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Analysing the Changes in Physiological Response to Different Soundscape Scenarios

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ABSTRACT

Noise pollution is one of the key environmental stressors leading to multiple health impacts for people and communities. Exposure to high noise levels may also be responsible for sudden emotional and physiological changes in humans. The experiment examines the change in Galvanic Skin Response (GSR) signals during exposure to pre-recorded soundscape scenarios. These scenarios were recorded in New Delhi, India and London, UK, using a binaural microphone set. The listening experiment was conducted in a laboratory, where 27 healthy individuals without any hearing impairment or any psychological issues participated. A total of 30 soundscape scenarios were presented to each participant in a randomised order. The continuous decomposition analysis is conducted to decompose that data into tonic and phasic components. The phasic component of the signal is used for the analysis. It is observed that skin conductance response increases with changes in eventfulness of the signal ($P<0.05$). The pleasantness of the signals has not shown a statistically significant relationship with the change in skin conductance response.

Keywords: Traffic Noise, Galvanic Skin Response (GSR), physiology, soundscape scenarios

1. INTRODUCTION

Noise pollution is one of the major environmental stressors causing multiple health impacts, leading to multiple physical and psychological impacts on human health. The physical impact of the noise exposure includes annoyance, stress, hypertension, blood pressure, cardiovascular issues, sleep deprivation and damage to auditory organs [1]. Traffic noise pollution is one of the significant contributors to environmental noise pollution. The high traffic volume in urban areas increases overall noise levels in cities, leading to multiple health impacts on urban dwellers.

Among key health impacts, the increase in stress and annoyance are significant and the most common issues. The change in emotions is mainly dependent on the perception of soundscape scenarios by the user. The perception of the soundscape scenarios can be described in various scales, of which pleasantness and eventfulness are the leading indicators. As per ISO standards, 12913:2:2018 [2] shows that eventfulness and pleasantness are among the major descriptors of

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soundscape perception. These indicators are also proposed by F Aletta and J Kang [3] as a major indicator for the soundscape assessment.

The assessment of these issues is mainly done through self-reported subjective assessments. In recent years, laboratory assessment to analyse the emotions associated with soundscape has been in progress. Authors have used different physiological signals, such as heart rate (HR), Skin conductance level (SCL), electromyography (EMG) and Respiration Rate (RR), along with the perceptual attributes [4–6]. In past studies, the assessment of perception of soundscape is done using subjective surveys, whereas few have investigated the role of physiological indicators in soundscape assessment [7,8]. The current studies related to soundscape perception are mostly limited to the subjects' soundscape attributes and subjective responses. The studies related to the exploration of physiological and neural changes due to soundscape are limited, creating a need for a more comprehensive evaluation.

The galvanic skin response (GSR) is one of the physiological indicators that mainly relate to the subject's stress level and arousal level. Physiologically it is the activation of the endocrine system driven by the Central Nervous System (CNS) and Peripheral Nervous System (PNS). It is referred to as a variation in the electric activity of the skin in response to the sweat secretion [9]. The constant low voltage is applied to the skin, and the fluctuation in skin conductance is noted due to sweat secretion. This is one of the non-invasive methods to calculate the physiological response to different external stimuli.

The study attempts to find the relation between different perceptual attributes for soundscape assessment and change in GSR signals. Two perceptual attributes, 'Eventfulness' and 'Pleasantness', are considered for the analysis. The study also investigates the change in GSR signals in different soundscape scenarios.

2. METHOD AND MATERIALS

This study consisted of a listening experiment conducted at the University College London (UCL), where participants were presented with different soundscape scenarios, mainly from traffic and urban street conditions. The dataset consists of noise scenarios from London and New Delhi. While listening to the noise stimuli, the galvanic skin response is collected along with other physiological signals. In the second part of the experiments, participants were asked to listen to the noise stimuli again and report their perceptions in terms of pleasantness and eventfulness level on a linear scale. The following section presents the experiment methodology in detail.

2.1 Collection of on-site data in UK and India

The audio recordings are collected in New Delhi and London. A total of fifteen noise locations describing different soundscape scenarios are collected from each city, comprised of very noisy to quiet streets. The majority of the locations in both the city were streets, parks, and residential and commercial neighbourhoods. For data collection in London, the SQobold four-channel data acquisition system and (BHS II) Binaural headphones are used for the data collection. In London, a binaural data acquisition system was used. In New Delhi, a Class 1 sound level meter is used to collect the noise equivalent levels and the spectral data of the environment, while a dedicated binaural recorder is used to record audio, which is further used for psychoacoustic analysis. The on-site campaign in London was performed within the framework of the research project Soundscape Indices, following the dedicated protocol as described in [10,11]. Whereas in New Delhi, the data is collected according to the Soundscape Indices protocol, with few minor changes.

The soundscape scenario in India and UK is very different. The maximum noise levels in London were noted in the Camden town area at 81.72 dB, and the minimum noise levels were noted at 62.09 dB in Regents Park. In comparison, the maximum noise level for New Delhi city was 85.67 dB at Karol Bagh and Shahdara, and a minimum of 65.23 dB at Asian games village. The major change in noise is due to changes in traffic volume and a high level of heterogeneity in the traffic scenarios. The commercial areas are the loudest location in both scenarios.

The major change in noise is due to changes in traffic volume and a high level of heterogeneity in the traffic scenarios. The commercial areas are the loudest location in both scenarios. After acquiring the soundscape stimuli, the dataset is checked for discrepancies and further processed to get the relevant psychoacoustic indicators. Since it is observed that both binaural and monaural recording correlates approximately in a similar way to the subjective and listening responses, The soundscape stimuli were converted to the monaural recording with a sample sampling rate of 48000 Hz [12]. The psychoacoustic parameters such as loudness, sharpness, fluctuation strength and roughness are calculated for these stimuli using Artemis software. These indicators are used to characterise the noise stimuli as per the ISO standard [13].

2.2 Laboratory assessment

The laboratory assessment is conducted at the Acoustic Lab of University College London (UCL). The experiment was approved by the ethical committee at UCL, dated 12/11/2021. The participants were invited to the experiments using posters and emails. The inclusion-exclusion criteria were informed to the participants in advance while inviting them to the experiment. The healthy participants with good hearing conditions without any heart or psychological issues were selected for the experiment. The length of the experiment was 90 min which includes the experimental setup, listening experiment and subjective surveys.

2.3 The demographic details

A total of 30 participants participated in the experiment, of which three were excluded due to issues with data acquisition. A total of 27 people were analysed for the experiment, of which 16 males and 11 females participated. The galvanic skin response while listening to different traffic stimuli is recorded and presented in the following section.

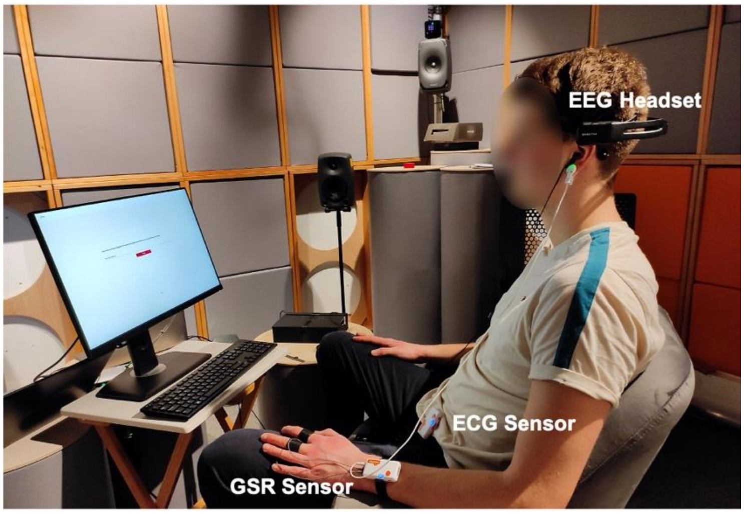

Figure 1: Figure showing the experimental setup during the listening experiment.

The participant was asked to visit the lab for the experiment. The experiment process is introduced to the participant; after getting the participant's written consent, the experiment was started. The experiment includes the collection of three physiological responses viz EEG, ECG and GSR. The EEG data is collected from EMOTIV epoch+ headset, whereas the ECG and GSR data is collected from the SHIMMER Sensing device. All the physiological signals were collected at the frequency of 128 Hz. For an initial 10 minutes, the participant was asked to sit and get comfortable with the lab setup; this period was utilised to set up the sensors. The participant was provided with a comfortable non-revolving seat and a screen to look at the experiment's instructions. The EEG, ECG and GSR sensors were set up on the participant's head, chest, and palm, respectively (see Figure 1). It was ensured that the contact quality of all the sensors in 100 percent. After the experimental setup, a participant was left alone in the lab, and the experiment was operated from the control room.

2.4 Presentation of stimuli:

A total of 30 audio samples were presented in a random order using EmotivPro and Shimmer ConsensysPRO data acquisition software. Half of the stimuli were from New Delhi and a half from London. The participant was unaware of the composition of noise stimuli in the experiment. The length of each stimulus is 15 sec, which was presented at the minimum interval of 30 sec, which acted as a resetting period and baseline measurement for the participant after each stimulus. The 30 signals were presented in the three parts, where participants were asked to initially listen to 10 stimuli followed by a break of 10 min and later, the process was followed a second and third time. After listening to all 30 signals, all the sensors were removed from the participant's body and allowed to rest for 15-20 minutes. During this period, they were allowed to move outside the laboratory.

2.5 Subjective assessment

A total of 30 noise signals, as described in the above section, were presented to the participants while recording to the GSR. At the end of the experiments, participants were asked to report their perception of participants towards each stimulus in terms of pleasantness (Valance) and eventfulness (arousal).

The overall mean of the responses towards each stimulus is considered as a threshold to determine the high/low and positive/negative category of the perception. The score for eventfulness above the mean score is considered 'Eventful', and the score below the mean is considered 'Uneventful'. A similar concept determines the 'Pleasant' and 'unpleasant' stimuli.

This paper only reports the change in galvanic skin response due to the exposure to different noise scenarios.

2.6 Galvanic skin response

Skin conductance response is measured using the shimmer3 GSR+ unit, which is a wearable device with two 8 mm snap style finger type Ag-AgCL electrodes with a constant voltage of 0.5 V. The two sensors were attached to the left index and ring finger of the participant's non-dominant hand. The SC recording device was wirelessly connected to a PC, and data was digitalised using the Shimmer ConsensysPRO software. The gain was set to 10 mSiemens (μS)/ Volt, and the A/D resolution was set to 12 bits, allowing responses ranging from 2 to 100 μS to be recorded.

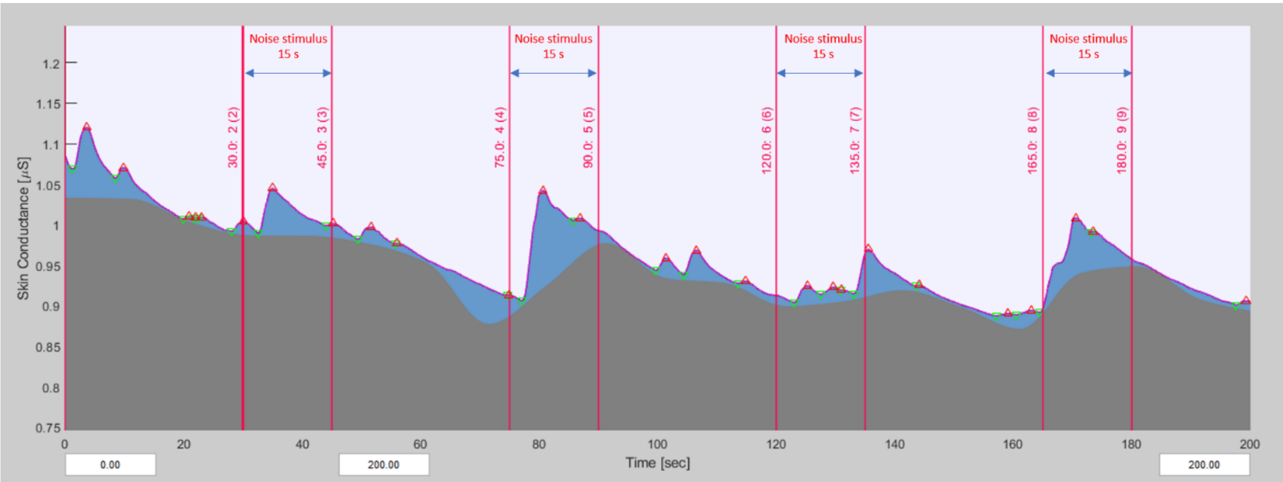

Figure 2: Variation in Skin conductance while listening to soundscape stimuli.

The 'LEDAlab', a MATLAB based toolbox, is used for data processing. The data was initially recorded at 128 Hz, which was downsampled at 16 Hz (factor 8), followed by manual smoothing of data using moving average at 8th order gauss window. The Butterworth low pass filter is applied to the data at the first order and lower cut-off frequency of 5 Hz, the default for LEDALab. Further, the 'Continuous Decomposition Analysis' CDA is used for extracting different components from the GSR data [9]. Previous research has shown that resampling has no effect on signal quality because SCR waveforms can be perfectly represented using fs = 8 Hz (or even fs = 4 Hz), but it does allow us to significantly reduce computation time. [14,15].

The galvanic skin response consists of two tonic and phasic activity components. The tonic activity component, also known as skin conductance level (SCL), is a slow response to the stimuli, which changes over 10-60 sec. The phasic activity component is the faster response to the stimuli, which changes over 1-5 sec. In this experiment, the Phasic component is used for the analysis since we were interested in finding the instantaneous response of soundscapes to human physiology. Through the continuous decomposition analysis, four features are extracted from the GSR data i.e.

1. **CDA.SCR:** The value shows the phasic activity within the response window most accurately but does not fall back on classic SCR amplitudes (muS)
2. **CDA.nSCR:** Number of significant SCR within response window.
3. **CDA.AmpSUM:** Sum of SCR-amplitude of significant SCR within response window.

The SCR data is obtained across all four features; the raw data was extracted from 15 s of stimuli response, and the previous 30 s data was used for the baseline extraction. Due to greater differences between participants, the acquired physiological signals are normalised. Using the formula below, each physiological response is converted to a percentage of its difference from the baseline value.:

Percentage change (%) = [(raw value – baseline value)/baseline value] $\times$100

Further, these changes are normalised to analyse the difference in GSR features in various conditions. The subjective responses are converted into two categories considering the mean values as a threshold for the category split. For pleasantness, the stimuli with a score above the mean value are considered 'Pleasant' stimuli and the stimuli with a lower score are termed 'unpleasant' stimuli. Similarly, the eventfulness score is divided into the 'Eventful' and 'Not eventful' categories based on the mean score threshold. Further, this data is used for analysing the change in GSR with respect to these categories.

3. RESULTS AND DISCUSSION

3.1 The change in GSR values with the change in pleasantness levels

The change in GSR is recorded for the pleasantness level, using three features, 'nSCR', 'SCR' and 'AmpSCR'. Fifteen noise stimuli were reported as 'Pleasant' and 15 as 'Unpleasant'. The mean % change in nSCR for the pleasant and unpleasant categories was 0.01 and 0.05, respectively. The percentage change in SCR for pleasant conditions is 0.20 and for unpleasant conditions is -0.35. For the AmpSCR, the percentage change in pleasantness was 0.08 and for unpleasant was -0.30.

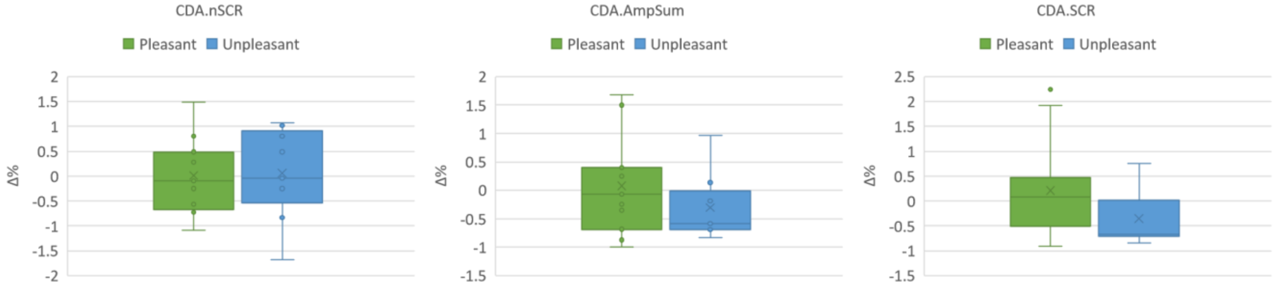

Figure 3: Change in GSR feature in pleasant and unpleasant scenarios.

Figure 3 presents the boxplot for the pleasantness with the normalised quartile ranges and median value. The figure shows that GSR variation across all features is higher for the pleasant category. The average change in nSCR for both pleasant and unpleasant conditions is primarily similar, and the % change in pleasant conditions is in a positive direction compared with unpleasant conditions. From the results, it is deduced that an average change in GSR is slightly more for the pleasantness category but not statistically significant. The overall change in SCR may be due to the passive soundscape situation that the listener dislikes, resulting in an inactive/not aroused physiological state. The higher number of SCRs (nSCR) in unpleasant conditions may be triggered due to unwanted soundscape scenarios, such as traffic noise or honking, which has led to the less pleasant scenario.

3.2 The rate of change in SCR features for eventfulness level:

Figure 4 shows the normalised rate of change in GSR for the eventfulness of the noise stimuli. It is noted that the average rate of change in nSCR is 0.11 for eventful conditions, whereas, for the uneventful conditions, the rate of change in nSCR is -0.08 units. For AmpSCR, the percentage change for the eventful conditions is 0.10, and for an uneventful condition, the rate of change is -0.39. Similarly, for SCR, the rate of change for an eventful condition is 0.23, and for an uneventful condition, the percentage change is -0.46 units.

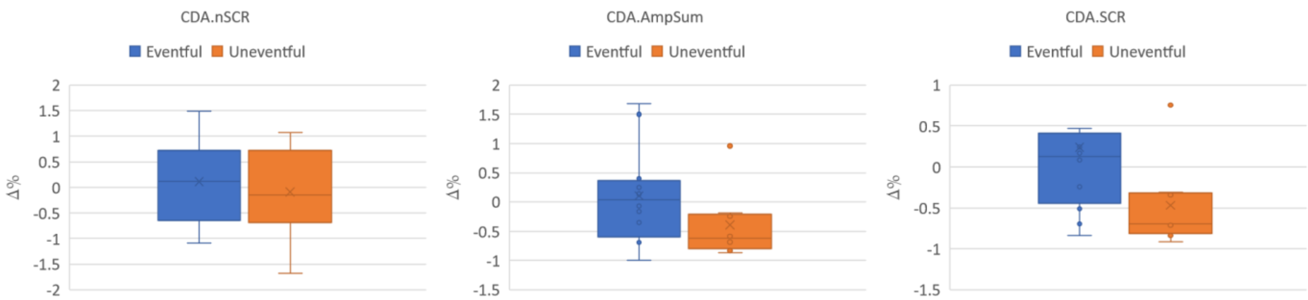

Figure 4: Change in GSR feature in eventful and uneventful scenarios

It is noted that the change in GSR values is more for the eventful condition. The change in nSCR shows that for eventful conditions, there are higher skin conductance responses triggered when compared with uneventful conditions. The total sum of SCR peaks (AmpSum) is more in the eventful condition. Also, the overall change in skin conductance response (SCR) is more for eventful conditions. It can be inferred that the eventful condition, i.e. arousal level, directly impacts the change in galvanic skin response.

The statistical analysis is carried out to find the significant variation due to pleasantness and eventfulness on GSR. The two-tailed t-test with unequal variance is carried out to compare the two groups for a statistically significant difference. It is observed that the pleasant and unpleasant categories do not have much significant difference, where the $P<0.1$. For eventfulness, a significant statistical difference is observed for SCR with $P<0.05$. This shows that SCR changes significantly due to changes in the eventfulness of the soundscape scenario.

3.3 Change in SCR for New Delhi and London soundscape stimuli

In this section, the variation in GSR is noted across two different locations, i.e. New Delhi and London. Though participants were unaware of the location identity of the stimuli, an attempt was made to study the difference using SCR signals.

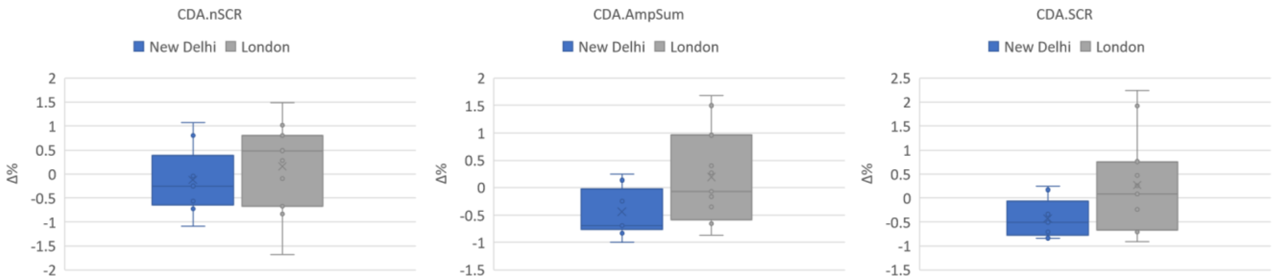

Figure 5: Change in GSR features for New Delhi and London soundscape stimuli.

Figure 5 shows the rate of change in GSR value for New Delhi and London using the box plot. Interestingly, the activation of the GSR signal is more for London soundscape scenarios than New Delhi. The mean value for all three features is higher for London, with a significant change in skin conductance response. The mean change in the nSCR for new Delhi was -0.12, whereas for London was 0.16. The total summation of skin conductance peaks for London was 0.19 and for new Delhi was -0.43. A similar trend is observed for overall skin conductance response (SCR), where the average change in New Delhi was observed to be -0.42, and for London, it was 0.26.

A considerable change in all three features is observed for London. This may be because of more familiarity of the British participants with the local soundscape scenario, leading to a more eventful and pleasant perceived environment. Also, a few of the sound stimuli from New Delhi were loud traffic noise scenarios, with lots of honking sometimes contributing to unpleasant soundscape perception.

3.4 Change in GSR features in four soundscape scenarios

Based on the above results, the two-dimensional soundscape model based on perceived affective quality responses is used for further analysis, as per ISO 12913:3:2019 [13]. The subjective response based on soundscape quality can be represented in a two-dimensional model based on pleasantness and eventfulness, resulting in different soundscape scenarios. Four categories, based on the average subjective response, are considered, (a) Eventful and pleasant condition, (b) Eventful and unpleasant condition, (c) Uneventful and unpleasant condition, (d) Uneventful and Pleasant condition. Two representative soundscape stimuli are considered for each condition, each from New Delhi and London. These stimuli were part of the 30 soundscape stimuli presented to the participant for the listening experiment.

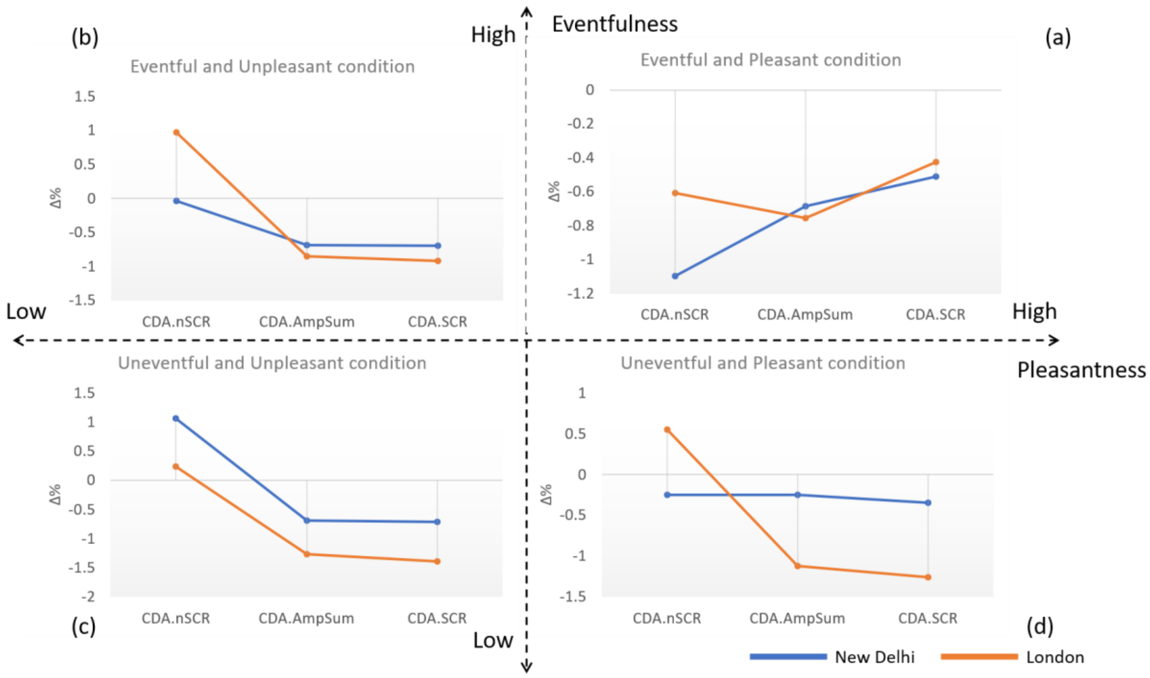

Figure 6: Change in GSR features in four different conditions. One location from New Delhi and London is considered for each condition based on the subjective response of participants.

Figure 6 represents the change in skin conductance response across four conditions. From the figure, it is noted that for condition (a), the change in SCR is more significant for London when compared with New Delhi due to high eventful and pleasant scenarios leading to more vibrant soundscapes. In condition (b), the change in SCR is greater in New Delhi city, whereas the significant SCR is higher in London; this is due to the eventful nature of both the location. For condition (c), a clear distinction between the change in SCR and the number of significant SCR is observed for both the city. This category represents uneventful and unpleasant scenarios such as continuous traffic and monotonous environments. Since it is observed in New Delhi city that the traffic noise is very high with lots of honking, the Skin conductance response increase considerably. Condition (d), an uneventful and pleasant condition, shows a higher rate of change in SCR for New Delhi city. Also, the number of significant SCR is more for the London area. While comparing the location using the SCR, it is observed that the major and significant changes are observed for the London soundscape stimuli due to the highly eventful and pleasant soundscape scenario on the streets. But it is an evident report from figure 6 that streets in new Delhi are more eventful and less pleasant, leading to higher variation in SCR than in London soundscape.

From the analysis, it is observed that SCR does not appropriately describe the pleasantness level of the auditory stimuli. But it is worthwhile to note that the change in pleasant stimuli has impacted the % change in SCR. The higher change in SCR for pleasant stimuli demonstrates the activation of the autonomic activation of sweat glands due to exposure to loud and vibrant noise conditions. The skin conductance response shows a significant variation for eventful categories. The activation of SCR is significantly noted for eventful stimuli, with higher mean and median values. It demonstrates that with an increase in the eventfulness/arousal state of the soundscape, the SCR increases considerably. Also, it is independent of the pleasantness/valance state of the stimuli. The results complement the experiments conducted by Bradly and Lang [16], describing the effect of eventfulness and pleasantness levels on GSR values. Similar results are noted in various other studies describing parallel trends. These results support the recent finding that though there is no change in GSR due to pleasantness level, still it is essential to study the eventfulness in conjunction with the pleasantness dimension to determine the specific impact of soundscape on physiological signals.

4. CONCLUSION AND FURTHER WORK

The study analyses the change in Galvanic Skin Response (GSR) signals during exposure to pre-recorded soundscape scenarios. The two perceptual attributes, pleasantness and eventfulness, are used to compare the change in GSR through a listening experiment. It is observed that the Pleasantness level of the soundscape scenarios is not directly associated with the activation of GSR. At the same time, eventfulness showed a significant relation with change in GSR values. It is observed that with an increase in eventfulness of the stimuli, the rate of change in GSR increases considerably. This study supports previous findings in a similar domain and helps analyse different aspects of change in human physiology due to noise exposure. Also, it is noted that the change in GSR is observed in the different conditions, which is a combination of eventfulness and pleasantness levels. The different type of locations and their associated perceptual attributes lead to GSR changes.

This study can be used to analyse the correlation between different acoustical and psychoacoustical attributes with changes in galvanic skin response. The psychoacoustical indicators can be used to characterise the soundscape scenario, which can lead to predicting the change in physiological signals, leading to the change in the listener's emotional state. Further, the researchers intend to analyse the change in heart rate and brain waves due to exposure to similar soundscape scenarios. This will help to identify the change in other physiological signals due to exposure to the different soundscape scenarios. There is also a need to analyse the impact of cross-cultural differences and the level of noise sensitivity by comparing the results of London and New Delhi on individual basics.

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