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PHYSIOLOGICAL RESPONSES AND SUBJECTIVE ESTIMATES OF SOUNDS: INITIAL RESULTS OF PILOT STUDY

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ABSTRACT

In an attempt to understand the effect of sounds on physiological measurements, along the positive (pleasant) - negative (unpleasant) subjective dimension, 51 subjects (26 male) listened to 13 sounds in clips of 8s interspersed with 16s of silence while their heart rate, respiratory rate and skin conductance were measured and they recorded the subjective pleasantness of the sound. The sounds were in three categories, natural (eg birdsong) human (eg crying) and transportation (eg aircraft take-off). There were highly significant decreases in heart rate and significant increases in respiratory rate with some gender differences in response to the sounds. Initial analysis showed no significant correlation between the physiological measures and the subjective evaluations of the pleasantness of the sounds.

1 INTRODUCTION

The application of soundscapes in community noise evaluation is attempting to provide practical data that can be applied by designers to create pleasing acoustical environments[1]. However, soundscapes provide complex auditory experiences and there are limited tools available to investigate their relative benefits. One approach is to investigate the sound elements of a soundscape is to determine the emotional response elicited. Sounds evoke various emotions and this can give rise to detectable changes in basic physiological measures. Therefore, recording physiological responses in association with subjective assessments of individual sounds could indicate meaningful patterns of response and provide a starting point for a more complete objective assessment of soundscapes. This approach of investigating the significant sound component elements by means of physiological recordings in association with subjective assessments to investigate the value of various soundscapes does not seem to have been applied before.

Emotions can be triggered by all our sensory systems but most early work on emotional response has been carried out on the visual modality. Bradley & Lang have been major authors in the study of physiological responses, subjective assessment and behavioural reactions associated with processing emotional images. They found reliable patterns of physiological change in visceral, somatic and central systems including heart rate variation and skin conductance measures in response to sound stimuli with different emotional and arousal content [2].

These authors investigated affective reactions to 60 sounds (6 second presentation) that varied in emotional content and arousing potential (eg. screams, clock ticking and baby cooing) and found the shape of the two dimensional space (pleasure v arousal) defined by the mean ratings for each sound was similar to that observed with pictures. They also reported that listening to unpleasant sounds resulted in larger startle reflex, EMG activity and heart rate (HR) deceleration than listening to pleasant sounds. They concluded that “acoustic cues activate the appetitive and defensive motivational circuits underlying emotional expression in ways similar to pictures” ie. common emotional systems underlie our responses to auditory and visual stimuli.

Gomez & Danuser studied[3] the affective judgments (pleasantness and arousal) and physiological responses to environmental noises and musical fragments (16 of each, 30 second presentations).

They found that respiratory rate (RR) and skin conductance (SC) increased for music while only RR increased for sounds. They concluded that differences in the relationships between subjective judgments and physiological responses suggested differences in the processing of music and sounds.

The above provides evidence that the response to sound can be described in terms of patterns of simple physiological measures e.g. heart rate, respiratory rate and skin conductance, which are related to emotional dimensions such as arousal and pleasantness.

The primary goal of the current pilot study was to investigate the response of 3 simple physiological measures HR, RR ad GSR to a total of 12 relatively common sounds in three general categories human, transport and natural plus pink noise. There were three specific questions posed:

- Is there a change in recorded physiology (HR, RR & SC) to sounds?
- What is the variation in response to the categories of sound?
- Is there a gender effect?
- Is there a relationship between the pattern of the physiological changes and the subjective assessment of pleasantness of the sound?

A key design objective was that the whole recording procedure should take less than 20 minutes for each subject, thus avoiding motivational, compliance and recruitment issues and the physiological measures should be easy to apply with minimal inconvenience to the subject.

2 METHOD

2.1 Subjects

51 subjects (26 male) took part, aged 18-22 and studying at Manchester Metropolitan University. The subjects were unpaid volunteers, selected opportunistically from the undergraduate population; simple screening eliminated anyone with declared hearing difficulties. University ethical procedures were followed throughout the experiment. The initial personal questionnaires were anonymous and names were not taken at any point during the experiment. The experiment was explained carefully to the participant before starting and they were told they were free to leave at any point if they did not wish to continue.

2.2 Stimulus Materials

Stimuli consisted of 13 sound clips (from the “Freesound project”) edited to eight second, interspersed with 16 second silences. Each sound stimulus was normalised for sound level by using the “Audacity” software. This process looks for the maximum level in the clip and adjusts the lower level signals up to the maximum level. This resulted in all the clips being about the same overall level. The sounds were normalised to 100%, which allows the sounds to be played back at the highest level without any distortion. The sound series was recorded onto a CD and played to each subject with the same settings on the sound production software and through the same headphones (Coby Digital ®– CV 100)

The sounds were split into three different categories with four sounds in each category:
Natural: sea waves, baby bird, wind in trees and soft rain;
Human: crowd cheering, woman screaming, baby crying and woman laughing;
Transport: train, motorway traffic, tram and aircraft;
Pink noise was also used
The order of the sounds was arranged quasi-randomly so that the sounds did not occur in categories sequentially.

2.3 Physiological Measurement

Three Physiological recordings were taken during the listening task:

Heart rate (HR) was measured via ECG activity which was recorded by using standard ECG electrodes positioned on the upper right and left side of the chest and an additional earth electrode on the wrist of the non dominant hand.
Respiration rate (RR) was measured by recording breathing movements by placing a respiration belt around the participant between the waist and the rib cage, securely but without impeding normal respiratory movement.
Skin conductance (GSR) was measured by via skin conductivity via electrodes placed on the middle segments of the middle and index fingers on the non dominant hand. The GSR recordings had to be zeroed for each subject.
All of the equipment used was connected to a Powerlab® (multipurpose physiological recording system linked to a PC) and the computer program "Chart5" was used to process the physiologically signals.

2.4 Procedure and Study Design

The subject was seated at a bench in a small quiet experimental room facing a blank wall. The room was kept dimly lit to minimize all other stimuli. Each potential subject was given time to adjust to the surroundings and asked to fill out a personal details questionnaire with 8 short questions:

- Age
- Gender: Male/Female
- Respiratory Problems: Yes/No
- Do you exercise: Yes/No
- If yes how often per week
- Do you having hearing difficulties: Yes/No
- Do you live in a city, suburban or rural area?

If the subject had hearing difficulties they were excused from the remainder of the experiment.

All of the subjects were given the same instructions at the beginning of the experiment; this was ensured by the use of a script which the experimenter read out. The precise order of the experiment was explained to them starting with the attachments of the electrodes, where they would be placed and what they would be measuring, that they would listen to 13 sounds and how they should respond. They were instructed not to rate the sound until it had finished playing.

After the electrodes and the respiration belt were attached and the recordings checked, the subject had a few minutes to adjust and relax, then the sound clips were played through headphones. After each sound the participant gave a subjective response, via pencil-and-paper, to the sound using a 5-point pleasantness questionnaire, then sat quietly and waited for the next sound. The stimulus sounds were played in the same order for all of the 51 participants.

The CD lasted 312 seconds and the preamble, electrode attachment with adjustment and checking plus final removal took about a further 10 minutes. So the whole procedure took less than 20 minutes per subject.

2.5 Data Analyses

The physiological recordings from the 16 second quiet period were split into 2 x 8 seconds and the 8 second silence period before each of the sounds was used for comparison with the following sound period. The measures extracted from the 8 seconds recordings were mean heart rate (beats/minute); mean respiration rate (breaths per minute); skin conductance as the maximum slope in the GSR. These measures were extracted via the Data-pad facility on the PowerLab®. The measures were taken during each sound and during the eight second silence before the sound. The measures were entered into a large in Microsoft Excel for statistical analysis via Minitab and SPSS.

Some preliminary analysis for heart rate and respiratory rate is reported here. A paired t-test was carried out on all the data for heart rate and respiration rate regardless of the type of sound and gender. This test was done to show if there was a significant difference due to sound. To investigate any gender differences paired t-tests were carried out on respiration rate and heart rate and the different types of sounds for males and females. Spearman's rank correlations were carried out between heart rate and respiration rate during the sound and the personal subjective rank of the sound. This was done to see if the physiological reaction is related to the sounds position on the pleasant – unpleasant continuum. ANOVA, discriminant and cluster analysis are planned to see how subjective scores correlate with physiological measurements.

3 RESULTS

3.1 Silence v sounds:

The mean HR in the silence before the sounds was 75.90 beats/m which was then significantly (paired t-test; $p<0.001$) decreased to a mean value of 73.98 b/m during the sounds. The mean RR in the silence before the sounds was 15.19 breaths/m which was then significantly increased (paired t-test; $p=0.012$) to a mean value of 15.71 breaths/m during the sounds.

3.2 Males and females:

Paired t-tests showed more significant findings for males than females (Tables 1,2,3 &4) :
Male HR was significantly reduced after exposure to all categories ie. natural, transport and human sounds while females HR were significantly reduced with natural and human sounds. Also, male RR was significantly increased during transport and human sounds while female's RR was only significantly reduced during human sounds.

Physiological Measure	Gender	Sound Type	Mean Quiet before	Mean During Sound	p
HR	Male	Natural	73.52	70.73	***
HR	Male	Traffic	73.69	71.45	**
HR	Male	Human	72.60	70.47	**
HR	Male	Pink Noise	71.56	71.34	NS

Table 1: Mean HR values for males for different types of sound, before and during exposure to the sound (*** p<0.001, ** p<0.01, p<0.05, NS p>0.05).

Physioloical Measure	Gender	Sound Type	Mean Quiet before	Mean During Sound	p
HR	Female	Natural	78.93	77.03	***
HR	Female	Traffic	78.94	77.99	p=.06
HR	Female	Human	79.39	77.24	***
HR	Female	Pink Noise	78.12	77.42	NS

Table 2: Mean HR values for females for different types of sound, before and during exposure to the sound (*** p<0.001, ** p<0.01, p<0.05, NS p>0.05).

Physiological Measure	Gender	Sound Type	Mean Quiet before	Mean During Sound	p
RR	Male	Natural	16.18	15.78	NS
RR	Male	Transport	15.51	16.40	*
RR	Male	Human	15.22	17.62	***
RR	Male	Pink Noise	16.12	16.24	NS

Table 3: Mean RR values for males for different types of sound, before and during exposure to the sound(*** p<0.001, ** p<0.01, p<0.05, NS p>0.05).

Physiological Measure	Gender	Sound Type	Mean Quiet before	Mean During Sound	p
RR	Female	Natural	16.72	16.40	NS
RR	Female	Transport	17.28	16.42	NS
RR	Female	Human	15.74	18.07	**
RR	Female	Pink Noise	16.71	16.09	NS

Table 4: Mean RR values for females for different types of sound, before exposure to the sound and during exposure to the sound(*** p<0.001, ** p<0.01, p<0.05, NS p>0.05).

Subjective estimates of pleasantness compared with physiological response:

Subjective ranking of all the sounds was calculated by tallying all the subjects individual subjective scores for all the sounds (Table 5).
In order to investigate if there was a correlation between the subjectively ranked sounds and their HR and RR responses a Spearman’s rank correlation was calculated.

Rank	Sound	Cumalative Subjective Scores
1	Screaming	249
2	Pink Noise	225
3	MotorwayTraffic	175
4	Aircraft	172
5	Baby Crying	166
5	Laughing	166
7	Train	158
8	Soft Rain	155
9	Tram	151
10	Cheering	140
11	Sea Waves	125
12	Wind	124
13	Baby Bird	105

Table 5: Total subjective ranking for all subjects and all sounds, the highest score was the most unpleasant

Both physiological measurements, HR and RR have weak non significant correlations with the subjective ranks of -0.042 and 0.040 respectively.

The GSR results for skin conductance have not yet been analyzed.

4 DISCUSSION

In terms of the initial questions posed, the preliminary analysis has shown that there was a highly significant deceleration of the HR in response to sounds of about 2 beats per minute. This agrees with most previous work(2,3,4) eg. Bradley & Lang showed(2) the largest reduction in HR was for 'screaming' of 2.83 bpm. However, some other work(3)), which used longer stimulus presentations (30s), showed an increase in HR associated with increased arousal ratings. Alterations in the RR to sounds were not as prevalent in our results as the HR results but a significant increase was observed. This agrees with others(3).

However, with the present results we were unable to replicate previous findings(2) of greater HR deceleration with unpleasant sounds. Further more focused and sophisticated analysis may show this. From a physiological perspective the allocation of sounds to categories can be considered arbitrary, analysis needs to focus more on the pleasantness arousal dimensions.

In terms of categories of sounds it seemed that 'natural' and 'human' had more significant effects on HR than 'traffic' while 'human' sounds caused more significant RR changes. Human sounds showed the most significant results across category and physiological measure. There could well be issues of novelty and habituation with some of the sounds chosen as 'road traffic' noise is part of most UK citizens experience (particularly for our MMU subjects which has both an elevated motorway and a major commuter route running through the campus) while the noise of young birds would be more novel.

There were indications of gender differences in their response with more significant affects of sounds from males. Gender differences for HR and RR response to sounds are not clearly stated in the literature. This may be due to the well established fact that the normal resting heart rate for females is about 5 beats/m faster than for males.

The results here show that the subjective response on whether the subject found the sound pleasurable or not had no positive correlation to the way the subjects HR and RR responded to the sound. These findings disagree with previous studies[2,3]. This difference may in part be explained by the fact that these authors[2,3] used a 9 point scale, rather than our 5 point scale, to measure pleasantness and they subjectively assessed arousal which would provide additional information for analysis.

Limitations and Future Research

There are a number of ways that this approach could be developed to assess more real-life scenarios and soundscapes:

- The methods could be improved to include an assessment of the arousal associated with each sound so that the emotional space would be more completely mapped and allow more insights into the subject responses. In addition the subjective scales could be increased from 5 to a 9 point discrimination, both these changes would add little time to the procedure.

- The duration of a single sound could be increased to investigate habituation and within sound analysis (every second) could be employed.

- The influence of context could be investigated by having "contextually supportive" sounds eg. wind in trees background with bird noise added and "contextually incongruence sounds" sea waves background with short periods of city traffic.

- Another contextual theme could be have "contextually supportive" visual images to accompany sounds compared with "contextually disparate" visual images.

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