MADRID
inter.noise 2019
June 16 - 19
NOISE CONTROL FOR A BETTER ENVIRONMENT

Towards biophysiological and acoustic markers for perceived annoyance in response to reproduced environmental soundscapes

Williams, Duncan A.H., Brook, Chloe, Murphy, Damian T.[1]
University of York, Heslington,
York, YO10 5DD, UK

Thomas, Adam, Cox, Ben J., Clark, Charlotte[2]
Arup, 3 Piccadilly Place,
Manchester, M1 3BN, UK

ABSTRACT

This paper presents preliminary findings from a pilot study which asked participants (n=37) to rate their perceived annoyance (ISO BS15666) and self-reported sensitivity to noise, whilst listening to first order ambisonic recordings of various environmental soundscapes (including aircraft, trams, different types of road, and high-speed trains). A bespoke graphical user interface was developed to minimize visual distraction whilst participants undertook the experiment, promoting "active listening". A series of synchronous biophysiological measurements were also recorded, including brain activity using an 8-channel electroencephalogram with electrodes placed on the scalp according to the 10/20 protocol, electrodermal activity, and heart rate variability, as captured by an optical wrist sensor. Analysis of perceived responses suggests that participants found sounds with certain acoustic correlates (temporal impulsive content, and high frequency tonal components), to be most annoying – tram curving, for example, was reported to be much more annoying than road and air traffic.

Biometric data from subjects was plotted along with their self-reported noise annoyance. These plots show some interesting results and have steered thinking towards more refined hypothesis that can be tested in further work.

Direction for further work includes training a regression algorithm on the acoustic correlates to assist in annoyance prediction, and to develop a machine learning model to analyse the large biometric dataset resulting from these experiments.

Keywords: Noise, Environment, Annoyance

I-INCE Classification of Subject Number: 61

[1] duncan.williams@york.ac.uk

[2] adam.thomas@arup.com

1. INTRODUCTION

Previous work has shown that there are measurable neurological and physiological responses to sound stimuli [1]. When listening to sound, our bodies may respond by inducing reactions such as pupil dilation, increased heart-rate, blood pressure, and skin conductivity [2].

This pilot study aimed to identify methodologies for determining the biometric response in human subjects – if any - invoked by different environmental sound sources, specifically soundscape recordings of different sounds that might be characteristically encountered in urban environments around large infrastructure projects (such as road, rail, and air traffic). With these soundscapes in mind the study deliberately focussed on responses in terms of *perceived annoyance*, as has been found previously useful in examination of urban spaces [3]. Self-reported data was collected during the test allowing participants to report their level of annoyance in response to an acousmatic stimulus set, played back in a randomised order via a first order ambisonic loudspeaker system. For a discussion of various ambisonic playback methods, the interested reader is referred to [4]. Simultaneously to playback of each stimulus, biometric data including heart rate variability (HRV), Galvanic Skin Response (GSR) and electrical activity in the brain was recorded synchronously using an electroencephalogram (EEG).

Prior to the subjects undertaking the experiment they were allowed some time to acclimatise to the laboratory environment and to wearing the set of biosensors being used. Baseline levels for biosensors for each participant, and for the sensors in the laboratory environment without a participant were also captured for use in subsequent signal processing. Each iteration of the experiment lasted for approximately 15 to 20 minutes including time for familiarisation with the laboratory environment for each participant, a duration which should not create fatigue by conventional listening test practices [5], though the use of the various biosensors adds a compounding factor in terms of comfort and fatigue which some participants remarked on informally at the end of their session.

2. MATERIALS AND METHODS

Thirty-seven participants took part in this study. Participants were recruited from a working office environment and were compensated for their time. All subjects were healthy, reported no medical problems or being under the influence of any medication at the time of taking part. Approval for the study was provided by University of York Physical Sciences Ethics Committee, including specific requirements for data storage and compliance with GDPR. Profile data was gathered from the subjects via a questionnaire before each iteration of the experiment began, and this data was stored anonymously on a cloud based server with AES-128 encryption.

Immediately prior to the start of the listening test sequence, participants were asked to rate their own noise sensitivity on a scale of 0-7, following an existing protocol by Clark *et al.*, [6]. Responses received ranged between 2-6. Participant ages varied from 17-55 years of age, the majority of respondents being between 25-35 years old. No participants declared a history of hearing impairment.

2.1 Stimuli

Participants were played the complete stimulus set shown in Table 1, in a randomised order.

Table 1 - Complete stimulus set with calibrated playback level. Each stimulus was cropped with a linear fade in and fade out to a total duration of 30s. The aircraft pass-by was played twice in every session (in a randomised order).

Sound Stimulus	**Playback level**
High speed train	82 $dBL_{Amax,s}$
Urban Traffic	65 dBL_{Aeq}
Aircraft pass-by (650ft height)	82 $dBL_{Amax,s}$
Tram curving (wheel squeal)	82 $dBL_{Amax,s}$
Construction - Breaker	76 dBL_{Aeq}
Highway	76 dBL_{Aeq}

Between the playback of each sound stimulus, participants had an interval period during which they were invited to report on their perceived annoyance (see section 2.2 for details of the scale used), when thinking about the previous stimulus (i.e., to evaluate the sound they had just heard).

Care was taken to ensure participants were not exposed to the otherwise low background noise levels (<PNC15) in the test environment. This was necessary as people can often find such low noise levels as disconcerting and the large dynamic range of being exposed to the stimuli immediately after such low noise levels would be unrealistic and possibly alarming. Therefore, during the evaluation periods an anchor soundscape was played, which consisted of a semi-rural/suburban environment that was mostly made up of natural sounds (e.g., birdsong) but included some distant road traffic. This was used as it was a soundscape that was expected to be reasonably neutral and familiar to participants living in an urban environment, without containing specific cues from transport or construction.

One of the stimuli (the aircraft pass-by at 650ft overhead) was played back twice for each participant as part of the randomised order of stimulus playback, in order to provide a control signal to facilitate within-participant comparison of variance if necessary.

The stimuli were played back through an ambisonic loudspeaker array at calibrated sound levels within the Arup SoundLab™ facility in Manchester to give an aural experienced close to that of encountering the noise sources within the real world. Before undertaking the experiment, participants were asked to conduct active and focused listening to the sound and how the sound made them feel.

2.2 Qualitative response

The participants were asked to rate each sound stimulus considering their perceived annoyance using an 11-point scale, based upon ISO BS15666, [7], with 0 being labelled "not at all annoying" and 10 being labelled "extremely annoying". This data was gathered immediately after the playback of each individual stimulus, in the interval period mentioned above which was of no fixed duration. This interval period allowed participants to take as much or as little time as they felt necessary to complete the evaluation, before the next sound stimulus in the randomised sequence was played. During the evaluation phase, a portable tablet illuminated in front of the participant to allow them to enter their response using a touchscreen slider. This interface was designed to blank during each stimulus playback in order to minimize distraction from the visual interface and to encourage focussed listening in the participants. An additional intention of this interface design was to minimize visual stimulation which might create unwanted artefacts in the biometric data (in particular the visual cortex as recorded in the EEG). Visual stimulation has previously been shown to modulate responses in multimodal contexts (i.e., simultaneous audiovisual evaluation and the like) – particularly relevant to this work in research considering the influence of multimodal stimulation on assessment of affect and emotional state [8], [9].

2.3 Biometric capture

During this experiment, biometric data was gathered from the participants using an EEG and a wearable biometric sensor device. Five physiological cues were recorded: electro-dermal activity (skin conductance), heart-rate variability, frontal and parietal asymmetry, and relative balance of alpha/beta waves across the sum of the EEG. EEG was collected according to the standard 10/20 positioning of electrodes and recorded with a resistance of less than 1000m- ohms per channel. Electrodermal and heart-rate activity were recorded using an optical wrist-based sensor (E4) and sensors were synchronised by means of word clock to the audio stimulus playback, triggered by participants using the custom designed GUI presented via the portable tablet during the experiment.

3. RESULTS

Results across the range of participants, and within specific participant groups based on age and other factors were then analysed.

3.1 Self-reported response to noise annoyance

Initial examination of self-reported annoyance rankings using a single factor ANOVA and a two-sample t-test assuming equal variance ($p=<0.05$) suggested that participants found sounds with certain acoustic correlates (temporal impulsive content, and high frequency tonal components), to be most annoying – tram curving, for example, was reported to be much more annoying than road and air traffic. However, a robust analysis of correlations between individual acoustic features and reported annoyance remains an area for further work, with a larger sample size of listeners. The current sample size, as shown in table 2 which gives mean, variance, and standard deviation across the responses, suggests that the sample size was not large enough in this case to apply descriptive statistics to such a model with any meaningful confidence.

Table 2. Mean responses to each stimulus type (rounded up to 2 decimal places). Confidence of >=80% is highlighted in bold, which are found in the car traffic sounds (anecdotally the likely most familiar stimulus type in the set).

Sound Stimulus	Mean	Variance	St. Dev	Conf. Level
High speed train	6.3	4.7	2.2	0.7
Urban Traffic	4.3	6.0	2.4	**0.8**
Aircraft pass-by (650ft height)	6.5	4.9	2.2	0.7
Tram curving (wheel squeal)	7.1	4.9	2.2	0.7
Construction - Breaker	7.2	5.5	2.3	0.8
Highway	5.1	6.0	2.4	**0.8**

The mean annoyance across all subjects for the different sound stimuli are shown in Figure 1. The urban traffic – arguably the most heard of the stimulus types in ordinary day-to-day city living – was rated as the least annoying soundscape, with the construction sound of a breaker slightly more annoying that the tram curving (or wheel squeal sound) which would be familiar to many of the participants in Manchester, UK, a large city with a significant transport infrastructure including trams and buses.

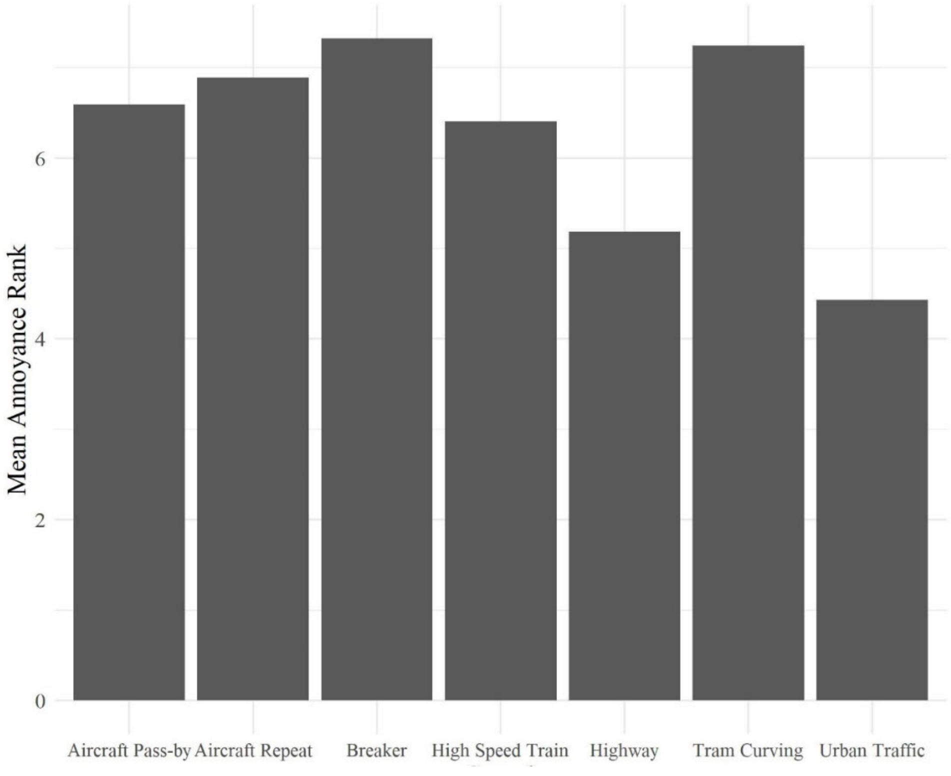

Fig. 1 – Mean annoyance as reported by all subjects across the complete stimulus set. Note the repeat of the aircraft was marginally higher than in the first iteration.

Figure 2 shows another visualisation of responses to the sound described as most annoying – the breaker construction sound. Whilst a few participants reported a limited degree of annoyance, the distribution is clearly weighted heavily towards the very annoying end of the scale. In contrast to this we see a much broader distribution in Figure 3, which shows the Highway traffic responses.

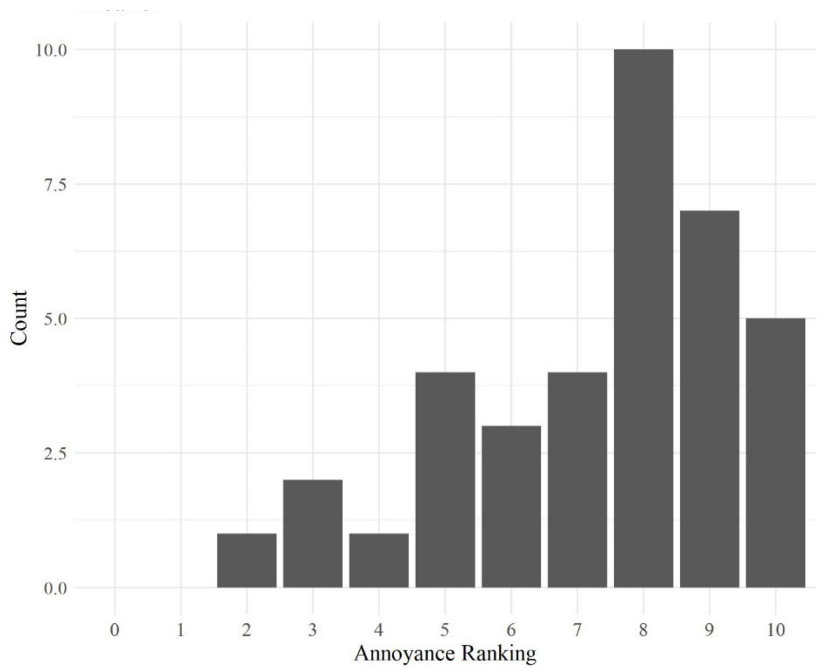

Fig. 2 – Annoyance rankings across participants for the construction breaker

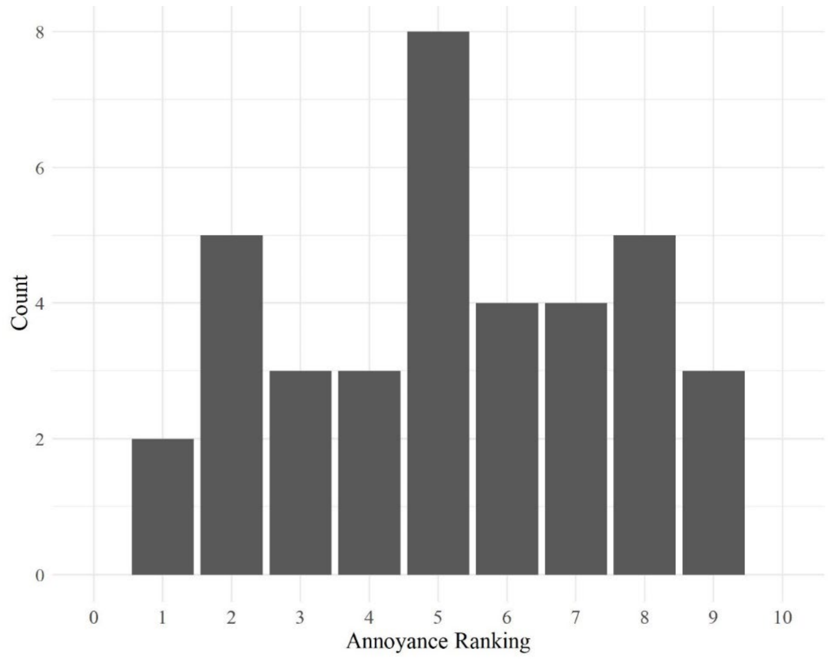

Fig. 3 – Annoyance rankings across participants for the highway traffic stimulus

3.2 Biometric response

Instantaneous heart rate (HRV) and Galvanic Skin Response (GSR) measured via the wrist based optical sensor were plotted for all subjects against the time that they were exposed to the environmental noise soundscapes. The data varied significantly between participants but generally participants aged between 20 and 30 showed a more marked reaction in their biometric response to the sounds. Biometric plots were generated which only contain the active listening part of the experiment (the acclimatisation period when the test was explained and the sensors were fitted) has been removed. The coloured rectangular sections show the periods when the participant was exposed to individual sound stimulus and the shade of colour has been plotted to show their self-reported annoyance to that individual sound, with redder shades being more annoyed. Figure 4 shows an example of one such participant. This participant shows a marked peak in GSR upon listening to each stimulus.

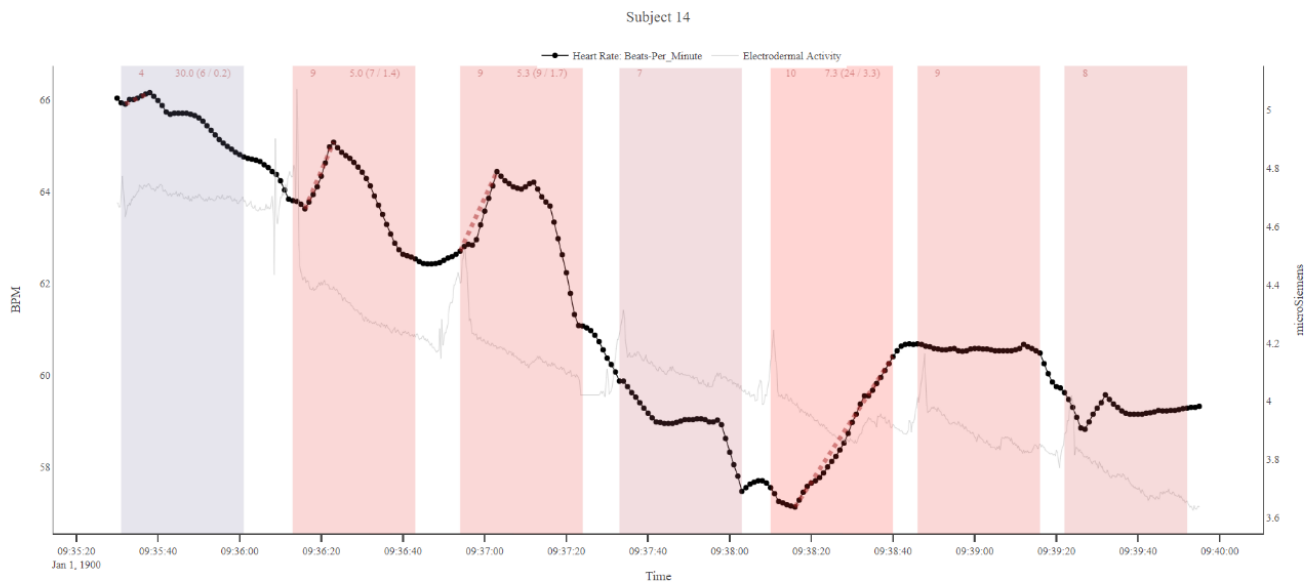

Fig. 4 - GSR and heart rate across a single listening session (participant 14). Note leap in GSR synchronously with each successive stimulus set, and distinctive slope in GSR as a continuous drop. This phenomenon has been previously documented in studies correlating emotional arousal with GSR report [2].

Many participants exhibited a small peak in the measured heart rate near the start of each new sound stimulus. This heart rate peak value itself does not directly correlate to the participants self-reported annoyance (which was collected after each stimulus had finished playing back), but often in subjects we see a slower rise in heart rate after being exposed to stimuli that they reported as being more annoying. We consider this a useful area for further work, exploring the contribution of heart rate variability rather than heart rate as a standalone value. Previous work has suggested that heart rate variability may be correlated with mindful states of mind when people are feeling relaxed, or with sleep apnea when high variability is reported [10], [11]. As such these are highly related areas of interest when considering sleep disturbance in an urban population who may be impacted by the types of sounds under consideration in this work. Whilst we found that a number of younger subjects showed biometric responses with promising signs of a reaction to the anticipated ‘noisier’ stimuli in relation to the self-reported annoyance, a number of the participants showed a larger variance in the data, particularly heart rate.

There are many factors that could influence this, these could include the cardiovascular health of the participant (even though participants reported no health problems at the beginning of the test) activities participants completed immediately before the test (the test was conducted during a normal office day but intakes of food or stimulants such as caffeine and nicotine were not recorded), or the novelty of being in a laboratory test environment itself. Neurophysiological experiments using music as a stimulus have shown that familiarity can have a significant biophysiological influence on the emotional response of the listener [12], and as such it is conceivable that other stound stimuli might evoke similar reactions in unfamiliar environments.

4. FURTHER DISCUSSION

The distinction between affective state, emotion, and mood, is complex, but in the context of sound and particularly noise evaluation, cognitive scientists have suggested the temporal nature of the response can be a useful method of delineating between such descriptors [13]. Metrics such as perceived annoyance have several existing emotional connotations. The potential to utilise biophysiological data to better understand people's response to noise is appealing. Certain acoustic artefacts within sounds (impulsive or highly tonal content) could be assessed alongside the biometric data to enable prediction of peoples annoyance to certain environmental sounds. Biophysiological regulation may also help to circumvent some of the problems of self-reported emotion (e.g., users being unwilling to report particular felt responses, or confusing perceived responses with felt responses [14]).

The biometric results suggest signs of correlation between self-reported annoyance and their biometric measurements as shown in heart rate and galvanic skin response. This appears only really be consistent in younger participants for HRV and there is a greater degree of variance in older age groups with regard to cardiovascular activity. However, these inferences remain an area for further statistical analysis and ideally a larger, homogenous sample size.

5. CONCLUSIONS

This paper outlined a pilot study intended to take steps towards a combined approach using biosignal synchronous metrics with self-reported perceptual metrics of annoyance in response to ambisonic recordings of real-world noise stimuli. This work has implications for the future design and implementation of novel portable metering systems, and autonomous noise reporting.

Analysis of perceived responses using a single factor ANOVA and a two-sample t-test assuming equal variance suggests that participants found sounds with certain acoustic correlates (temporal impulsive content, and high frequency tonal components), to be most annoying – tram curving, for example, was reported to be much more annoying than road and air traffic.

Beyond additional data capture, direction for further work includes training a regression algorithm on the acoustic correlates to assist in annoyance prediction, and to develop a machine learning model to analyse the large biometric dataset resulting from these experiments, and to consider analysing features in the brain activity as captured via EEG to seek correlations between EEG, self-report, GSR and cardiovascular metrics in a consolidated models.

This work was jointly conducted by Arup and the Digital Creativity Labs (www.digitalcreativity.ac.uk). Academic funding was provided by

EPSRC/AHRC/InnovateUK under grant no EP/M023265/1. Arup have internally funded the research through their Invest in Arup programme.

6. REFERENCES

1. I. Daly *et al.*, "Automated identification of neural correlates of continuous variables," *Journal of neuroscience methods*, vol. 242, pp. 65–71, 2015.

2. S. D. Vanderark and D. Ely, "Cortisol, biochemical, and galvanic skin responses to music stimuli of different preference values by college students in biology and music," *Perceptual and motor skills*, vol. 77, no. 1, pp. 227–234, 1993.

3. P. J. Lee and J. Y. Jeon, "Soundwalk for evaluating community noise annoyance in urban spaces," in *The 9th Congress of the International Commission on the Biological Effects of Noise-ICBEN. B. Griefahn (Ed.), ps*, 2008, pp. 595–599.

4. G. Bates Enda; Boland, Frank; Furlong, Dermot; Kearney, "A Comparative Study of the Performance of Spatialization Techniques for a Distributed Audience in a Concert Hall Environment," in *Audio Engineering Society Conference: 31st International Conference: New Directions in High Resolution Audio*, 2007.

5. R. McGarrigle *et al.*, "Listening effort and fatigue: What exactly are we measuring? A British Society of Audiology Cognition in Hearing Special Interest Group 'white paper,'" *International journal of audiology*, vol. 53, no. 7, pp. 433–445, 2014.

6. C. Clark, M. Smuk, S. Stansfeld, R. Van De Kerckhove, and H. Notley, "What factors are associated with noise sensitivity in the UK population?," in *INTER-NOISE and NOISE-CON Congress and Conference Proceedings*, 2014, vol. 249, pp. 5904–5913.

7. ISO, "BS 15666," *Acoustics–Assessment of noise annoyance by means of social and socio-acoustic surveys*, 2003.

8. D. Glowinski *et al.*, "Using induction and multimodal assessment to understand the role of emotion in musical performance," *Emotion in HCI–Designing for People*, p. 8, 2010.

9. A. Camurri, G. Volpe, G. De Poli, and M. Leman, "Communicating expressiveness and affect in multimodal interactive systems," *Multimedia, IEEE*, vol. 12, no. 1, pp. 43–53, 2005.

10. M. Ballora, B. Pennycook, P. C. Ivanov, A. Goldberger, and L. Glass, "Detection of obstructive sleep apnea through auditory display of heart rate variability," in *Computers in Cardiology 2000*, 2000, pp. 739–740.

11. J. R. Krygier, J. A. J. Heathers, S. Shahrestani, M. Abbott, J. J. Gross, and A. H. Kemp, "Mindfulness meditation, well-being, and heart rate variability: A preliminary investigation into the impact of intensive Vipassana meditation," *International Journal of Psychophysiology*, vol. 89, no. 3, pp. 305–313, 2013.

12. C. S. Pereira, J. Teixeira, P. Figueiredo, J. Xavier, S. L. Castro, and E. Brattico, "Music and Emotions in the Brain: Familiarity Matters," *PLoS ONE*, vol. 6, no. 11, p. e27241, Nov. 2011.

13. D. Västfjäll, "Influences of Current Mood and Noise Sensitivity on Judgments of Noise Annoyance," *The Journal of Psychology*, vol. 136, no. 4, pp. 357–370, Jul. 2002.

14. A. Gabrielsson, "Emotion perceived and emotion felt: Same or different?," *Musicae Scientiae*, vol. 5, no. 1 suppl, pp. 123–147, 2002.