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Using music as a signal for biofeedback

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ABSTRACT

Studies on the potential benefits of conveying biofeedback stimulus using a musical signal have appeared in recent years with the intent of harnessing the strong effects that music listening may have on subjects. While results are encouraging, the fundamental question has yet to be addressed, of how combined music and biofeedback compares to the already established use of either of these elements separately. This experiment, involving young adults (N = 24), compared the effectiveness at modulating participants' states of physiological arousal of each of the following conditions: A) listening to pre-recorded music, B) sonification biofeedback of the heart rate, and C) an algorithmically modulated musical feedback signal conveying the subject's heart rate. Our hypothesis was that each of the conditions (A), (B) and (C) would differ from the other two in the extent to which it enables participants to increase and decrease their state of physiological arousal, with (C) being more effective than (B), and both more than (A). Several physiological measures and qualitative responses were recorded and analyzed. Results show that using musical biofeedback allowed participants to modulate their state of physiological arousal at least equally well as sonification biofeedback, and much better than just listening to music, as reflected in their heart rate measurements, controlling for respiration-rate. Our findings indicate that the known effects of music in modulating arousal can therefore be beneficially harnessed when designing a biofeedback protocol.

1. Introduction

Music's continuous, intensive, and multifaceted effect on listeners is extensively documented (Koelsch, 2010; Levitin and Tirovolas, 2009; Peretz, 2006). Numerous studies show several significant benefits of music used for arousal modulation towards therapeutic interventions, for a review see Nilsson (2009). Primarily it has been found to reduce the stress and anxiety experienced by patients in hospital care, through its facility to regulate mood and modulate arousal, and to serve as an effective analgesic, by distracting patients from the experience of pain.

Little research however has investigated the combined use of music with other technologically based interventions such as biofeedback. Our intention is to tackle this shortcoming, by investigating the benefits of using biofeedback and music in combination, towards modulating the level of arousal in healthy subjects. Our experiments were aimed at examining the possible effects arising from this combination, and to investigate the viability of music as a signal for biofeedback.

While research has contributed a significant body of knowledge on the effect of music compared to non-musical sound or silence, very little is known about how the effects of different types of music vary consistently across the human population, the *universals* of music. One clearly established universal effect is the direct correlation between the level of arousal as represented through the tempo and volume of the music, and the level of arousal experienced by its listeners (Hunter and Schellenberg, 2010; Khalfa et al., 2002; Trappe, 2010; Zatorre, 2005). Besides the level of induced arousal, music universally also has the effect of *entrainment* on humans: the subconscious synchronization of various bio-rhythms to rhythms in the music. Besides entrainment on volitional movement (gait, tapping, head-nodding etc.) there are several reports on physiologically detectable effects on Autonomic Nervous System (ANS) responses (Clayton et al., 2005; Khalfa et al., 2008; Orini et al., 2010; Trappe, 2010). Direct entrainment effects have been observed on respiration rate (Haas et al., 1986), while Bernardi et al. (2009) demonstrated a clear synchronization between physiological measures (e.g., heart rate, respiration rate) and musical rhythm. These effects were observed across participants regardless of musical preference, with few differences in effect resulting from musical training. Further well established characteristics are that we are apt at perceiving fine variation and great detail in musical stimuli, and that music is particularly effective at drawing and maintaining our listening attention (Levitin, 2006). Using a range of physiological measurements, primarily cardiovascular and electrodermal, researchers have succeeded in differentiating between when subjects are listening to musical pieces of low and of high arousal (Hunter and Schellenberg, 2010).

The term *music intervention* refers to the use of music in a therapeutic context that is not supervised nor conducted by a trained music therapist; a much narrower context of application in comparison to music therapy, with demonstrated efficacy only in contexts where analgesic, anxiolytic

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and relaxing effects are desired (Nilsson, 2009). In the modern development of *neurologic music therapy* (NMT), knowledge about specific neurological mechanisms pertaining to music perception and production is harnessed, with application primarily in neurorehabilitation (De l'Etoile, 2010), for example in training gait control and speech production.

Commonly in biofeedback with sound, the feedback signal consists of a continuous tone of fixed timbre, whose frequency and/or amplitude are mapped to the underlying physiological measure, for example pitch increasing with chest expansion, or volume decreasing to reflect a decrease in tonic skin-conductance level. Single short tones commonly reflect events, for example heart-beats. Stereo panning or 3D audio may indicate the location of the conveyed parameter. For example, Chiari et al. (2005) use all three parameters for balance training: anterior–posterior acceleration modulates frequency, media-lateral acceleration modulates left–right balance, while both also control amplitude.

In established biofeedback practice, when physiological signals are conveyed sonically, as well as in *auditory display*, and more generally where information is conveyed through sound, the process involved is termed *sonification*: "the transformation of data relations into perceived relations in an acoustic signal for the purposes of facilitating communication or interpretation" (Kramer et al., 2010). In contrast, while music may also contain information as to the events or data that gave rise to it, music differs in intention: the emphasis is placed on the resulting sound itself, to be perceived and appraised for the listeners' aesthetic enjoyment (Hermann, 2008), while for sonification aesthetic enjoyment is a secondary concern to maximizing the ability of transparently reflecting data. Particularly relating to modern/atonal music, the distinction may not always be clear, since under composer Edgar Varèse's famous description of music as "organized sound" (Ross, 2007), sonified data also qualify as music. Under normal circumstances however the two are easily told apart.

The fact that both music interventions and biofeedback rely on analogous physiological processes, and that both interventions are used to treat similar conditions, leads to asking what benefits may be drawn from their combined use. The fact that musical stimuli have such universally powerful effects on listeners may be very positive in biofeedback if these effects are accounted for, but also very detrimental if not. Indeed it has been stated that much research is needed to examine how the combined use of biofeedback and music may be effectively accomplished, as little systematic work has been carried on this to date (Ellis and Thayer, 2010).

Few experimental studies report explicit use of a musical feedback signal. For alpha activity neurofeedback training, van Boxtel et al. (2012) used participant-selected music, relying on music's ability to attract and maintain attention, and to entertain participants. In the context of biofeedback studies, Liu (2010) details his successful application of a HR biofeedback based in-flight music recommendation system, for regulating the arousal of long-haul flight passengers. Cui et al. (2010) present a multimodal biofeedback system for regulating the respiration during computer tomography, for eliminating artifacts in the captured image caused by irregular breathing. Chen et al. (2009) described two musical and visual biofeedback protocols for training stroke patients in reaching and grasping an object, both using the same predefined music across participants. Yokoyama et al. (2002) presented a biofeedback system where music was controlled using the heart rate (HR) of a subject, and evaluated the system's usefulness towards relaxing the subject during office work.

We have not identified any studies preceding ours that directly compare their music biofeedback protocols to biofeedback protocols that do not use music as the feedback signal, or to the effects of music alone. It thus remains an empirical question as to whether listening to music in the context of a biofeedback paradigm elicits more effective (stronger) changes than either technique alone. Hence, this research directly addresses this issue, through an experiment comparing the effectiveness at modulating the participants' state of physiological arousal following each of three conditions. Besides answering the above hypothesis, we also set out to learn and report what design considerations are important in devising a musical biofeedback protocol.

In the main experiment reported, we observed the participants' responses to such a combined stimulus, by measuring physiological responses of participants instructed to arouse and relax as much as they could under three different conditions: A) while either listening to arousing or relaxing music, B) a sonification of their heart rate using a sine-wave varying in pitch, or C) the previously used arousing and relaxing music, the tempo and volume of which was controlled by the subject's heart rate (which we've christened *combined biofeedback*). Higher HR increased musical tempo (with pitch remaining stable) and amplitude, while lower HR resulted in slower tempo and lower amplitude. Our hypothesis was that each of the conditions (A), (B) and (C) in order, would be increasingly better than the previous two in the magnitude to which it enabled participants to increase and decrease their state of physiological arousal: (C) > (B) > (A). Besides quantitative physiological measurements, we also gathered qualitative responses using questionnaires, on the experience, musical ability, and on participant's body perception awareness.

2. Methods

2.1. Participants

Participants (18 females, 6 males, $M_{age} = 28.2$ years, $SD = 6.3$, age range: 19–44 years) were recruited over email or from around University of Barcelona's Psychology campus. Participants were compensated with 6€ for their participation. Focusing on the musical experience of the sample, sixteen of the participants had attended music lessons, three had formal music studies, while only three identified themselves as being amateur musicians or better. Twenty participants reported that they listen to music daily, with the reported motivation for listening to music having a median value of 4.0, IQR (interquartile range) = 0 on a 1–5 Likert type scale (1 being graded as not motivated at all, 3 neither a little nor a lot, and 5 extremely motivated). Chills from listening to music were reportedly experienced by twenty one participants, and while twenty three reported that music alters their emotional state, all reported that their emotional state varies depending on the musical genre listened to. For safety reasons, pregnant women, people with epilepsy or with cardiovascular problems were excluded, and we also excluded people that reported severe uncorrected auditory and visual problems. Upon arrival at the laboratory all participants were asked to read and sign a consent form. The study was carried out in accordance with the regulations of the Comisión de Bioética de la Universitat de Barcelona, and was therefore performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki.

2.2. Materials

2.2.1. Musical biofeedback system overview

For our protocol we emphasized controlling the known universal effects of music to modulate level of arousal, and to draw attention without distracting from the biofeedback training. Optimal enjoyment, albeit considered important, was given less priority. We decided to convey the physiological state of participants by controlling musical tempo and volume, since past studies have shown that these parameters are capable of modulating changes in arousal (Khalfa et al., 2002; Zatorre, 2005; Hunter and Schellenberg, 2010; Trappe, 2010).

To determine the design of the experiment and of the biofeedback system and protocol to be used, we carried out two pilot experiments. This experience helped us pick whether heart rate (HR) or Galvanic Skin Response (GSR) was the most suitable physiological measurement to use as a feedback signal. We observed HR to vary as desired, mostly contained within a ± 20 BPM range, while for GSR, participants showed comparatively few changes and low variability. This might be due to

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