery, the visualisation of images or pictures in the mind's eye, in explaining any observed reductions in negative affect reported during and following the listening experiences. Visual imagery has been proposed as a mechanism by which emotions are induced by music (Juslin, 2013; Juslin & Västfjäll, 2008), and has been shown to be a significant predictor of the aesthetic appeal of music (Belfi, 2019). Previous research into the content and function of visual imagery has also demonstrated that music is able to induce visual imagery that has the ability to soothe (Küssner & Eerola, 2019) suggesting visual imagery may partly explain the ability of certain music to reduce stress and anxiety. The current research explores this possibility, thus extending previous research that have failed to explore underlying mechanisms.

Question 1: Is ambient music more effective at reducing stress/anxiety?

Increases in stress and anxiety have been shown to be indexed by cortisol (Woody et al., 2018), skin conductance (Lazarus et al., 1963) and, to some extent, oscillatory (alpha, beta and gamma frequency bands) neural activity in the brain (Ehrhardt et al., 2021; Minguillon et al., 2016). However, while such physiological indices are important in offering objective measures of these negative states, they are best complemented with measures of subjective experiences that can be captured using validated psychometric tools (questionnaires).

The current study thus examined skin conductance and oscillatory changes in the brain to examine how different auditory tracks may modulate the objective signatures of distress and anxiety. However, in order to get an accurate gauge of how, and the rate at which, stress/anxiety reduction may be subjectively experienced as a function of what it is being listened to, we probed listener's self-report of their feelings multiple times over the listening period (Polychroni et al., 2021; Taruffi et al., 2017). In line with previous meta-analyses (Panteleeva et al., 2018), we expected to find that signatures of stress and anxiety (particularly the subjective signatures) would reduce most and/or at the fastest rate when a track with relaxing acoustic properties (in this case, the MM track) was being listened to.

Methodology

Participants

We collected data from 28 healthy adults, aged 18-59 (20 female, 8 male; mean (M) = 24.4, standard deviation (SD) = 8.3). As a precaution, considering the nature of our stress task, we precluded those with a history of a diagnosis of post-traumatic stress disorder, depression, and/or anxiety from taking part in the research.

Stress/Anxiety Induction & Listening Task

Stress/anxiety was induced using an adapted version of the Mannheim Multicomponent Stress Test (MMST; Reinhardt et al., 2012). Our task incorporated four different types of stressors: cognitive (arithmetic task), emotional (negative affective sound clips), auditory (loud white noise), and motivational (loss of money based on performance). See Figure 1 for an outline of the task.

The full study was comprised of three listening blocks, each of which included a different auditory track. These were an ambient track by MassiveMusic with high relaxation potential (henceforth referred to as Ambient (MM)), a less acoustically relaxing techno track as a music control (henceforth, Techno (NR)), and a radio show entitled ‘A New Take on Darwin’s “Origin of Species”’ as a non-musical auditory control condition (hencforth, Podcast (PC); Groarke et al., 2020).

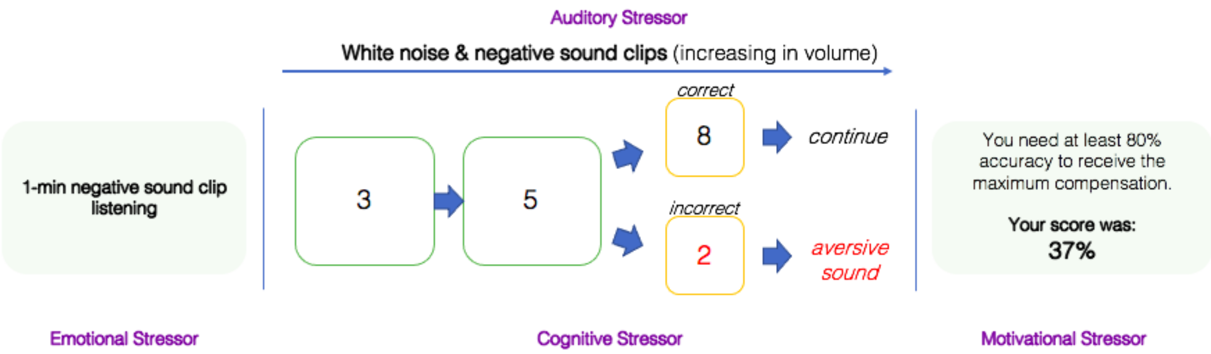


Figure 1. Stress/Anxiety Induction Task comprising four types of stressors: emotional (negative sound clips), auditory (white noise and negative sound clips), cognitive (arithmetic task), and motivational (loss of money)

Behavioural Ratings

We used a shortened 6-item version of the State-Trait Anxiety Inventory known as the STAI-6 (Tluczek et al., 2009) to assess levels of subjectively experienced stress and anxiety over the listening experience. Participants’ emotional responses were sampled at the start of the block (as a baseline measure), after stress induction (to ensure effective induction of stress/anxiety with our task), and three times over the course of the listening experience: approximately 6 minutes into the track, 12 minutes into the track and at the end of the track (to allow comparisons of effects across conditions over time).

Neural & Physiological Recording

Brain data were measured using the mobile Waveguard 32-channel cap from ANT Neuro, The Netherlands. Signals were amplified using the eego EEG recording amplifier. The EEG was set to a sampling rate of 500 Hz, later resampled to a rate of 200 Hz with a low-pass frequency of 50 Hz. An Independent Component Analysis was computed to manually remove artefacts caused by eye movements and eye blinks. The reference was set to electrode CPz. Skin conductance response (SCR) was measured using Shimmer3, a wearable sensor device. SCR recording was set to a sampling frequency of 512 Hz.

Procedure

Participants were taken through consent forms, before being fitted with the EEG cap. For the experiment, participants sat in a dimly lit room and were first provided with a verbal outline of the experiment, before being re-presented with relevant instructions on the computer screen. The experiment was approx. 2 hours long. To start, participants sat in silence for one minute (the goal of which was to neutralise their mood), then completed the STAI-6 and fixated on a black dot on the middle of the screen for one minute (pre-stress task; time period 1; TP1). This baseline measure was then followed by the stress/anxiety induction task for 5 mins. Participants then completed a second round of the STAI-6 and stared at a fixation dot again for 1 minute (post-stress task; TP2; allowing measurement of the post stress task physiological state). Next, participants listened to approx. 18 mins of either the relaxing Ambient (MM) track, the non-relaxing Techno (NR) track, or the Podcast (PC) track, and were probed approx. every 6 minutes to once more answer the STAI-6 (6 mins into listening, 12 minutes into listening and at the end of listening). After listening, participants stared at a fixation dot for a final duration of 1 minute (post-listening; TP3; allowing measurement of the post-listening physiological state). The entire experiment comprised three blocks of these sets of tasks to allow for the effect of each listening track to be evaluated in each participant. See Figure 2 for a visual overview of the full experimental procedure.

Time Frequency Decomposition

When scrutinising the effect in alpha, beta and gamma oscillatory bands, analysis focused on a set of frontal EEG electrodes (F7, F3, Fz, FPz, F4, and F8) in line with previous

EEG research conventions (e.g., Ehrhardt et al., 2021) and the notion that the prefrontal cortex is where a stress/anxiety response may be most apparent using EEG. However occipital electrodes (O1, Oz, and O2) were also analysed as a contrast area, and to even more clearly illustrate the flow of the experimental procedure (e.g., stages of eyes open and closed). Neural oscillatory power was segmented according to standard ranges: alpha (8-12 Hz), beta (13-30 Hz), and gamma (30-40 Hz).

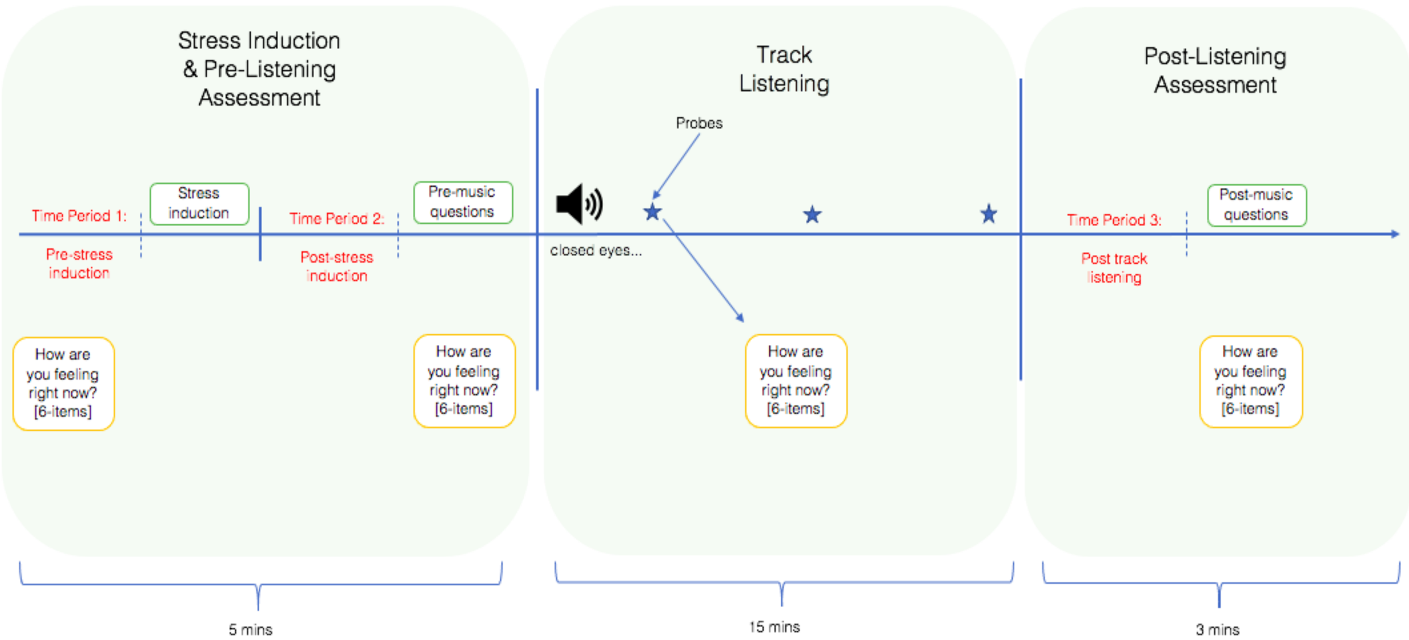
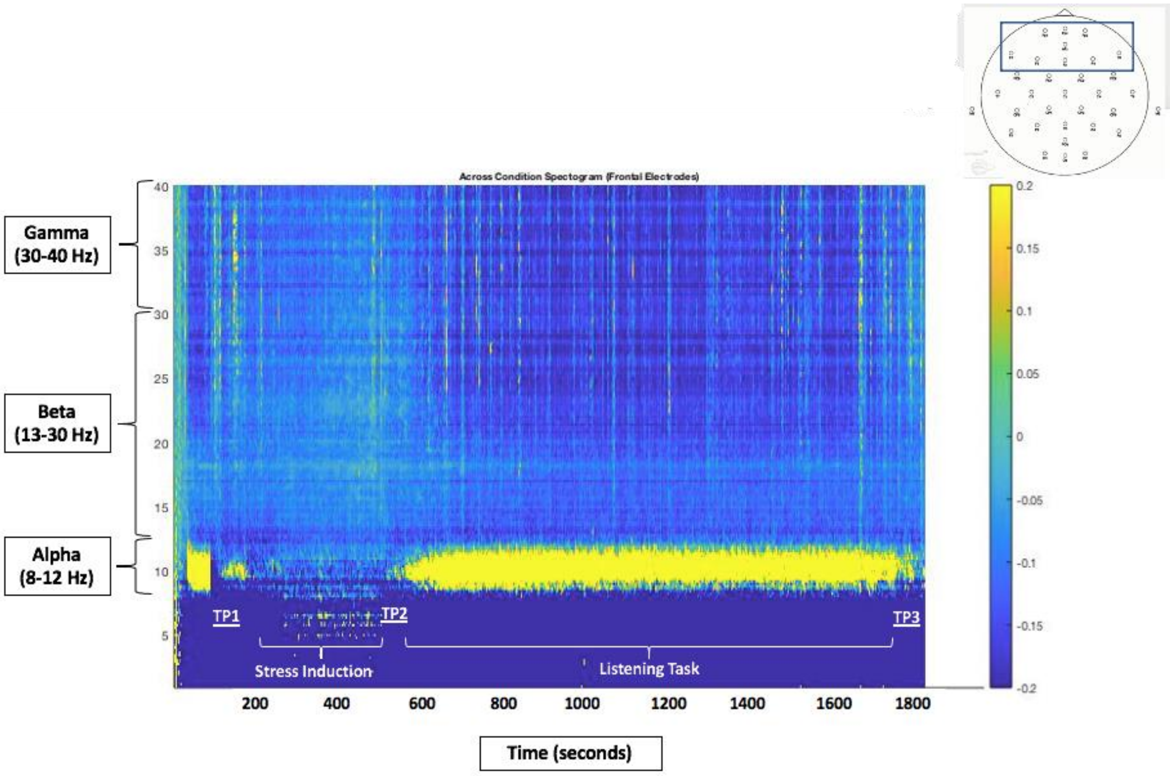


Figure 2. Summary of Experiment Flow

Results and Summary

Figure 3 shows the time frequency decomposition of EEG recordings averaged across the three listening conditions (Ambient (MM), Techno (NR), Podcast (PC)). Here, we can see clear modulations of the alpha, beta and gamma bands as a function of the stage of the experimental flow. For example, a clear drop in alpha and an increase in gamma during the stress/anxiety induction task compared to the listening periods, especially in the frontal electrodes (Ehrhardt et al., 2021). Note that the more prominent alpha (and low beta) power in occipital electrodes during the eyes-closed listening period is also in line with these electrodes capturing visual activity best (Geller et al., 2014).

Frontal electrodes



Occipital electrodes

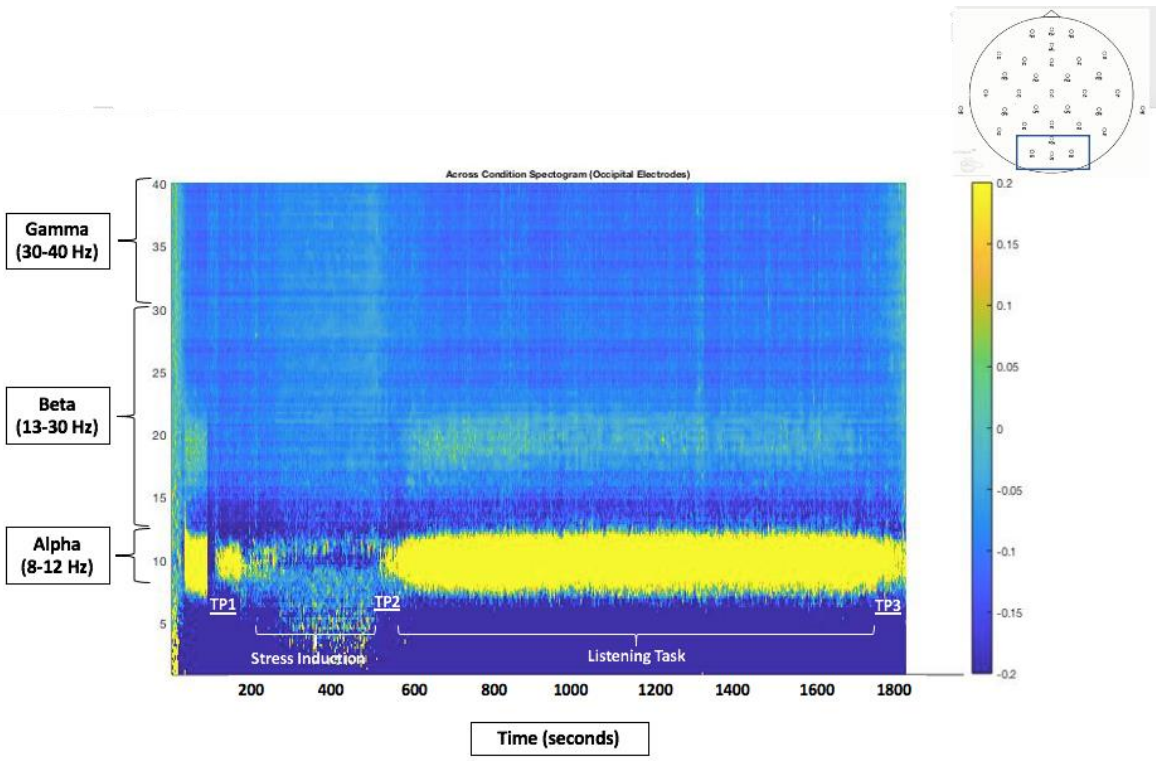


Figure 3. Time frequency plot of full experiment (TP1, Stress/Anxiety Induction, TP2, Listening Task, TP3) averaged across listening conditions (Ambient (MM), Techno (NR), Podcast (PC)) in sets of frontal (F7, F3, Fz, FPz, F4, and F8) and occipital electrodes (O1, Oz, O2)

In Figure 4, mean frequency power during TP1 (pre-stress task rest period), TP2 (post-stress task rest period) and TP3 (post-listening rest period) are presented. Table 1 shows the results of linear mixed models with Power as dependent variable, Time Period (TP1, TP2, TP3) and Listening Condition (Ambient (MM), Techno (NR), Podcast (PC)) as fixed effects, and Participant as random effect, for alpha, beta and gamma bands separately.

As expected, these analyses showed a significant effect of time period on mean beta and gamma power, whereby levels of activity were higher during TP2 (immediately post stress task) than TP1 and TP3, although there was no main effect of time period or listening condition for the alpha band.

That there was no effect of Listening Condition, and no interactions between Listening Condition and Time Period suggests that changes in beta and gamma before the stress task, after the stress task, and after 18 minutes of listening did not show strong differences across listening conditions. However, it is worth noting (see Figure 4) that the Ambient (MM) track led to a drop in gamma power from TP1 (pre-stress) to TP3 (post-listening) that was not seen in other listening conditions.

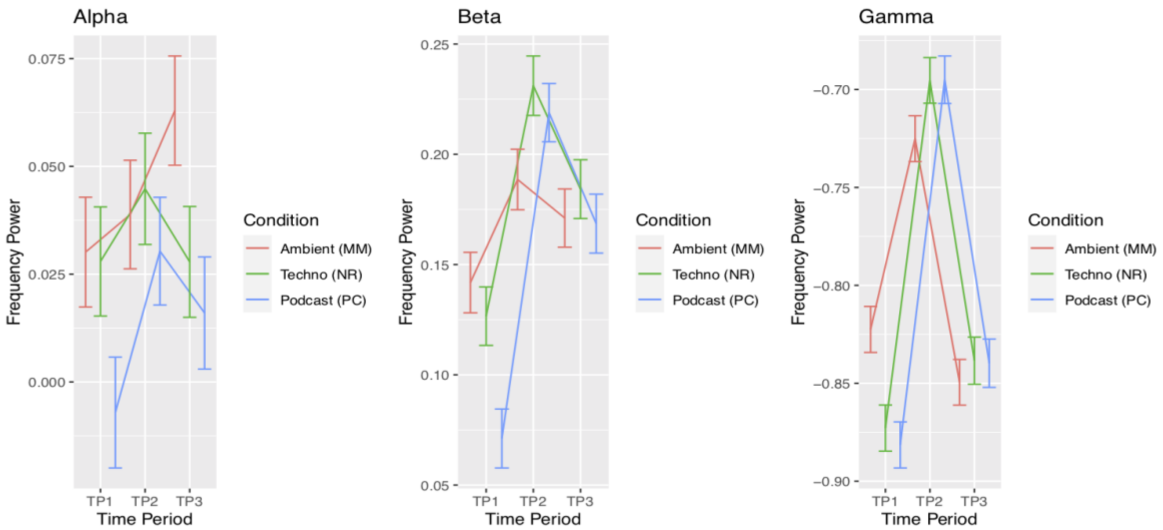


Figure 4. Effect of stress task on EEG signatures, alpha, beta and gamma; across time periods: TP1 (Pre-Stress task), TP2 (Post-Stress task), and TP3 (Post-Listening)

Table 1.
Linear mixed models of effect of stress task on EEG signatures: alpha, beta and gamma

Alpha Power

Variables	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr(>F)
Time Period	0.038	0.019	2	214.996	1.979	0.141
Condition	0.036	0.018	2	214.996	1.882	0.155
Time Period * Condition	0.013	0.003	4	214.996	0.345	0.847

Variables	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	-0.001	0.051	34.665	-0.02	0.984
TP2	0.033	0.026	214.992	1.239	0.217
TP3	0.022	0.026	214.992	0.843	0.4
Ambient (MM)	0.033	0.026	214.992	1.247	0.214
Techno (NR)	0.014	0.027	215.011	0.537	0.592
TP2 * Ambient (MM)	-0.02	0.037	214.992	-0.542	0.588
TP3 * Ambient (MM)	0.01	0.037	214.992	0.273	0.785
TP2 * Techno (NR)	0.007	0.037	215.001	0.178	0.859
TP3 * Techno (NR)	-0.005	0.037	215.001	-0.124	0.901

Beta Power

Variables	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr(>F)
Time Period	0.356	0.178	2	215.008	6.238	0.002**
Condition	0.032	0.016	2	215.008	0.556	0.574
Time Period * Condition	0.087	0.022	4	215.008	0.759	0.553

Variables	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	0.076	0.088	34.533	0.867	0.392
TP2	0.141	0.045	215.004	3.12	0.002**
TP3	0.102	0.045	215.004	2.269	0.024*
Ambient (MM)	0.069	0.045	215.004	1.537	0.126
Techno (NR)	0.061	0.046	215.022	1.338	0.182
TP2 * Ambient (MM)	-0.103	0.064	215.004	-1.619	0.107
TP3 * Ambient (MM)	-0.077	0.064	215.004	-1.203	0.23
TP2 * Techno (NR)	-0.045	0.064	215.013	-0.704	0.482
TP3 * Techno (NR)	-0.056	0.064	215.013	-0.878	0.381

Gamma Power

Variables	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr(>F)
Time Period	1.201	0.6	2	215.012	20.059	0***
Condition	0.001	0.001	2	215.012	0.02	0.981
Time Period * Condition	0.073	0.018	4	215.012	0.608	0.657

Variables	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	-0.875	0.075	38.974	-11.704	0***
TP2	0.186	0.046	215.006	4.027	0***
TP3	0.046	0.046	215.006	0.988	0.324
Ambient (MM)	0.055	0.046	215.006	1.186	0.237
Techno (NR)	0	0.047	215.034	-0.006	0.995
TP2 * Ambient (MM)	-0.083	0.065	215.006	-1.268	0.206
TP3 * Ambient (MM)	-0.072	0.065	215.006	-1.103	0.271
TP2 * Techno (NR)	-0.006	0.066	215.02	-0.098	0.922
TP3 * Techno (NR)	0.001	0.066	215.02	0.015	0.988

Note. *** < 0.001, ** < 0.01, * < 0.05

Figure 5 shows mean skin conductance response (SCR) at TP1, TP2 and TP3 for the three listening conditions (Ambient (MM), Techno (NR), Podcast (PC)). We carried out a linear mixed model with SCR as dependent variable, Time Period (TP1, TP2, TP3) and Listening Condition as fixed effects (Ambient (MM), Techno (NR), Podcast (PC)), and Participant as random effect. As expected, (see Table 2), this once more revealed a significant effect of Time Period reflecting the fact that that the SCR at TP2 (post-stress task) was higher than at TP1 (pre-stress task) and TP3 (post-listening).

That there was no effect of Listening Condition, and no interactions between them suggests that changes in SCR during TP1 (post-stress task), TP2 (post-stress task), and TP3 (post-listening) did not show strong differences across listening conditions. However, as can be seen in Figure 5, the Ambient (MM) track led to a larger drop in SCR from TP1 (pre-stress task) to TP3 (post-listening task). When assessing the differences between TP1 (pre-stress task) and TP3 (post-listening task) for each listening condition separately, only the Ambient (MM) track showed a significant effect of time period (p = 0.025), pointing to a potential strength of this track, compared to the other listening conditions (see Table 2), in promoting a relaxed state.

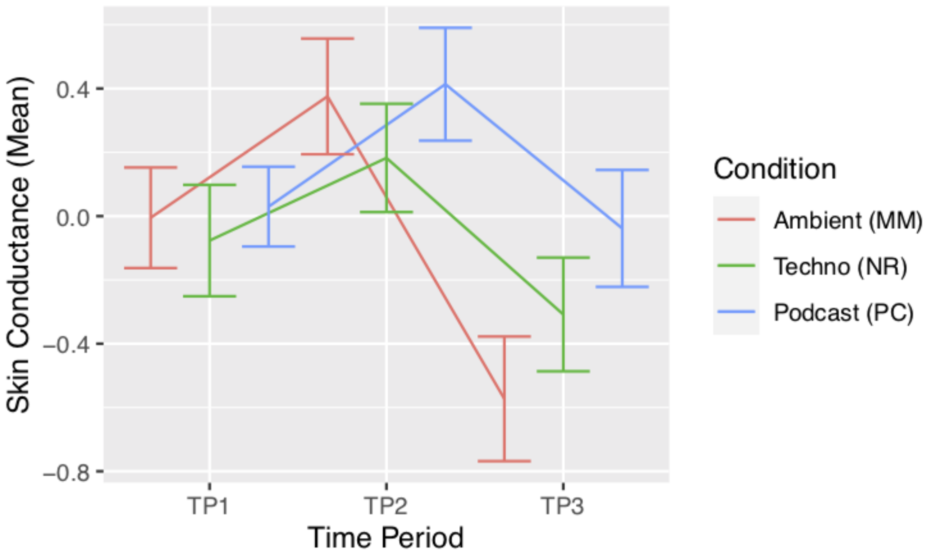


Figure 5. Effects of stress task on SCR across time periods: TP1 (Pre-Stress task), TP2 (Post-Stress task), and TP3 (Post-Listening)

Table 2

SCR across time periods (TP1 (Pre-Stress task), TP2 (Post-Stress task), and TP3 (Post-Listening)) between listening conditions (Ambient (MM), Techno (NR), Podcast (PC))

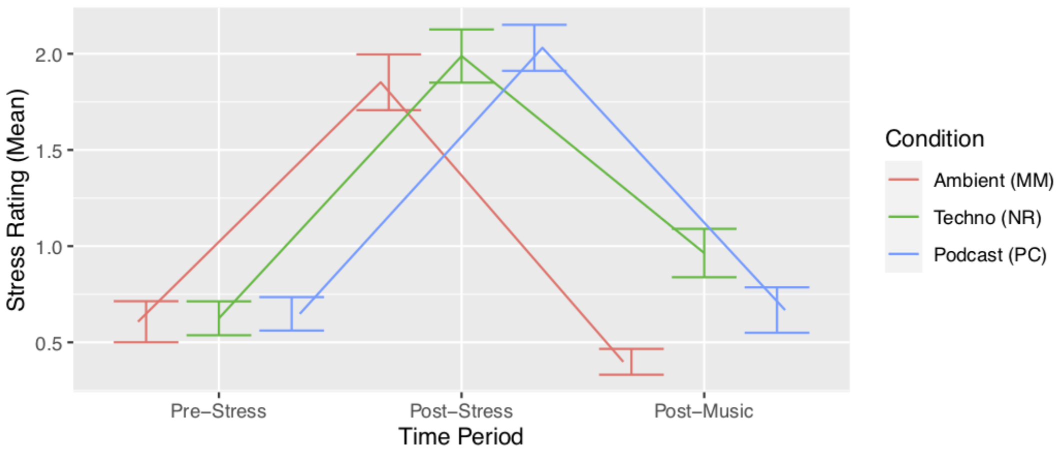
Variables	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr(>F)
Time Period	16.726	8.363	2	243	10.048	0***
Condition	2.296	1.148	2	243	1.379	0.254
Time Period * Condition	2.727	0.682	4	243	0.819	0.514
Variables	**Estimate**	**Std. Error**	**df**	**t value**	**Pr(>|t|)**	
(Intercept)	0.03	0.172	243	0.173	0.863	
TP2	0.384	0.244	243	1.574	0.117	
TP3	-0.068	0.244	243	-0.28	0.78	
Ambient (MM)	-0.035	0.244	243	-0.143	0.886	
Techno (NR)	-0.106	0.244	243	-0.436	0.663	
TP2 * Ambient (MM)	-0.003	0.345	243	-0.009	0.993	
TP3 * Ambient (MM)	-0.499	0.345	243	-1.448	0.149	
TP2 * Techno (NR)	-0.125	0.345	243	-0.362	0.718	
TP3 * Techno (NR)	-0.163	0.345	243	-0.474	0.636	

Note. *** < 0.001, ** < 0.01, * < 0.05

Finally, Figure 6A shows how subjective measures of anxiety changed over the three main time periods (pre-stress task, post-stress task, post-listening). We estimated a linear mixed model with mean STAI-6 (anxiety) rating as dependent variable, Time Periods and Listening Condition as fixed effects and Participant as random effect. This analysis showed a significant main effect of Time Period, Listening Condition, and the interaction between them (see Table 3). While the Time-Period effect showed that self-report of anxiety at TP1 (baseline) was smaller than post stress task (TP2) and not so different from post listening (TP3), the interaction reflected differences in the extent to which the three listening conditions were able to bring self-reports of anxiety back down to baseline (TP1) levels. Specifically, it reflected the fact that the Ambient (MM) track was able to reduce post listening anxiety levels (TP3) to below baseline levels (TP1), while the Podcast (PC) and the Techno (NR) track were less effective in reducing self-reports of anxiety.

Figure 6B shows a more detailed illustration of how subjective measures of anxiety changed over five time periods (before stress task, after stress task, 6 mins into listening, 12 minutes into listening and at the end of the listening experience). Here, the speed at which, and the degree to which the Ambient (MM) track is able to reduce negative affect (anxiety) more effectively than the other listening conditions is clearly apparent.

(A)



(B)

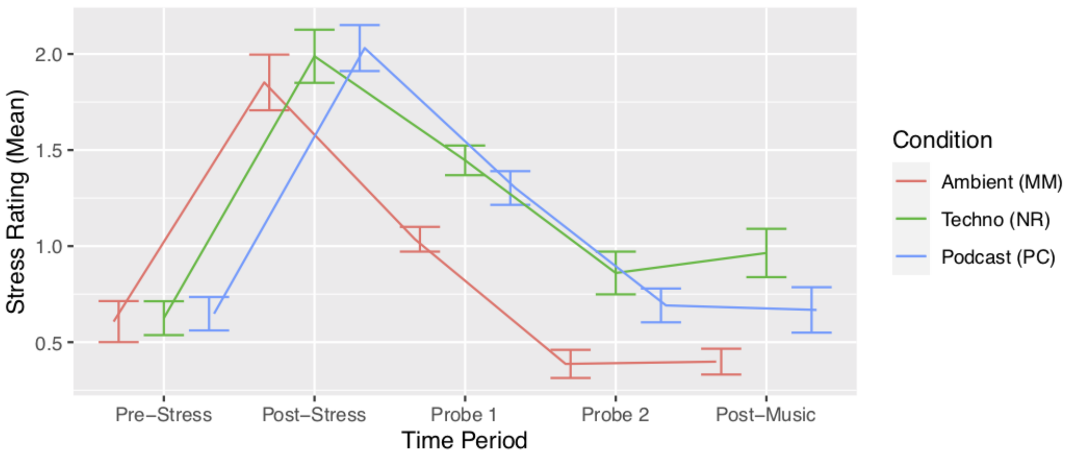


Figure 6. Self-report of anxiety levels at different time periods

Table 3.

STAI (anxiety/negative affect) ratings across the three time periods (Pre-Stress task (TP1), Post-Stress task (TP2), and Post-listening (TP3)) between listening conditions (Ambient (MM), Techno (NR), Podcast (PC))

Variables	**Sum Sq**	**Mean Sq**	**NumDF**	**DenDF**	**F value**	**Pr(>F)**
Time Period	93.024	46.512	2	211.907	239.119	0***
Condition	2.494	1.247	2	212.314	6.411	0.002**
Time Period * Condition	2.454	0.613	4	211.906	3.154	0.015*
Variables	**Estimate**	**Std. Error**	**df**	**t value**	**Pr(>|t|)**	
(Intercept)	0.628	0.114	94.866	5.52	0***	
Post-Stress	1.383	0.12	211.878	11.519	0***	
Post-Music	0.02	0.12	211.878	0.165	0.869	
Ambient (MM)	-0.021	0.119	212.084	-0.175	0.861	
Techno (NR)	-0.003	0.119	212.084	-0.025	0.98	
Post-Stress * Ambient (MM)	-0.148	0.169	211.941	-0.873	0.384	
Post-Music * Ambient (MM)	-0.228	0.168	211.878	-1.356	0.177	
Post-Stress * Techno (NR)	-0.02	0.168	211.878	-0.117	0.907	
Post-Music * Techno (NR)	0.32	0.168	211.878	1.899	0.059	

Note. *** < 0.001, ** < 0.01, * < 0.05

Summary of findings

We were able to show an effect of our stress task on subjective anxiety (STAI-6), and objective (EEG and SCR) measures; namely increases in levels post-stress induction (TP2) compared to baseline (pre-stress task; TP1). Further, while the three listening conditions showed similar levels of subjective anxiety reduction by the end of the listening blocks, results showed that the Ambient (MM) track had a particular advantage over other listening conditions in this regard.

Interestingly, our pattern of results, whereby music's stress/anxiety reduction effects was most noticeable in self-report (subjective) measures, is in line with previous findings (e.g., Panteleeva et al., 2018). When interpreting the observation from their literature review that physiological effects of music listening may be generally less reliably observed than subjective ones, Panteleeva et al (2018) emphasised the importance of considering the more complex cognitive mechanisms (e.g., spontaneous autobiographical memories, mental imagery) that may be driving listener's perceived benefits of music on stress/anxiety and negative affect reduction more generally. In the second part of this report, we use the MM track and others to explore the potential role of visual imagery (which may comprise a wide range of content including spontaneous autobiographical memories) in music's benefits on stress/anxiety reduction.

Question 2: Is there a role of visual imagery prevalence and content on the negative affect reduction?

Visual imagery has been proposed as a key mechanism by which music is able to induce emotions during music listening (Juslin & Västfjäll, 2008; Vuoskoski & Eerola, 2015). With regard to music's ability to reduce stress and anxiety, one hypothesis is that the images conjured up by a given piece of music may result in affect-enhancing outcomes that go above and beyond any acoustic effects (Küssner & Eerola, 2019).

In the current study, we regularly asked participants to describe what they were imagining while they heard the Ambient (MM) track, the control Techno (NR) music track and the control auditory Podcast (PC) track. These, however, constituted examples of unfamiliar tracks only, and therefore in order to gain insights into how familiarity of the heard stimuli affects imagination, we also collected and analysed data from another set of participants that had undergone four music listening conditions: non-familiar tracks with high relaxation potential (the Ambient (MM) track, amongst others), non-familiar control tracks with low relaxation potential, self-selected familiar tracks with (self-judged) high relaxation potential, self-selected familiar tracks with (self-judged) low relaxation potential. For the unfamiliar tracks, relaxation potential was determined based on the literature (Baltazar & Västfjäll, 2020) and the results of an online pilot study collecting the evaluations of an independent sample of listeners.

Methodology

Participants

Data from 28 participants (as described above in "Question 1" of this report) who were presented with the Ambient (MM) track, the Techno (NR) track and the Podcast (PC) were analysed alongside data from a further 30 participants (aged 18-49, 20 female, 9 male, 1 non-binary; M = 27.03, SD = 7.5) who were presented with four other conditions (familiar tracks with high relaxation potential, familiar control tracks; non-familiar tracks with high relaxation potential (Ambient (MM) track, amongst others; see Appendix 1) and non-familiar control tracks).

Procedure

Across all conditions in both studies, participants were probed approximately every 40 seconds during the listening phase and asked to provide answers to two questions: 1) ‘Just before the probe, did you experience any visual imagery?’ (*Yes/No*); and, if *Yes*, 2) ‘Was it spontaneous or deliberate?’ (*Spontaneous/Deliberate*). At the end of each listening condition, participants rated their agreement with a set of statements probing the content of their visual imagery. Specifically, participants rated on a scale of 1 to 7 how much their experience of visual imagery contained a narrative, characters (that they did not know), a location or setting, memories, image(s) of themselves, image(s) of friends and family, abstract images, or moving images.

Additionally, a subset of participants also provided a written description of the content of their visual imagery (during the Ambient (MM) track, the control Techno (NR) music, and the contrast Podcast (PC) tracks) using a free field text box.

Data Analysis

We first explored the prevalence of visual imagery during the different listening conditions. Then to test whether prevalence of visual imagery is associated with reduction of aversive affect, we examined how drops in signatures of stress/anxiety as a function of listening (TP3–TP1) were related to amount of any visual imagery experienced.

Next, we explored the content of the visual imagery, reported across all listening conditions. First, we carried out factor analyses to explore how participants’ ratings on content variables were grouped, and then examined how the different listening conditions differed with respect to the extent to which these dimensions of visual imagery showed dominance. Finally, we analysed the free text descriptions of visual imagery content using a dictionary analysis approach (Linguistic Inquiry and Word Count; LIWC). The LIWC software allows interpretation of language and text content, by calculating the proportion of words that fall within certain categories.

Results and Summary

Figure 7 shows how the incidence of visual imagery differed across the different listening conditions. Linear mixed model analyses revealed greater prevalence of imagery in the Ambient music (MM) condition (when compared to the two control conditions; see Figure 7A and Table 4). However, it is interesting to note that the greatest prevalence of imagery was observed for tracks which were both high in relaxation potential and familiarity (as compared to all others; see Figure 7B and Table 4). There was no difference across conditions in whether experienced imagery was spontaneous or deliberate.

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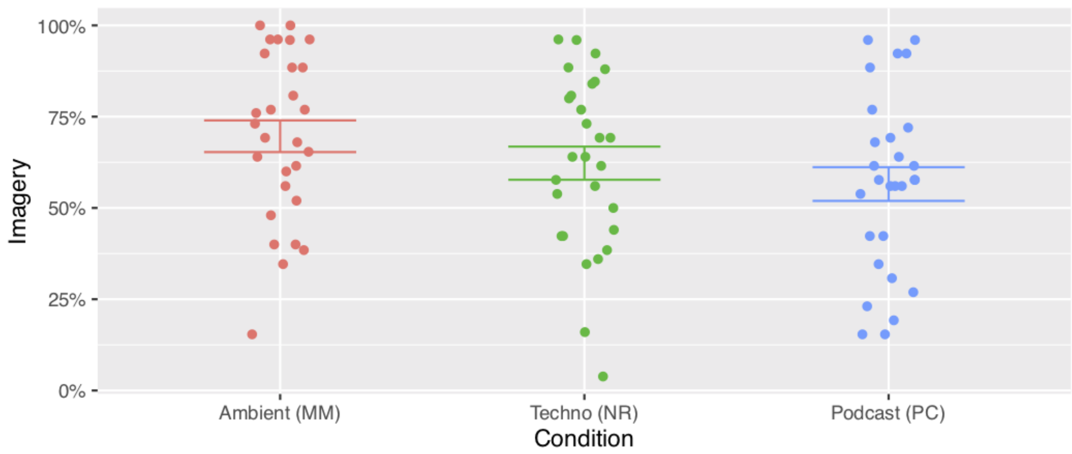
(A)



(B)

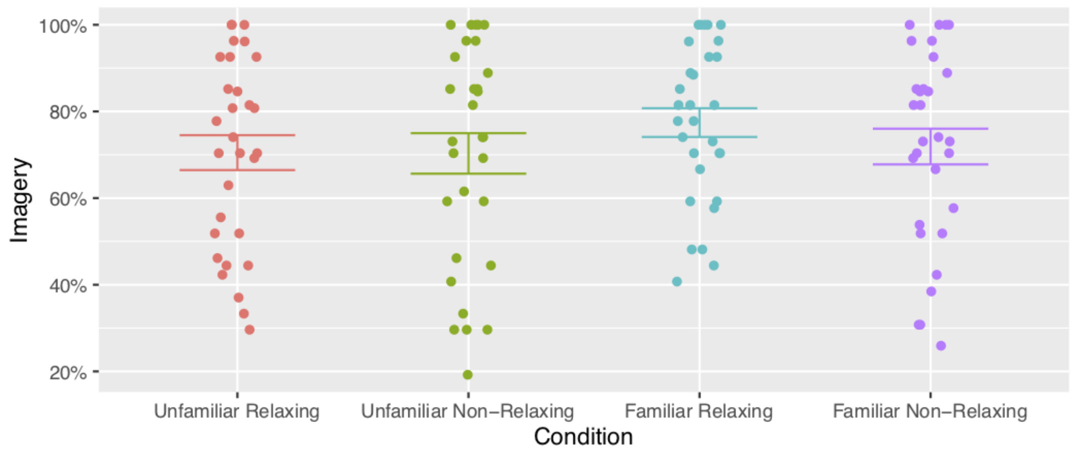


Figure 7. Incidence of visual imagery in the different listening conditions: **(A)** Listening conditions including tracks Ambient (MM), Techno (NR), Podcast (PC); **(B)** Listening conditions including tracks Unfamiliar Relaxing, Unfamiliar Non-Relaxing, Familiar Relaxing, Familiar Non-Relaxing

Table 4.
Visual Imagery Incidence Across Listening Conditions: Ambient (MM), Techno (NR), Podcast (PC)

Variables	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr(>F)
Condition	0.241	0.121	2	54	4.461	0.016*

Variables	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	0.565	0.045	52.405	12.569	0***
Ambient (MM)	0.131	0.044	54	2.979	0.004**
Techno (NR)	0.057	0.044	54	1.301	0.199

Note. *** < 0.001, ** < 0.01, * < 0.05

Table 5.
Visual Imagery Incidence Across Listening Conditions: Unfamiliar Relaxing, Unfamiliar Non-Relaxing, Familiar Relaxing, Familiar Non-Relaxing

Variables	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr(>F)
Condition	0.1	0.033	3	87	3.287	0.024*

Variables	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	0.705	0.041	40.067	17.344	0***
Unfamiliar Non-Relaxing	-0.002	0.026	87	-0.069	0.945
Familiar Relaxing	0.069	0.026	87	2.663	0.009**
Familiar Non-Relaxing	0.014	0.026	87	0.54	0.591

Variables	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr(>F)
Relaxation Potential	0.024	0.024	1	87	2.402	0.125
Familiarity	0.054	0.054	1	87	5.352	0.023*
Relaxation Potential * Familiarity	0.021	0.021	1	87	2.108	0.15

Variables	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	0.705	0.041	40.067	17.344	0***
Non-Relaxing	-0.002	0.026	87	-0.069	0.945
Familiar	0.069	0.026	87	2.663	0.009**
Non-Relaxing * Familiar	-0.053	0.037	87	-1.452	0.15

Note. *** < 0.001, ** < 0.01, * < 0.05

Next, we asked whether the prevalence of visual imagery experience was related to stress/anxiety reduction; specifically, whether the degree of decrease in the different signatures of stress/anxiety were related to the amount of visual imagery experienced during the music (Ambient (MM) and Techno (NR)) tracks. Figure 8 shows that there was a strong significant correlation between how much visual imagery was experienced and how effective the heard music was at reducing subjective measures of anxiety ($p < 0.001$). With regard to objective measures, while the relationship between imagery prevalence and EEG signatures (here, gamma) did not reach significance, the relationship between imagery prevalence and drops in SCR ($p = 0.02$) did.

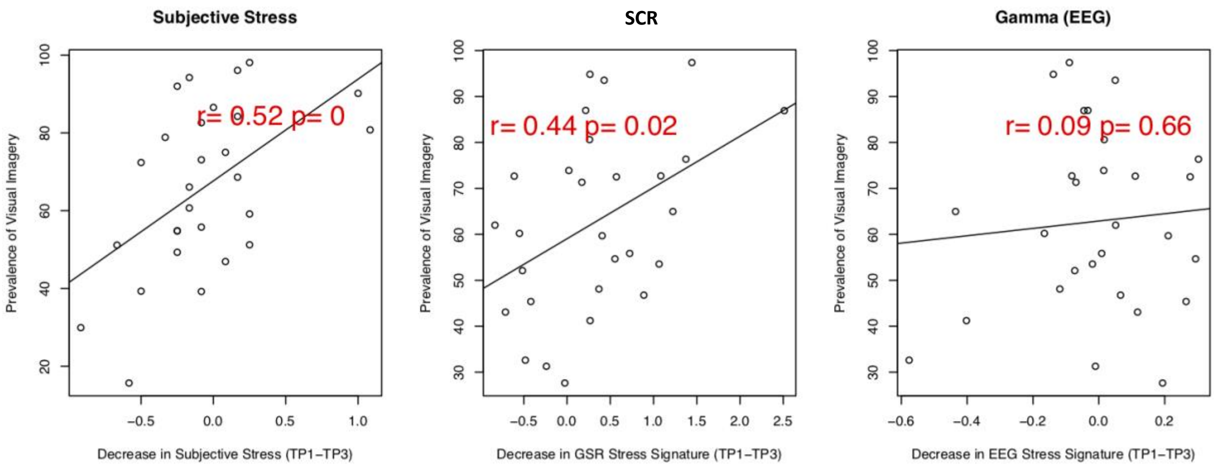


Figure 8. Scatter plots showing the relationship between signatures of anxiety reduction and amount of visual imagery experienced during the listening conditions (Ambient (MM), Techno (NR), Podcast (PC))

Next, we explored the content of the visual imagery participants reported experiencing in response to each track. We first ran factor analyses on behavioural ratings provided on the prevalence of certain visual imagery content in participants' experience of the tracks. The purpose of a factor analysis is to take several variables and reduce them to a smaller set of factors that characterise how much they co-relate with each other. Figure 9A shows the results of the factor analysis with data from the Ambient (MM), Techno (NR), and Podcast (PC) tracks, whereby two dimensions that we called "Personal" and "Story-like" were obtained. Personal was so named because it comprised imagery factors referring to oneself, past memories and references to friends and family, while Story-like was so-named because it comprised references to broad narratives comprising the imagination of general characters and locations.

Figure 9B shows the results of the factor analysis with data from participants who underwent familiar and non-familiar high relaxation and control conditions. This analysis also yielded two dimensions, characterised by almost identical groupings of variables as in Figure 9A, and which we thus also named "Personal" and "Story-like".

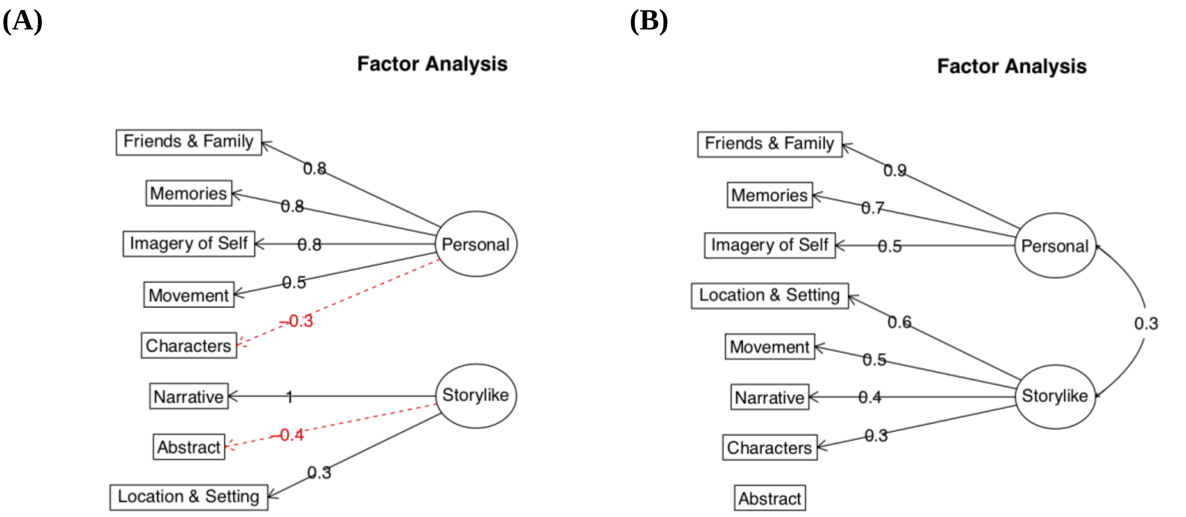
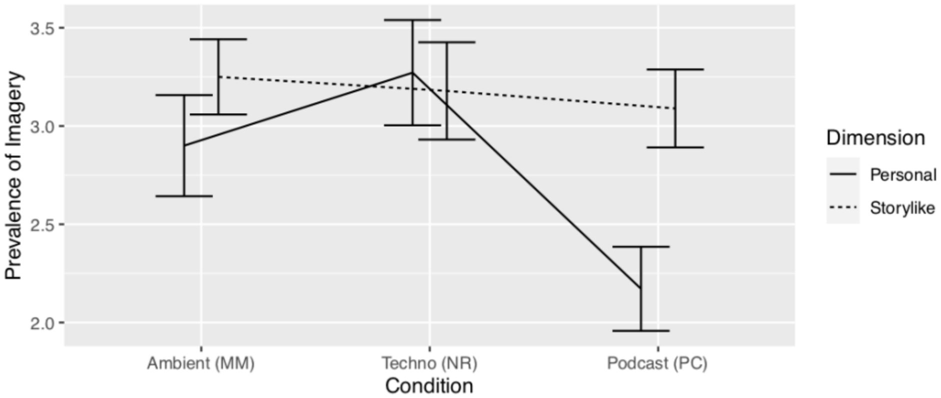


Figure 9. Results of factor analysis exploring dimensions of content of visual imagery; **(A)** content in response to listening conditions Ambient (MM), Techno (NR), Podcast (PC); **(B)** content in response to listening conditions Unfamiliar Relaxing, Unfamiliar Non-Relaxing, Familiar Relaxing, Familiar Non-Relaxing

Figures 10A and 10B shows how prevalent the two key dimensions produced from the factor analysis of visual imagery content were in the different listening conditions. We saw that while Story-like imagery was equally prevalent across the Ambient (MM), Techno (NR) and Podcast (PC) tracks, personal imagery was more prevalent during both musical conditions (Ambient and Techno) than during the podcast (Figure 10A).

We however also saw a particular capacity for familiar music to promote personal memories. Specifically, although relaxing tracks (like the Ambient (MM)) seemed to induce more personal imagery than non-relaxing tracks when both were unfamiliar, the results clearly showed the intuitive finding that familiar excerpts (regardless of relaxation potential) induced the most personal imagery (see Figure 10B).

(A)



(B)

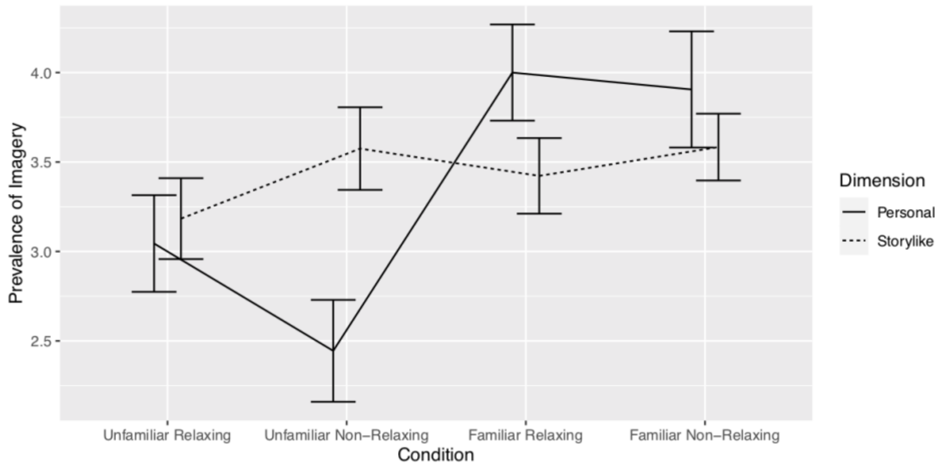


Figure 10. Imagery context as a function of different listening conditions: (A) MassiveMusic vs. control tracks; (B) non-familiar high relaxation potential tracks (including MM) vs familiar high relaxation potential tracks (including MM) vs. familiar and non-familiar control tasks.

Table 6.

Prevalence of Visual Imagery Content by Listening Condition (Ambient (MM), Techno (NR), Podcast (PC)) and Content Factor Dimension (Personal and Story-like)

Variables	**Sum Sq**	**Mean Sq**	**NumDF**	**DenDF**	**F value**	**Pr(>F)**
Condition	10.711	5.356	2	135	4.056	0.019*
Dimension	6.443	6.443	1	135	4.88	0.029*
Condition * Dimension	7.187	3.594	2	135	2.722	0.069

Variables	**Estimate**	**Std. Error**	**df**	**t value**	**Pr(>|t|)**
(Intercept)	2.171	0.231	151.38	9.389	0***
Ambient (MM)	0.729	0.307	135	2.372	0.019*
Techno (NR)	1.1	0.307	135	3.582	0***
Story-like	0.918	0.307	135	2.989	0.003**
Ambient (MM) * Story-like	-0.568	0.434	135	-1.308	0.193
Techno (NR) * Story-like	-1.011	0.434	135	-2.327	0.021*

Note. *** < 0.001, ** < 0.01, * < 0.05

Table 7.

Prevalence of Visual Imagery Content by Listening Condition (Unfamiliar Relaxing, Unfamiliar Non-Relaxing, Familiar Relaxing, Familiar Non-Relaxing) and Content Factor Dimension (Personal and Story-like) and Level of Familiarity (Familiar and Unfamiliar) and Relaxation Potential (Relaxing and Non-relaxing) of the track

Variables	**Sum Sq**	**Mean Sq**	**NumDF**	**DenDF**	**F value**	**Pr(>F)**
Condition	25.88	8.627	3	200.565	5.702	0.001**
Dimension	0.55	0.55	1	200.186	0.364	0.547
Condition * Dimension	24.849	8.283	3	200.184	5.475	0.001**

Variables	**Estimate**	**Std. Error**	**df**	**t value**	**Pr(>|t|)**
(Intercept)	3.044	0.252	176.279	12.062	0***
Unfamiliar Non-Relaxing	-0.6	0.318	200.099	-1.889	0.06*
Familiar Relaxing	0.927	0.324	200.826	2.862	0.005**
Familiar Non-Relaxing	0.861	0.318	200.099	2.712	0.007**
Story-like	0.139	0.318	200.099	0.437	0.662
Unfamiliar Non-Relaxing * Story-like	0.992	0.449	200.099	2.208	0.028*
Familiar Relaxing * Story-like	-0.7	0.455	200.272	-1.539	0.125
Familiar Non-Relaxing * Story-like	-0.461	0.449	200.099	-1.027	0.306

Variables	**Sum Sq**	**Mean Sq**	**NumDF**	**DenDF**	**F value**	**Pr(>F)**
Relaxation Potential	0.037	0.037	1	200.582	0.024	0.876
Familiarity	25.394	25.394	1	200.582	16.786	0***
Dimension	0.55	0.55	1	200.186	0.364	0.547
Relaxation Potential * Familiarity	0.37	0.37	1	200.582	0.245	0.621
Relaxation Potential * Dimension	5.605	5.605	1	200.186	3.705	0.056
Familiarity * Dimension	17.151	17.151	1	200.186	11.337	0.001**
Relaxation Potential * Familiarity* Dimension	2.094	2.094	1	200.186	1.384	0.241

Variables	**Estimate**	**Std. Error**	**df**	**t value**	**Pr(>|t|)**
(Intercept)	3.044	0.252	176.279	12.062	0***
Non-Relaxing	-0.6	0.318	200.099	-1.889	0.06*
Familiar	0.927	0.324	200.826	2.862	0.005**
Story-like	0.139	0.318	200.099	0.437	0.662
Non-Relaxing * Familiar	0.535	0.453	200.47	1.179	0.24
Non-Relaxing * Story-like	0.992	0.449	200.099	2.208	0.028*
Familiar * Story-like	-0.7	0.455	200.272	-1.539	0.125
Non-Relaxing * Familiar * Story-like	-0.752	0.639	200.186	-1.177	0.241

Note. *** < 0.001, ** < 0.01, * < 0.05

Finally, we analysed the free responses regarding listeners' content of visual imagery when listening to the Ambient (MM) track vs. the other listening conditions (Techno (NR) and Podcast (PC)), using the text analysis tool, LIWC. We selected two indices related to the content of descriptions that were of most interest. *Analytic* refers to the degree of analytical and formal thinking in the text, whereas *Tone* refers to the emotional tone displayed by the participant when describing their imagery. Our results suggested that the visual imagery induced by the Ambient (MM) track induced similar levels of analytic thinking as the Podcast (PC) track, while emotional language was generally more prominent for musical experiences (Ambient (MM) and Techno (NR) tracks) than experiences of the spoken track (Podcast (PC)).

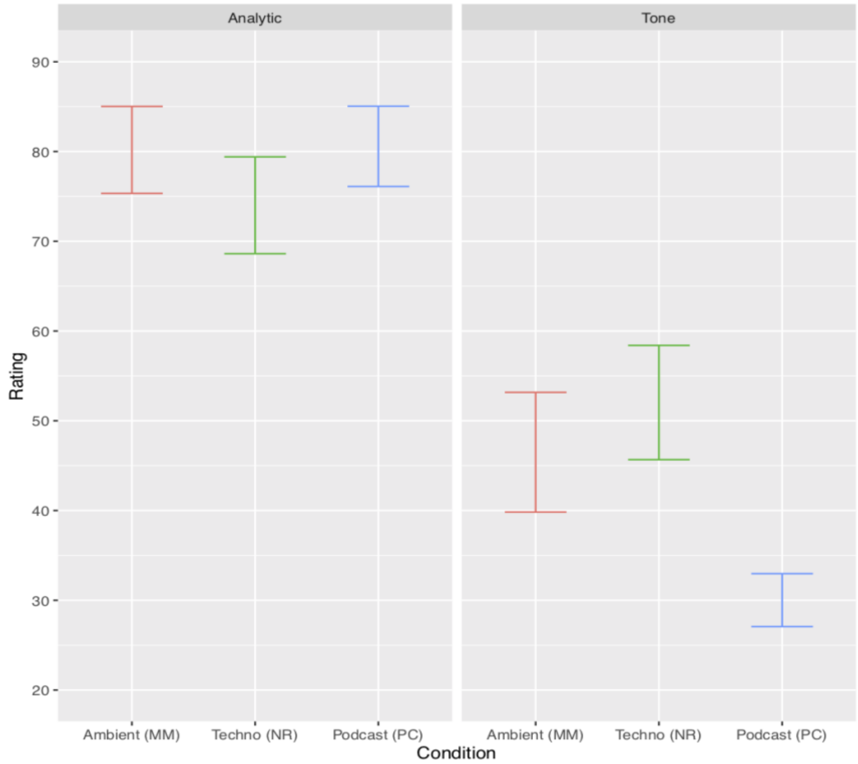


Figure 11. Level of visual imagery context (free response data) of Ambient (MM) track as compared to control tracks (Techno (NR) and Podcast (PC))

Summary of Findings (Visual Imagery as a Mechanism for Stress/Anxiety Reduction)

Regarding the prevalence of visual imagery in listeners' experience of the listening tracks, our findings show that the music tracks were more effective in inducing visual imagery than the spoken track; in particular, the Ambient (MM) track resulted in highest instances of visual imagery experience, followed by the Techno (NR) track, and then the Podcast (PC) track. Further, it appears that when looking across music listening conditions, visual imagery may be a prevalent mechanism underlying anxiety reduction, as illustrated by the relationship between visual imagery prevalence and reductions in both subjective (participants' conscious feelings of anxiety, STAI-6), and objective (albeit only SCR levels) measures of anxiety.

Listeners' visual imagery descriptions were groupable into two categories: Personal visual imagery and Story-like visual imagery. All listening tracks were equally capable of inducing story-like visual imagery. Intuitively, results showed that familiar excerpts led to more recollections of personal visual imagery than their unfamiliar counterparts. However, interestingly, when looking at unfamiliar excerpts alone, tracks with high relaxation potential were associated with more personal visual imagery. Taken together, our results support the idea that the perceived benefits of music – with regard to stress/anxiety reduction – may be driven not just by musico-acoustic features (like slow tempo, limited dynamic variation, and rhythmic simplicity), but also by the sorts of cognitive processes (such as spontaneous memories or mental imagery) that music may encourage (Panteleeva et al., 2018).

Conclusion

The Ambient (MM) track, when compared to other unfamiliar tracks, appeared to have a higher potential to reduce feelings of anxiety, which in turn is held to be both an important symptom and modulator of pain experience. We suggest the MM track's success may result from at least two sources: its conducive (for relaxation) musico-acoustic features, and its capacity to induce the significantly higher levels of visual imagery that have been proposed to reduce negative affect in a range of music-listening contexts.

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Appendices

Appendix 1: Musical excerpts included in Unfamiliar music-listening conditions

Piece	Artist/Composer	Genre	Relaxation Potential
Escape (Fictivision Mix)^	Fictivision	Electronic	High
Carnival Overture (Op. 92)^	Antonín Dvořák	Classical	High
The Flik Machine^	Randy Newman	Jazz	High
Ambient Track	MassiveMusic	Electronic	Low
Christmas Oratorio, BWV 248: Sinfonia in G^	Johann Sebastian Bach	Classical	Low
Hello My Lovely^	Enrico Pieranunzi	Jazz	Low

Note. Those marked with ^ were selected from Marti-Marca et al. (2020)