Cross-Country Variation in Psychophysiological Responses to Traffic Noise Exposure: A Laboratory Experiments in India and the UK

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ABSTRACT

Traffic noise exposure has detrimental effects on human health, including both auditory and nonauditory impact. As one such nonauditory factor, individuals and communities in different countries may exhibit different patterns of noise sensitivity and corresponding tolerance levels, leading to a change in overall noise perception. This paper investigated the cross-country differences in psychophysiological responses to traffic noise exposure between Indian and British individuals. A psychophysiological signal-based (Heart Rate Variability (HRV) and Skin Conductance Response (SCR)) listening experiment was conducted in the Indian and United Kingdom to analyze changes in noise perception and psychophysiological responses resulting from exposure to the same noise stimuli. HRV analysis indicated greater cardiovascular impact and parasympathetic dominance in the Indian group due to a significant decrease in Heart Rate (HR) ($W = 653$, $p<0.01$). Also, a significant increase in the SCR ($W=535$, $p<0.001$) was noted, indicating a greater level of physiological arousal among British participants due to traffic noise stimuli. These findings highlight the difference in noise perception due to cross-country variation using psychophysiological responses. Understanding these cross-country differences can inform targeted interventions and policies to mitigate the adverse effects of traffic noise on human well-being.

KEYWORDS: Traffic noise exposure; Soundscapes; Cross-country differences; Psychophysiology

I. INTRODUCTION:

According to ISO 12913-1, soundscape is an acoustic environment that is perceived and experienced by humans [1]. The soundscape impacts the health, quality of life, and well-being of people and communities in context [2,3]. The acoustic environment in urban areas is complex, with interactions among multiple noise sources from pedestrians, vendors, restaurants, etc., leading to different qualities of soundscape [4].

Models such as the Circumplex Model of Affect help assess soundscape impacts on humans by characterizing emotional experiences based on valence and arousal. [5]. To specifically tailor this model for the soundscape domain, a "Soundscape Circumplex Model" has been proposed [6]. This model is based on two perceptual dimensions: Pleasantness and Eventfulness. Pleasantness refers to the degree of positive or negative affective response to a soundscape, while eventfulness pertains to the degree of perceived activity or calmness in a soundscape.

Noise annoyance, a key sound descriptor, is defined by ISO/TS 15666:2021 [7] as an individual's reaction to noise. It is considered for both long-term exposure (e.g., traffic, rail, aircraft noise) and short-term experiences in soundscape studies [8]. Models have been developed to understand noise annoyance in various settings, examining its physiological and psychological effects, such as changes in heart rate and stress levels [9]. Recognized as an essential indicator of noise environment quality, annoyance is included in the Soundscape circumplex model [10], overlapping with the negative side of pleasantness. Hence assessing annoyance, along with eventfulness and pleasantness, aids in a comprehensive understanding of soundscape impacts, particularly in urban settings.

Previous studies have shown that perceptions and reactions to noise vary across nationalities due to socio-cultural factors [11–13], affecting noise sensitivity and tolerance levels. These differences heavily influence how individuals perceive their acoustic environment [12–14]. A study comparing European and Chinese participants found significant differences in their perceptions of the pleasantness and dominance of sound sources [15]. Similarly, research involving Chinese and Croatian participants revealed significant differences influenced by environmental indicators, cultural backgrounds, and types of sound sources [16]. A study comparing UK and Chinese participants found cross-cultural differences in living environment preferences, noise perception, annoyance, sleep disturbance, activities, and sound preferences [14]. A comparative study between British and Chinese participants on soundscape expectations revealed that both groups prefer natural sounds, but the Chinese expect more natural, livestock, and melodic sounds, and fewer traffic and industrial sounds than the British participants [18]. Additionally, landscape preference assessments indicated that vegetation is significantly more important to the Chinese than to the British [19]. A study between Japanese and Vietnamese participants reported that the perception of the soundscape was influenced by language, lifestyle, and environmental experiences. At the same time, there were differences in noise source identification between the groups [20]. A laboratory assessment with French, Korean, and Swedish participants noted similarities in pleasantness assessments but differences in eventfulness assessments [21]. A study conducted among participants from cities, towns, and villages regarding soundscape perception revealed that city residents perceived 'natural' sounds as more monotonous, uneventful, and less vibrant compared to village residents [22]. These studies show that cross-national differences as well as other socio-demographic parameters influence soundscape perceptions, necessitating an assessment of the underlying factors. Furthermore, these cross-national studies on soundscape perception have predominantly relied on subjective questionnaires, with limited research exploring this evaluation using psychophysiological signals.

The soundscape perception model is based on a subjective survey, which sometimes does not correlate with the physiological changes induced by the noise exposure [23]. These variations are mainly due to changes in noise sensitivity level, habituation to noise and other sociodemographic parameters. To compensate for the ambiguity of subjective responses, an alternative approach for analyzing psychophysiological signals can be adopted [24]. The Investigation of psychophysiological signals in soundscape studies helps to understand the physiological and psychological responses to soundscapes. Analyzing psychophysiological signals, such as heart rate and electrodermal activity, provides objective measures of these responses, offering insights into the emotional and physiological processes triggered by sound environments.

Research has shown that the soundscape in India and the UK is notably diverse, primarily due to distinct traffic conditions and cultural contexts [25]. In India, urban areas are often characterized by high population density, congested roads, and a lack of comprehensive noise control measures [26,27]. As a result, the Indian population is exposed to higher levels of traffic noise, leading to increased annoyance and potential health impacts [27]. On the other hand, the urban soundscape in the UK is characterized by a homogeneous transportation system with a low rate of honking and the implementation of various noise mitigation and management strategies. These changes in soundscapes lead to a high level of health issues due to noise exposure. Simultaneously, there is a change in noise sensitivity levels and habituation to loud signals, which can lead to a change in the perception of noise.

In this context, this study investigated the differences in psychophysiological responses to urban noise stimuli between British and Indian subjects. The study is based on listening experiments involving Indian and British participants who were subjected to traffic noise stimuli recorded in different urban settings in London, UK, and Delhi, India.

In this study, two psychophysiological signals, i.e., electrocardiography (ECG) and skin conductance response (SCR), were used. By conducting this experiment, the goal is to gain insights into how soundscape scenarios in different countries can influence individuals' perceptions of noise and how it affects psychophysiological responses. This analysis will shed light on whether there are distinct patterns in noise perception and psychophysiological reactions between the two groups.

II. METHOD

This section outlines the study's methodology, detailing the noise data collection process and the listening experiments conducted in both India and the UK. Figure 1 presents a schematic flowchart of the experimental procedure followed in the study.

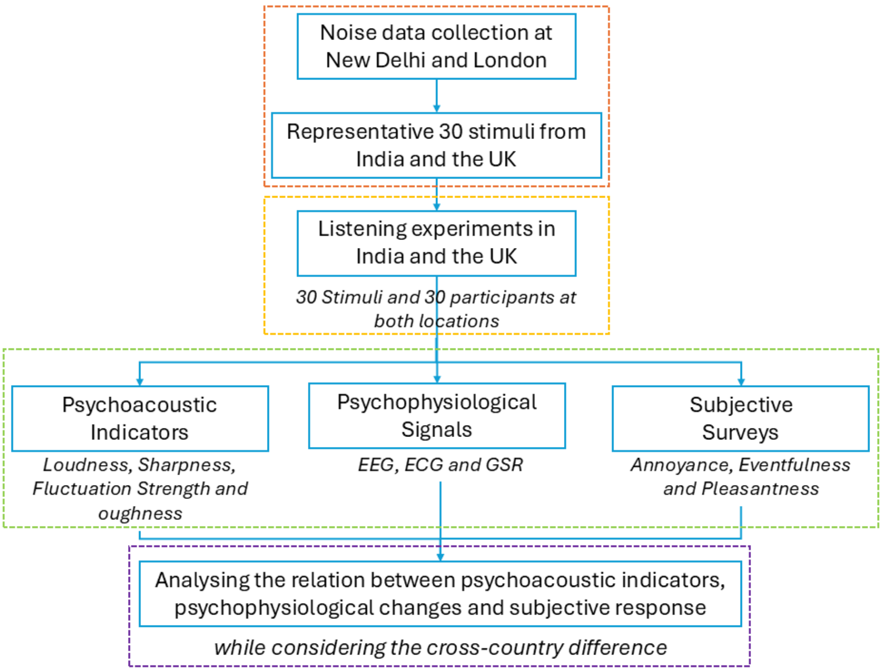

Figure 1: Schematic flow of the experimental procedure adopted in the cross-country study on noise perception for participants in both New Delhi and London, illustrating the details in noise data collection, listening experiments, data collection, and analysis process.

A. Noise Data Collection in India and the UK

Audio recordings were gathered from New Delhi, India, and London, UK, encompassing a total of fifteen noise locations depicting various soundscape scenarios in each city. In New Delhi, recordings were made at the Asian Games Village, Connaught Place, and JLN Stadium areas, while in London measurements were taken at Camden Town, Regent's Park, and Russell Square. In London, data collection utilized a calibrated SQobold data acquisition system with the (BHS II) Binaural microphone. In New Delhi, a Delta Ohm Class 1 sound level meter was used to record noise equivalent levels and spectral data, while audio recording was conducted using the 3Dio binaural microphone and the Zoom H4N recorder. The data collection at both locations was done according to the Soundscape Indices SSID protocol [28,29]. In London, Camden Town had the highest noise level (LAeq over 1 min) at 81.7 dB, while Regents Park was the quietest at 62.1 dB. In New Delhi, noise peaked at 85.7 dB in Karol Bagh and Shahdara, with the lowest level of 65.2 dB in the Asian Games Village. Notably, commercial areas stood out as the loudest locations in both scenarios.

B. Relevance of psychophysiological parameters

Heart rate variability (HRV) measures the variation in time between heartbeats, indicating physiological state. Time-domain HRV indices like Standard deviation of beat-to-beat intervals (SDNN) reflect both sympathetic and parasympathetic activity and are related to VLF and LF power. LF power (0.04-0.15 Hz) is influenced by both, while HF power (0.15-0.40 Hz) reflects parasympathetic activity. The decrease in HF power is linked to stress, panic and anxiety. Whereas the LF/HF ratio represents the balance between sympathetic and parasympathetic tones [30].

In Skin Conductance Response (SCR) analysis, 'nSCR' indicates the number of significant responses above a threshold, showing intensity and frequency of arousal. The 'Global Mean' is the average SC value, indicating overall arousal. The 'AmpSUM' test measures the cumulative amplitude of significant SCRs, reflecting total physiological response strength [31].

C. Listening Experiment

The listening experiment in India was conducted at the Indian Institute of Technology (IIT), Roorkee in a quiet chamber with a reverberation time of T_{60} = 1.1 s. At the University College London (UCL), the experiment took place in an acoustic laboratory with a reverberation time of $T_{30,\ 500Hz\text{-}2kHz}$=0.13s. The room temperature was constant with no movement of people inside. The study was conducted as per Indian Council of Medical Research National Ethical Guidelines and received ethics approval from the UCL ethics committee (dated 12/11/21).

1. Participant details

In India, 30 participants (15 males, 15 females, aged 22-28, mean age 25.1, SD 3.5) took part in the experiments. In the UK, 30 participants (14 males, 16 females, aged 20-49, mean age 28.7, SD 6.1) participated. In the UK the age group of participants was mainly skewed between 22-30, with 4 participants in the age group of 32-49. The Sample sizes was based on previous studies [32–34] and power analysis. Most of the participants were postgraduate students. As an incentive, the UK participants received a £20 Amazon voucher, while Indian participants received INR 500 in cash.

Participants for the experiment were selected based on the following inclusion criteria: they had to be between 18 and 60 years old, with no hearing disorders, cardiovascular problems, psychological issues, or skin allergies. Additionally, they were required to avoid recreational drugs and psychotropic medications for two weeks prior to the study.

2. *Experimental Procedure*

The experiment involved the presentation of 30 stimuli: 15 from New Delhi, India, and 15 from London, UK. To ensure ecological validity, playback levels were calibrated using an artificial head to match the L_{Aeq} values measured on-site. These calibrated stimuli were presented to participants at both the locations, and their psychophysiological responses were recorded using EEG, ECG, and GSR measurements. Data collection involved the Emotiv Epoch+ ® EEG headset for EEG data and Shimmer ® Sensing devices for GSR and ECG. These sensors were placed on participant's body as depicted in Figure 2. Participants wore Etymotic ER4 flat response earphones and viewed instructions on an LED screen, which was managed remotely by the researcher.

At the beginning of the experiment, participants completed an information sheet and signed the consent form. They were asked to complete the Weinstein Noise Sensitivity Scale [35]. A preliminary test was conducted initially to ensure all sensors were functioning correctly and that participants were comfortable. A 30-second baseline measurement was taken prior to the first stimulus to establish a reference point for relative signal changes.

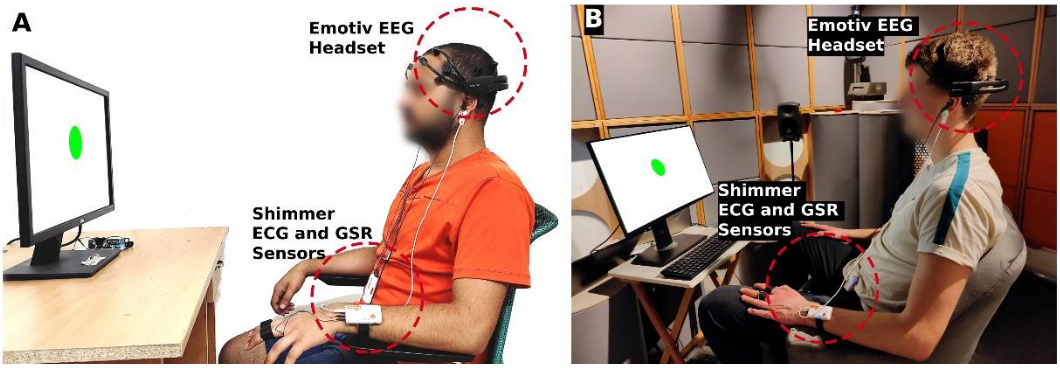

Figure 2: Image showing the setup of psychophysiological sensors, EEG, ECG, and GSR on participants, the placement of an LED screen for instruction, and the seating arrangement in the listening room in New Delhi (A) and London (B).

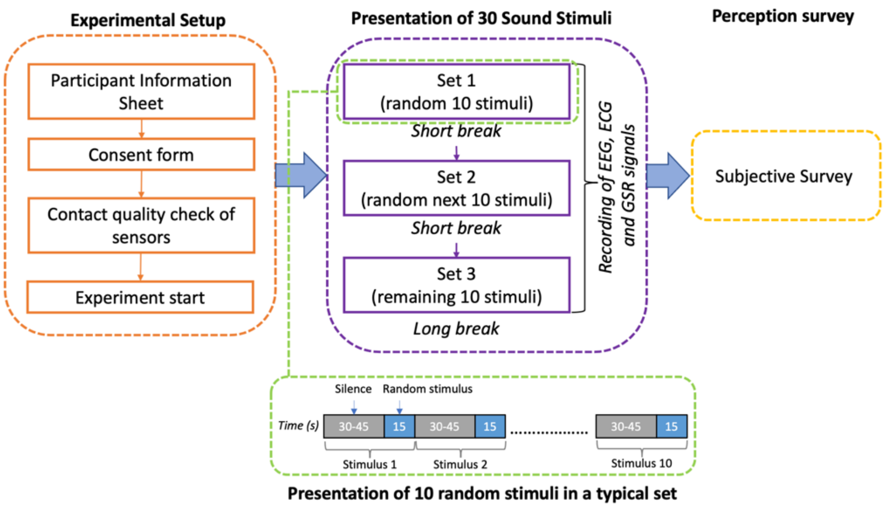

Figure 3: Schematic flow of the experimental setup used in the cross-country study on noise perception, illustrating the experimental setup, sequence of stimuli presentation for participants in both New Delhi and London.

The experiment consisted of three sets of 10 stimuli, each lasting 15 seconds. Interstimulus intervals were randomized between 15 to 30 seconds, and the order of stimuli was randomized. Participants had short breaks between sets but remained in the listening room. During stimulus presentation, participants focused on a white LED screen displaying a green dot and minimized movement. After all stimuli were presented, sensors were removed, and participants had a 10–15-minute rest period, during which they could leave the room if desired. Figure 3 outlines the experimental procedure.

3. Perception Survey

After the listening experiment, participants rated the sound stimuli on perceived annoyance, eventfulness, and pleasantness using a 0-10 scale on a web platform, where 0 indicated "Not annoyed," "Uneventful," or "Unpleasant," and 10 indicated "Annoyed," "Eventful," or "Pleasant.". Scores were categorized as "high" or "low" based on median values. All materials were in English, which was understood by the Indian and UK university students, hence no translation was needed.

4. Data Processing

Following the collection of psychophysiological data as a response to the traffic noise stimuli, data processing was conducted. The Head Acoustic Artemis Suite ® Software was used to extract the psychoacoustic parameters such as Loudness (N5) in sones, sharpness (S) in the acum, fluctuation strength (Fs) in the vacil, and roughness (R) from the wave files [36]. These parameters were used to cluster the noise stimuli into three clusters: 'Loud,' 'Active,' and 'Silent'. Finally, psychophysiological signals (ECG and SCR) were used to extract various features which are presented in the following section III.

For more details on the processing of wave files, psychophysiological signals, and the significance of the statistical tests adopted, see https://doi.org/10.5281/zenodo.13899348.

III. RESULTS

A. Comparing psychoacoustic indicators and PAQ responses

This section provides a statistical summary of psychoacoustic noise indicators extracted from noise stimuli (Table I). Additionally, a comparison between the psychoacoustic noise indicators recorded in India and those recorded in the UK was performed. This is followed by a comparison of the PAQ responses collected during the listening experiment.

Table I: Statistical summary of psychoacoustic indicators extracted from the noise dataset used for the listening experiment.

	L_{Aeq} (dBA)	N_5 (sone)	S(acum)	Fs (vacil)	R(asper)
Minimum	50.2	4.7	0.87	0.002	0.043
1st Qu.	66.1	14.1	1.22	0.015	0.073
Median	71.4	20.3	1.59	0.020	0.082
Mean	72.8	22.3	1.47	0.023	0.085
3rd QU.	75.3	26.7	1.65	0.023	0.100
Maximum	88.8	68.0	1.85	0.076	0.128

This high level of loudness is due to the high volume of traffic noise combined with sources such as engine noise and tire noise at both locations. Additionally, honking was another major noise source in the Indian context responsible for the change in overall loudness. A high level of honking has also resulted in a greater level of sharpness in the Indian context. Additionally, changes in the acceleration and engine noise of vehicles lead to changes in the roughness and fluctuation strength of the stimuli [37].

To maintain the balance between the composition of noise stimuli, care was taken to maintain the similarity between the datasets. **Figure 4** presents the variation in psychoacoustic parameters of sound stimuli recorded in New Delhi and London. Initially, care was taken to ensure that the overall characteristics of the stimuli were similar and comparable between the two locations. A t-test was conducted to identify any significant variations in N_5, S, FS, and R. It can be noted that the variation between each psychoacoustic noise indicator is not significant, which confirms that the nature of sound stimuli used from New Delhi and London dataset are similar in nature.

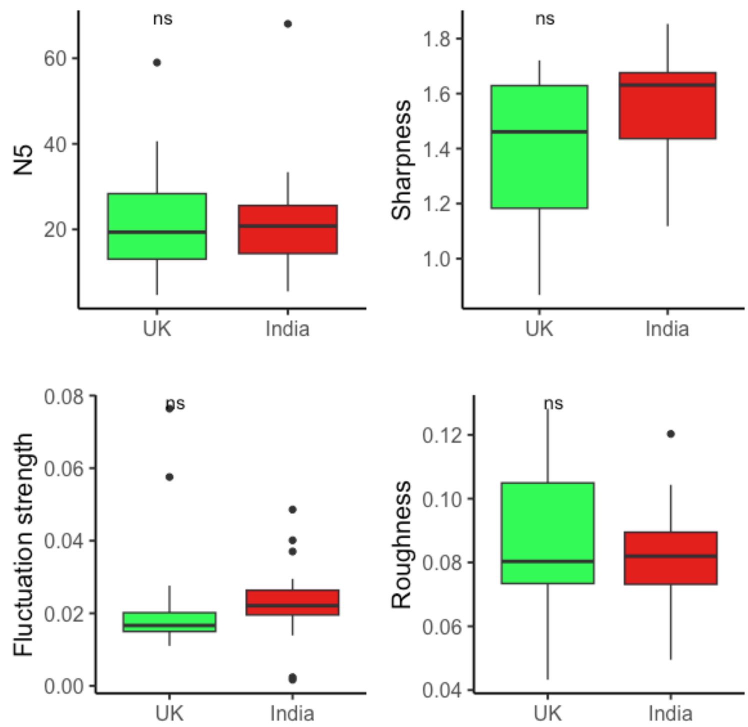

Figure 4: Variation in psychoacoustic indicators for stimuli across two locations (India and the UK). The t-test was used to determine the significance of differences between the groups. The significance levels of the statistical tests are indicated as follows: ns = Not Significant.

The N_5 value of the Indian stimuli was marginally greater than that of the noise stimuli from the UK, but no significant difference was found between the two groups. The sharpness level of the Indian noise stimuli was greater than that of the UK stimuli, which can be attributed to the elevated levels of honking resulting from traffic noise. However, no significant difference was observed between the stimuli in this respect. A similar trend was noted for FS and R, where the values did not significantly differ between the two groups.

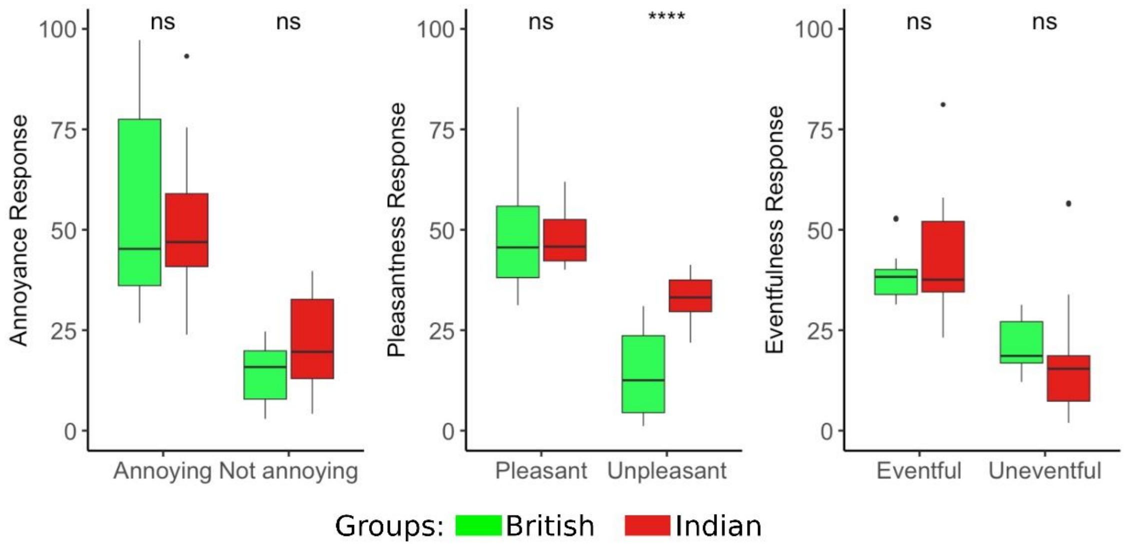

*Figure 5: Variation in PAQs responses among British and Indian groups collected during the listening experiment as a response to all presented stimuli. The Wilcoxon signed-rank test was used to determine the significance of differences between the groups, ns (not significant) and **** ($P \leq 0.0001$).*

Figure 5 presents the perceptual responses of participants from both groups regarding annoyance, eventfulness, and pleasantness levels using the Wilcoxon t-test. There was no significant difference in the annoyance response to the annoying and not annoying stimuli between the two groups. Considering the range of annoyance responses for the annoying stimuli, it is reported that the British group is more annoyed than the Indian group, indicating a lower noise tolerance level among the British group.

Regarding the perception of pleasantness, the Wilcoxon signed-rank test revealed that the unpleasantness rating for the Indian group was significantly greater than that for the British group ($W=14$, $p<0.001$). However, there was no significant difference in rating of pleasant stimuli. Also, no significant difference was found between the responses of eventful and uneventful stimuli. This finding suggested that the perception of eventfulness was similar for both groups, although the British group tended to perceive the sounds slightly more eventful than did the Indian group.

B. HRV parameters and noise exposure

This section examines the impact of traffic noise exposure on the HRV parameters of both Indian and British participants.

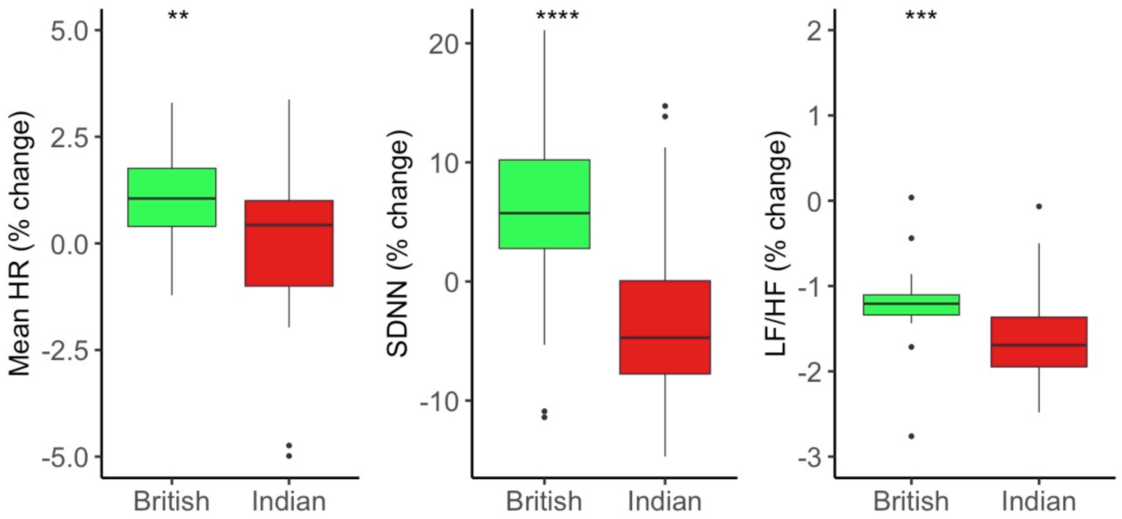

*Figure 6: Variations in HRV parameters for the British and Indian groups due to traffic noise exposure. The significance of differences between the groups was determined using the Wilcoxon signed-rank test , where ** (P ≤ 0.01), *** (P ≤ 0.001), and **** (P ≤ 0.0001).*

Figure 6 shows the variation in the HRV parameters for the Indian and UK groups due to traffic noise exposure using the Wilcoxon t test. The analysis revealed that the Indian group exhibited a significant decrease in the mean HR (W = 653, $p<0.01$), indicating the notable impact of noise exposure on their cardiovascular system. In contrast, the mean HR of the British group remained relatively unchanged. The SDNN, a parameter used to assess cardiovascular risk, was significantly lower (W = 712, $p<0.001$) in the Indian group than in the British group. This finding suggested that the Indian participants experienced a more pronounced influence on their cardiovascular system due to noise exposure. Additionally, compared with that in the British group, the LH/HF ratio in the Indian group was significantly lower (W = 676, $p<0.001$), further supporting the findings that Indian participants exhibit distinct cardiovascular reactions to noise exposure.

1. *Relationships between HRV parameters, psychoacoustic indicators, and PAQs*

This section presents the relationship between HRV parameters, psychoacoustic indicators, and PAQs for the two groups. The Spearman correlation test was conducted to assess the correlation between variables across the groups, as presented in Table II.

Table II: Spearman correlation analysis for the changes in HRV parameters, psychoacoustic indicators, and PAQs.

Groups	HRV parameters	N_5	S	FS	R	A	E	P
Indian	HR	0.24	-0.26	0.13	0.07	0.32	0.21	**-0.37***
	SDNN	0.22	-0.13	0.15	0.35	**0.33***	0.07	-0.33
	LF/HF	-0.18	0.06	-0.36	-0.1	-0.18	**-0.37***	0.21
British	HR	**0.37***	-0.28	0.13	0.16	0.21	0.23	-0.25
	SDNN	0.05	-0.23	-0.04	0.12	0.14	-0.01	-0.14
	LF/HF	-0.23	0.11	-0.17	-0.18	**-0.42***	-0.18	**0.46***

Where, 'A' is Annoyance, 'P' is Pleasantness and 'E' is Eventfulness. The significance levels are indicated as follows: * ($P \leq 0.05$).

The N_5 psychoacoustic indicator was significantly correlated with HR in the British group ($r = 0.37$, $p < 0.05$), but not in the Indian group. Other psychoacoustic indicators did not show significant correlations with HRV parameters. For the Indian group, Annoyance was positively correlated with SDNN ($r = 0.33$, $p<0.05$), while Pleasantness had a significant negative correlation with Heart Rate (HR) ($r=-0.37$, $p<0.05$). LF/HF did not significantly correlate with psychoacoustic indicators but showed a significant negative correlation with Eventfulness ($r = -0.37$, $p<0.05$). In the UK group, LF and HF exhibited strong negative correlations with Annoyance ($r = -0.42$, $p<0.05$) and strong positive correlations with Eventfulness ($r = 0.46$, $p<0.05$).

Overall, higher Loudness was associated with an increased HR in both groups, with a more significant effect observed in the UK group. Additionally, a higher HRV was linked to increased

Annoyance and decreased Pleasantness. In the UK group, louder sounds correlated with higher HR, and a higher HR was associated with a lower LF/HF ratio.

2. PAQs, Changes in HRV Parameters and Cross-country Differences

The Wilcoxon t-test was used to analyse the difference between HRV parameters for different PAQs and their subcategories for the British and Indian participant groups (**Figure 7**). For the annoyance level, the mean HR was significantly different ($W = 163, p<0.05$) for both the British and Indian participants in the annoyed condition. For the exposure to non-annoying stimuli, there was no significant difference in the HR. This finding suggested that the British group experienced greater physiological stress than the Indian group when exposed to annoying stimuli, whereas the Indian participants tended to be in a relaxed condition. This may be due to the habituation of loud traffic noise stimuli and increased tolerance to higher noise levels. Exposure to annoying stimuli resulted in a notable change in **SDNN** for both groups. Specifically, the Indian group exhibited a lower SDNN compared to the British group when exposed to annoying stimuli, suggesting a lower HRV and potential chronic stress or autonomic dysfunction in the Indian group. There was also a significant difference in SDNN when exposed to non-annoying stimuli, with the Indian group showing lower levels ($W = 197, p<0.001$). This indicates potential differences in autonomic heart regulation between the two groups. A significant change in the **LF/HF** ratio was observed with annoying stimuli, where the Indian group had a reduced LF/HF ratio ($W = 171, p < 0.05$). No significant difference was noted between the groups under non-annoying conditions, reflecting a state of relaxation.

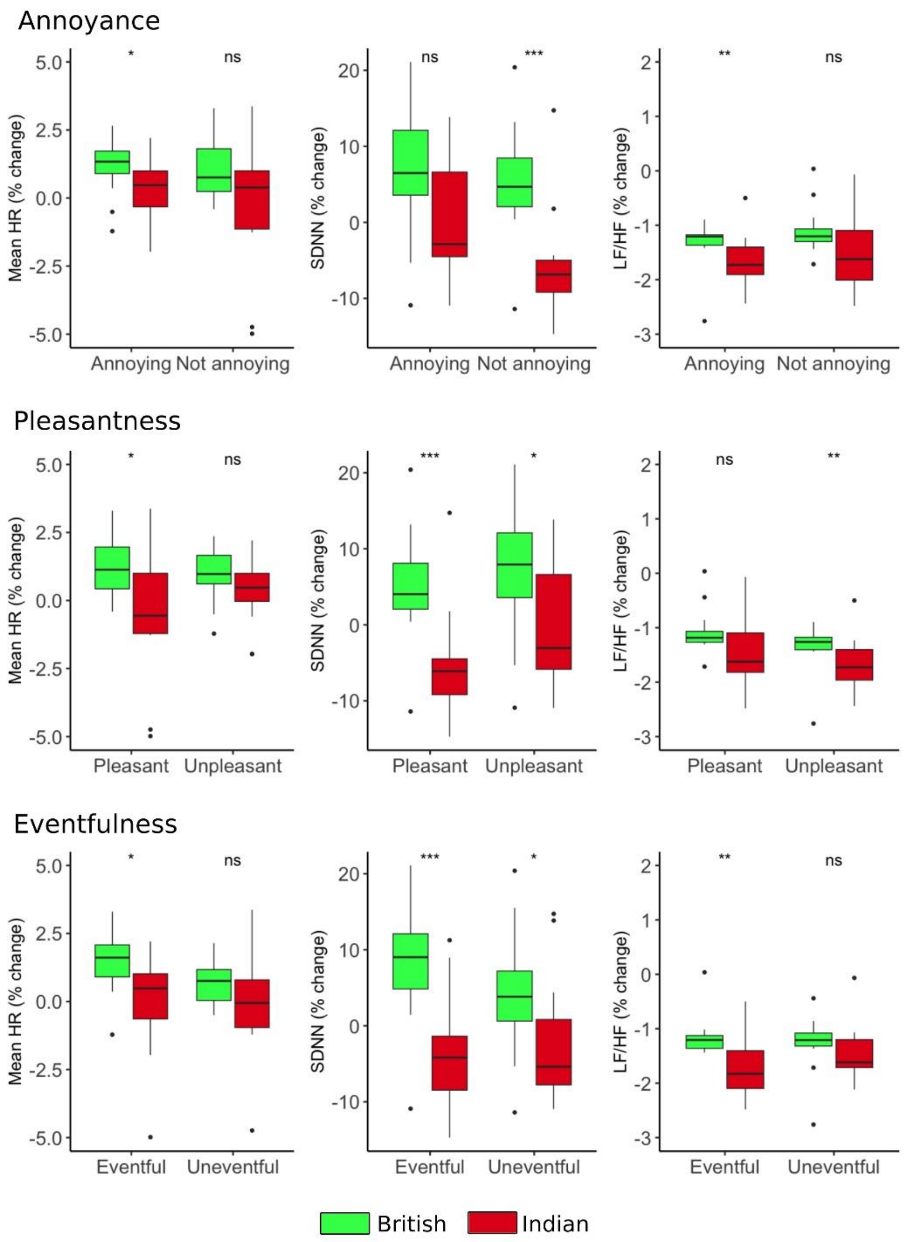

*Figure 7: Relative change in HRV parameters for the British and Indian groups across different PAQ responses. The Wilcoxon signed-rank test was used to determine the significance of differences between the groups, where ns (not significant), * (P ≤ 0.05), ** (P ≤ 0.01) and *** (P ≤ 0.001).*

Analysis of HRV responses to eventfulness and pleasantness stimuli revealed several key differences between the Indian and British groups. The Indian group exhibited significantly lower mean heart rates (HR) in both eventful ($W = 171$, $p<0.05$) and pleasant ($W = 174$, $p<0.05$) conditions. Significant differences were found in SDNN changes across various categories:

pleasant (W = 197, $p<0.001$), unpleasant (W = 162, $p<0.05$), eventful (W = 191, $p<0.001$), and uneventful (W = 170, $p<0.05$) between the two groups. Notably, the British group showed a significant increase in SDNN with eventful noise stimuli. There was a significant difference in the change in SDNN for the pleasant (W=197, $p<0.001$), unpleasant (W=162, $p<0.05$), eventful (W=191, $p<0.001$) and uneventful (W=170, $p<0.05$) categories between the two groups ($p<0.05$). Interestingly, a significant increase in SDNN was noted in the British group when participants were exposed to eventful noise stimuli.

The LF/HF ratio did not significantly differ between unpleasant and uneventful conditions. However, the Indian group experienced a significant decrease in the LF/HF ratio in both pleasant (W = 169, $p < 0.05$) and eventful (W = 176, $p < 0.01$) conditions.

3. Noise Scenarios, Changes in HRV Parameters and Cross-country Differences

The change in HRV parameters for the British and Indian groups was examined for silent, active, and loud clusters. The Wilcoxon signed-rank test was used to determine the significant difference between groups across the noise clusters.

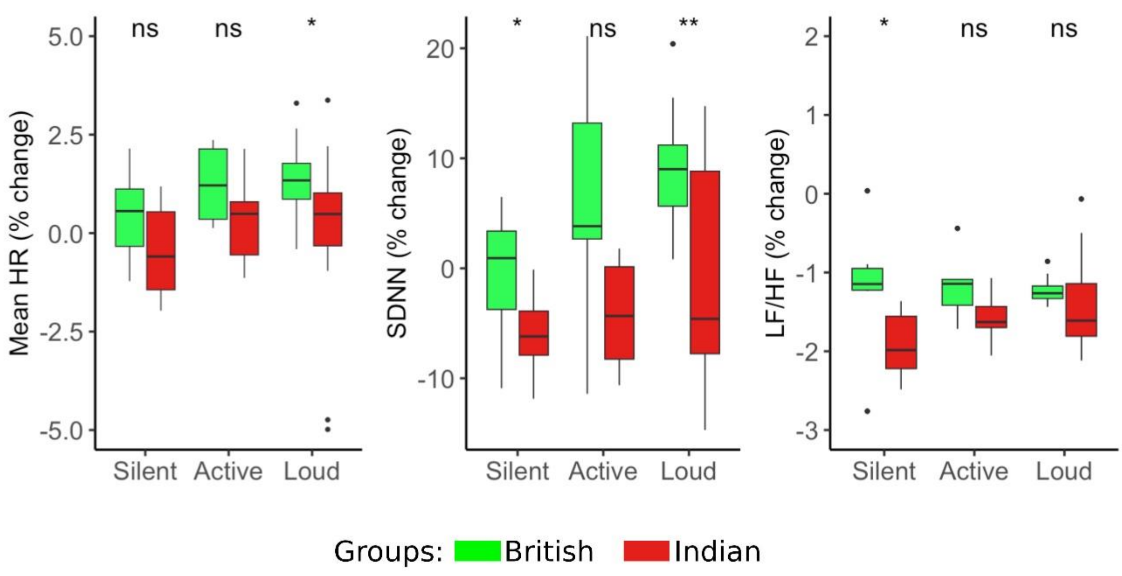

Figure 8: Variations in HRV parameters for different noise clusters across the British and Indian groups. The Wilcoxon

*signed-rank test was used to determine the significance of differences between the groups, where ns (not significant), * (P ≤ 0.05) and ** (P ≤ 0.01).*

Figure 8 shows the changes in HRV parameters with respect to different sound clusters. Significant differences (W=218, p<0.05) were observed in the loud cluster, where the British group had a greater heart rate (HR) than the Indian group. However, no significant differences were found in the active or silent clusters between the two groups. Notably, there was a significant increase in the SDNN in the Indian group when individuals were exposed to loud stimuli (W=228, p<0.01). In contrast, for the moderately loud active stimuli, no significant difference in the SDNN was observed between the two groups. Interestingly, in the silent cluster, there was a significant difference in the SDNN between the two groups (W=52, p<0.05), with the Indian group exhibiting lower levels of SDNN. In terms of the LF/HF ratio, a significant difference was found between the groups (W=203, p<0.05), with the Indian group having lower values. However, no statistically significant differences were noted for the active and silent clusters.

C. SCR Parameters and noise exposure

The change in the SCR was checked for two different groups, Indian and British, for similar noise exposure, and the results are presented in **Figure 9.**

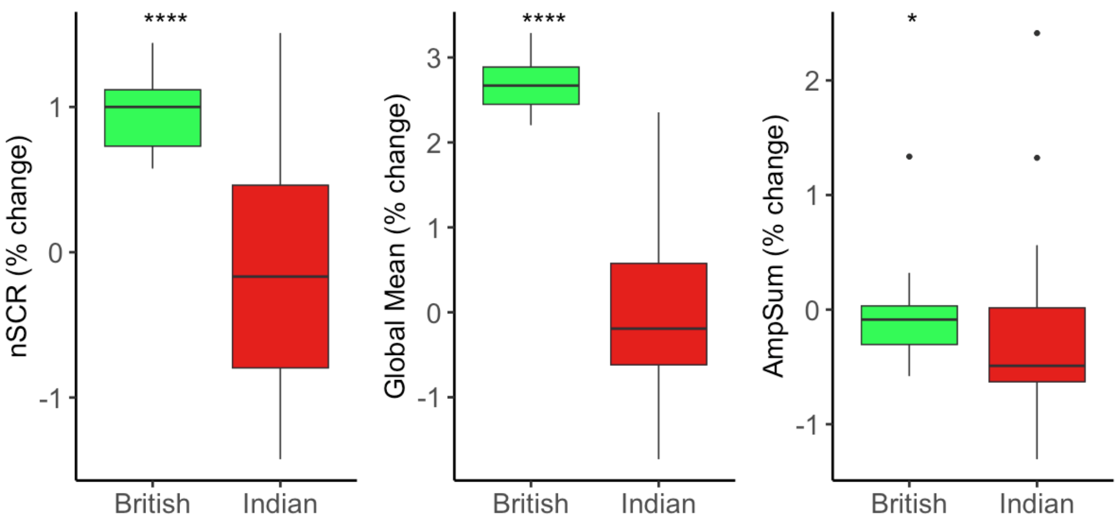

*Figure 9: Variations in the SCR parameters for the British and Indian groups due to traffic noise exposure. The Wilcoxon signed-rank test was used to determine the significance of differences between the groups, where * (P ≤ 0.05) and **** (P ≤ 0.0001).*

Three SCR variables, nSCR, global mean and AmpSum, were checked for variation in physiological stress among the listeners. The analysis revealed that there was a significant increase in the nSCR (W=535, p<0.001), global mean (W=618, p<0.001) and AmpSum (W=423, p<0.05) for British participants. Indicating that the British group has a greater level of physiological arousal in response to traffic noise stimuli than does the Indian group, leading to a greater level of stress.

1. Relationships between SCR parameters, psychoacoustic indicators, and PAQs

The relationship between the change in SCR parameters, psychoacoustic indicators, and PAQs was analyzed using the Spearman correlation test. Table III presents the Spearman correlation between changes in SCR parameters, psychoacoustic indicators, and PAQs for both the Indian and British groups.

Table III: Spearman correlation analysis for the change in SCR parameters, psychoacoustic indicators, and PAQs.

Groups	SCR parameters	N_5	S	FS	R	A	E	P
Indian	nSCR	0.52**	0.23	0.28	0.47**	0.50**	0.51**	-0.45*
	AmpSum	0.38*	0.19	0.12	0.40*	0.35	0.32	-0.31
	Global Mean	0.11	0.16	0.16	0.25	0.15	0.04	-0.16
British	nSCR	0.65**	0.43*	0.36	0.54**	0.64**	0.57**	-0.66**
	AmpSum	0.49**	0.31	0.14	0.44*	0.54**	0.47**	-0.56**
	Global Mean	0.06	0.12	0.21	0.26	0.08	0.13	-0.07

Where, 'A' is Annoyance, 'P' is Pleasantness and 'E' is Eventfulness. The significance levels are indicated as follows: * (P ≤ 0.05) and ** (P ≤ 0.01).

In the Indian group, the nSCR exhibited strong positive correlations with loudness and roughness (r=0.52, p<0.01; r=0.47, p<0.01, respectively), along with moderate correlations with sharpness and fluctuation strength. Additionally, nSCR showed strong positive associations with annoyance and eventfulness (r=0.50, p<0.01; r=0.51, p<0.01, respectively) but a strong negative correlation with pleasantness (r=-0.45, p<0.05). AmpSum displayed a significant moderate positive correlation with loudness and roughness (r=0.38, p<0.05; r=0.40, p<0.05, respectively) but no strong association with PAQs. The global mean showed weak positive correlations with most variables, except for a weak negative correlation with pleasantness.

In the British group, similar trends were observed, with nSCR showing strong positive correlations with loudness, sharpness, and roughness (r=0.65, p<0.01; r=0.43, p<0.05; and r=0.54, p<0.01, respectively). It also had strong positive correlations with annoyance and eventfulness (r=0.64, p<0.01; r=0.57, p<0.01, respectively) and a strong negative correlation with pleasantness (r=-0.56, p<0.01). AmpSum demonstrated strong positive correlations with loudness and roughness (r=0.49, p<0.05; r=0.44, p<0.05, respectively) and strong positive associations with annoyance (r=0.54, p<0.01) and Eventfulness (r=0.47, p<0.01), along with a strong negative correlation with Pleasantness (r=-0.56, p<0.01). Global Mean exhibited weak positive correlations with most variables and a weak negative correlation with pleasantness, mirroring the Indian group. Overall, the British group showed slightly stronger correlations between nSCR and psychoacoustic indicators than did the Indian group, while both groups displayed similar patterns of associations between nSCR, and subjective perception scales related to loudness, roughness, annoyance, eventfulness, and pleasantness.

2. PAQs, Changes in SCR and Cross-country Differences

The change in SCR parameters was analyzed across the PAQs, i.e., annoyance, eventfulness, and pleasantness, for the British and Indian groups. The Wilcoxon signed-rank test was used to analyze the significant difference between the groups, as illustrated in Figure 10.

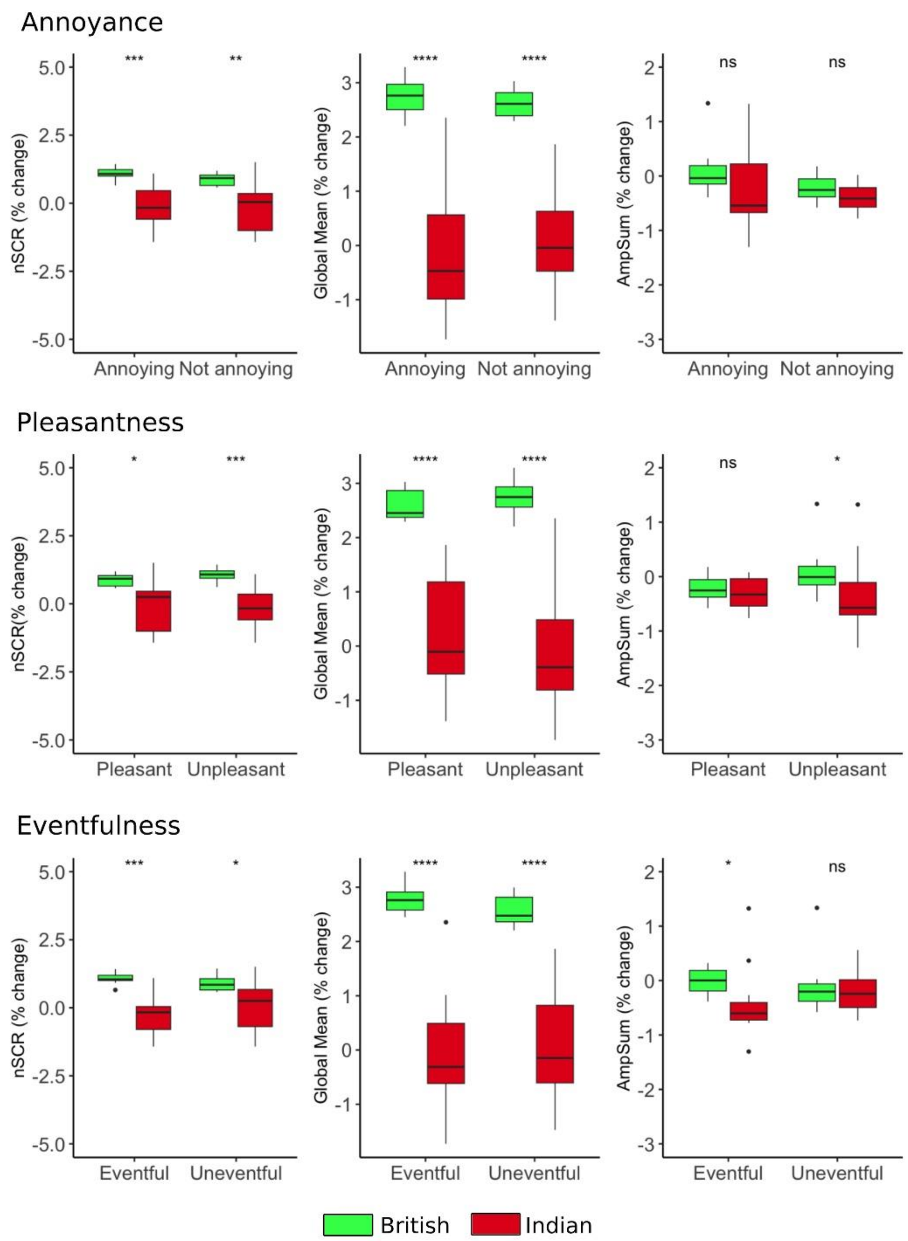

*Figure 10: Relative change (%) in SCR parameters for the British and Indian groups across different PAQ responses. The Wilcoxon signed-rank test was used to determine the significance of differences between the groups, where ns (not significant), * (P ≤ 0.05), *** (P ≤ 0.001), and **** (P ≤ 0.0001).*

British group exhibited significantly higher nSCR compared to the Indian group in both annoyed ($W = 134$, $p < 0.001$) and not annoyed conditions ($W = 136$, $p < 0.01$). This indicates a greater frequency of significant SCR events above the threshold for British participants across both types of stimuli. Additionally, the global mean SCR was significantly higher for the British group in both annoyed ($W = 142$, $p < 0.0001$) and not annoyed conditions ($W = 168$, $p < 0.0001$), suggesting generally higher SCR activity compared to the Indian group. However, AmpSUM did not differ significantly between the groups for either condition, indicating that while physiological arousal was similar, the amplitude range differed.

For pleasant stimuli, the British group had significantly higher nSCR for both pleasant ($W = 113$, $p < 0.05$) and unpleasant stimuli ($W = 158$, $p < 0.001$), reflecting more consistent and heightened physiological arousal. The variation in nSCR was smaller for the British group compared to the Indian group, suggesting mixed responses among Indian participants. The global mean also differed significantly between pleasant ($W = 143$, $p < 0.0001$) and unpleasant stimuli ($W = 167$, $p < 0.0001$), with British participants showing higher arousal for unpleasant stimuli and lower for pleasant stimuli, contrasting with the Indian group's response. AmpSUM did not vary significantly with pleasant stimuli but showed significant differences for unpleasant stimuli ($W = 127$, $p < 0.05$), with the British group displaying greater SCR amplitudes.

Regarding eventfulness, the nSCR was significantly different between eventful ($W = 136$, $p < 0.001$) and uneventful conditions ($W = 124$, $p < 0.05$). The global mean activity also varied significantly between the groups for both eventful ($W = 143$, $p < 0.001$) and uneventful conditions ($W = 168$, $p < 0.001$). The British group exhibited increased nSCR for eventful conditions, while the Indian group showed higher nSCR for uneventful conditions, indicating different perceptions of eventfulness. AmpSUM significantly differed for eventful conditions (W = 115, $p < 0.05$) but not for uneventful conditions, suggesting that while the frequency of high arousal events was similar, the amplitude scale varied between the groups.

3. Noise Scenarios, Changes in SCR Parameters and Cross-country Differences

The variation in the SCR for different types of traffic noise stimuli is analysed in **Figure 11**. The nSCR for silent urban noise was similar for both groups, with no significant difference. However, a significant difference was noted for the active (W=115, $p<0.05$) and loud (W=151, $p < 0.0001$) clusters.

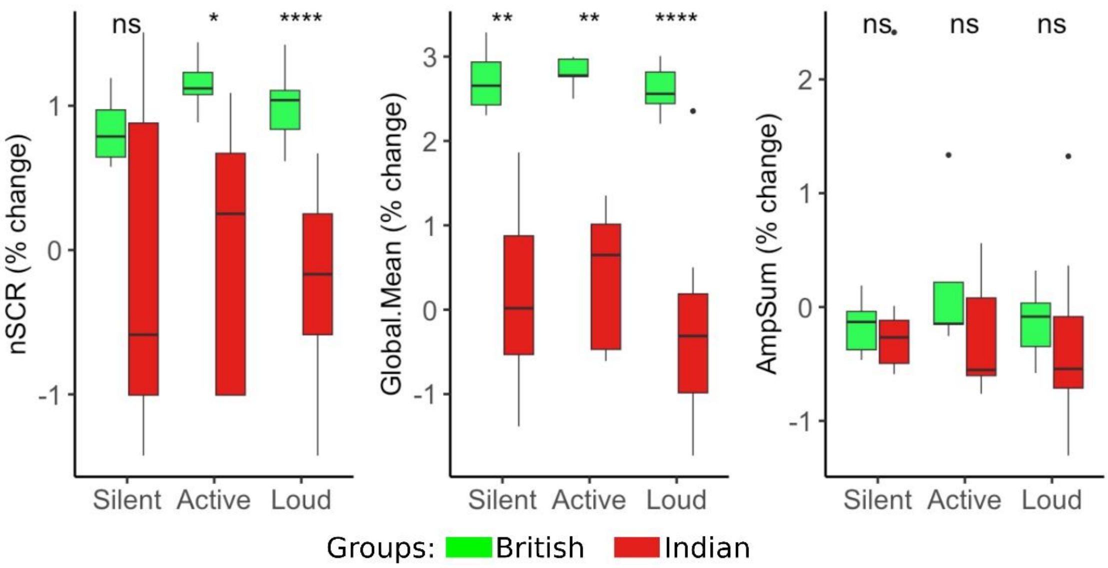

*Figure 11: Variations in SCR parameters for different noise clusters across the British and Indian groups. The Wilcoxon signed-rank test was used to determine the significance of differences between the groups, where ns (not significant), * ($P \leq 0.05$), ** ($P \leq 0.01$) and **** ($P \leq 0.0001$).*

An analysis of the global means of both groups across the three clusters revealed that overall SCR activity was significantly greater for the silent (W=56, $p<0.01$), active (W=25, $p<0.01$) and loud (W=152, $p<0.0001$) clusters. The highest activity was observed for the active clusters, followed by the loud and silent clusters, among both groups. This can be attributed to the occurrence of unexpected and intermittently loud events in the active cluster that were not anticipated by the participants. On the other hand, the loud cluster, which is expected to have a continuous loud level during the listening period, may lead to some level of adaptation and adjustment in arousal levels.

No significant differences in AmpSUM were observed between the two groups across the clusters. However, the fluctuations in the SCR signal were similar for both groups, but the intensity of the reaction to stimuli was significantly different due to cross-country factors, habituation, increased tolerance, and differences in noise sensitivity levels. These findings highlight the influence of different types of traffic noise on physiological stress responses, as indicated by the nSCR and global mean measurements.

IV. DISCUSSION

India and the UK have diverse traffic noise characteristics, where population from urban India experience higher amount of noise exposure [25]. Studies conducted in India have reported a strong association between traffic noise exposure and psychological distress [38]. This analysis provides valuable insights into how individuals from different national backgrounds respond to traffic noise. The findings indicate significant differences psychophysiological response for both the Indian and British groups, suggesting distinct patterns physiological and psychological arousal associated with noise exposure.

A. Changes in HRV parameters

Analysis of the variation in HRV parameters among Indian and British participants revealed significant differences between the groups. This finding indicates that there is diverse physiological response to traffic noise which is influenced by cross-national and environmental factors. The findings of this study align with previous research investigating the effects of noise exposure on HRV parameters and cardiovascular health. Consistent with the previous findings, the significantly lower SDNN in the Indian group than in the British group suggested a greater impact on the cardiovascular system of Indian participants in response to noise exposure. This finding supports the notion that noise exposure can adversely affect HRV and increase cardiovascular risk [39]. Moreover, the significant decrease in the LH/HF ratio in the Indian group compared to the British group indicates a shift toward parasympathetic dominance or increased vagal activity in response to noise exposure. This finding is in line with previous research indicating that noise exposure disrupts the autonomic balance and leads to alterations in sympathovagal activity [40].

Regarding annoyance, HRV, and cross-country differences, the higher mean HR observed in the British group, regardless of exposure to annoying stimuli, suggest that British participants are more susceptible to stressors than individuals from another group. This finding indicates that cross-country differences may influence physiological stress responses. The lower SDNN observed in the Indian group when exposed to annoyed stimuli and its potential association with chronic stress and autonomic dysfunction are in line with study highlighting the impact of chronic stress on HRV and its link to cardiovascular health [41]. This finding suggested that the Indian participants may have reduced coping mechanisms or adaptability to stressful situations compared to the British participants. The variations in SDNN changes across pleasant, unpleasant, and uneventful categories between the Indian and British groups support previous research indicating diverse stress response patterns and coping mechanisms in different populations [42]. The significant increase in the SDNN in the British group when exposed to eventful noise stimuli suggested greater adaptability and stress resilience, consistent with the findings of studies highlighting individual differences in stress responses and autonomic regulation [43]. The absence of significant differences in the LF/HF ratio between the Indian and British groups for unpleasant and uneventful categories suggested a similar sympathovagal balance under these conditions, corroborating previous research on autonomic responses to negative or neutral stimuli [44]. The significant decrease in the LF/HF ratio in the Indian group under pleasant and eventful conditions indicates a potential shift toward parasympathetic dominance and greater relaxation and emotional engagement, which is consistent with the findings of studies linking positive stimuli with increased parasympathetic activity [45].

B. Changes in the SCR parameters

The variation in skin conductance response (SCR) parameters among Indian and British participants exposed to traffic noise stimuli highlights significant cross-country influence in physiological stress responses. First, the observation that British participants exhibited greater physiological arousal, as indicated by increased SCR parameters, compared to the Indian group shows the influence of cross-country differences in stress responses to noise. This is consistent with the previous research which has highlighted the role of cultural factors in shaping individuals' reactions to noise stimuli [21]. Studies have reported that high levels of honking is associated with an increase in stress [47,48]. Additionally, habituation to noise is a significant factor in changes in SCR [49], particularly in response to tonal and impulsive noise [50]. Considering the exposure to honking noise in the Indian traffic noise scenario, which is relatively less common in the UK, this leads to heightened stress levels among British participants. The high level of roughness is mainly associated with engine noise, while honking is associated with an increase in sharpness [37,51]. The significant correlation between the levels of roughness and sharpness with nSCR among British participants suggests that they experienced higher stress due to traffic noise exposure.

The perception of annoyance and its association with changes in SCR align with the findings of previous studies that have demonstrated the relationship between noise annoyance and physiological stress responses. Evans et al. reported that exposure to environmental noise led to increased physiological arousal among school children, indicating a link between annoyance and stress [52]. The current analysis further supported this relationship, showing that British participants displayed higher SCR parameters for both annoyed and not annoyed stimuli, suggesting a consistent physiological response to traffic noise regardless of annoyance.

The investigation of pleasantness and its influence on SCR also aligns with the literature. Studies have demonstrated that the perception of pleasant and unpleasant stimuli can evoke differential physiological stress responses. The finding that British participants exhibited greater nSCR values in response to pleasant stimuli than Indian participants is consistent with the findings of previous research indicating that individuals from different cultures and locations may have distinct physiological reactions to positive stimuli [45,53]. The contrasting patterns observed in the global mean between the two groups for pleasant and unpleasant stimuli further support the notion that cross-national parameters can modulate the physiological stress response to different types of stimuli.

Regarding eventfulness, the analysis revealed slight differences in the perception of eventful stimuli between Indian and British participants. This finding is consistent with previous research suggesting that individuals from different nations may interpret and respond to events differently [34]. The variation in SCR parameters for eventful and uneventful conditions reflects the impact of cross-national factors on the physiological stress response to different levels of stimulus intensity and unpredictability.

C. Implications and future scope

Considering the changes in HRV parameters, it is concluded that the British group exhibited greater HRs in response to loud traffic sounds than did the Indian group. A greater decrease in the SDNN in the Indian group during exposure to loud stimuli indicates increased stress or decreased adaptability, consistent with the findings of other studies on the effects of noise exposure on autonomic nervous system regulation [54,55]. The lower LF/HF ratio in the Indian group overall, indicating relatively greater parasympathetic activity, is in line with studies highlighting differences in stress responses with respect to the country [43]. Moreover, the strong positive relationship between loudness and HR indicates that psychoacoustic parameters can be considered to explain the change in HR. Additionally, the significant relationship between the PAQs and HRV parameters suggested that HRV parameters can be linked with participants' subjective perceptions.

The examination of different noise scenarios and their influence on SCR aligns with prior studies investigating the effects of specific noise characteristics on physiological stress responses. Previous studies have shown that, factors such as loudness and intermittent and unexpected loud events can elicit heightened physiological arousal [56]. The finding that the British group exhibited increased nSCR in response to active and loud traffic noise clusters is consistent with the expected effects of higher loudness and arousing events on stress responses. The significant relationships between psychoacoustic indicators and PAQs and between the SCR parameters show that the SCR parameters can be used as reliable indicators of stress caused by noise exposure.

The contrasting patterns observed between the Indian and British groups are attributed to individual differences in the perception and tolerance of urban traffic noise. Continuous exposure to higher noise levels often leads to habituation among participants. Factors such as lifestyle, social norms, and environmental contexts influence how individuals from different backgrounds respond to traffic noise exposure [13,14]. Another crucial factor is noise sensitivity and attitude toward noise, which are largely developed by the cultural and national noise climates, leading to changes in noise perception and different psychophysiological responses. These aspects emphasize the importance of considering country or geographical location as factors when examining the effects of noise on humans.

Notably, these findings cannot be generalized to other groups. To establish more robust and comprehensive conclusions, future studies should include participants from a wider range of nationalities backgrounds to examine the generalizability of these findings. There is scope for future research based on the following limitations. First, expanding the sample size and including participants from various countries would enhance the generalizability of the findings and provide a more comprehensive understanding of the topic. Additionally, conducting longitudinal studies could provide insights into the long-term effects of chronic exposure to traffic noise on individuals' psychophysiological responses. Furthermore, investigating the potential moderating effects of individual factors such as age, sex, and socioeconomic status could provide a deeper understanding of the underlying mechanisms and help identify vulnerable populations. Finally, exploring interventions or strategies that target country-specific responses to noise, such as noise reduction measures or country-specific noise management policies, could contribute to mitigating the adverse effects of noise on individuals' physiological well-being and overall quality of life.

V. CONCLUSION

This study analyses the change in psychophysiological response in Indian and British individuals due to traffic noise exposure to study the cross-country effect. These changes are analyzed based on their relationship with psychoacoustic indicators, PAQs, noise scenarios, and psychophysiological signals.

This study concludes that there is a significant difference in the psychophysiological response on the individuals which are influenced by the cross-country influence. This cross-country influence is due to the difference in overall character of noise climate in different countries resulting in differences in noise sensitivity, attitudes toward noise, and habituation levels between the two groups. This results in significant differences in perception, reaction and resilience to similar noise events by different groups. The significant difference in HRV parameters highlight distinct cardiovascular reactions to noise, with Indians displaying lower SDNN and LF/HF ratio, suggesting greater impact on the cardiovascular system and parasympathetic dominance. In contrast, British participants exhibit higher adaptability and stress resilience, reflected in increased SDNN and stable LF/HF ratio. Additionally, British participants demonstrate greater physiological arousal (SCR variation) than Indian participants, indicating heightened stress from traffic noise exposure than the Indian group. These findings underscore the influence of cross-country parameters on individuals' physiological stress responses to traffic noise. Objective parameters such as psychoacoustic indicators and noise clusters provide a better understanding of these changes than the subjective perceptions measured by PAQs. There is a strong relationship between PAQs and changes in HRV and SCR parameters but cannot be considered alone without considering the objective noise parameters.

Before generalizing these results, it is necessary to comprehensively understand these changes by conducting large-scale studies with higher sample sizes and participants from different nationalities and diverse socio-demographic backgrounds. This will lead to a better understanding that noise perception and its effects on humans are influenced by cross-national parameters. Such understanding is crucial in developing global standards for noise perception, mitigation, and action planning strategies. This will facilitate the development of country-specific or region-specific tailored interventions and policies to mitigate the adverse effects of traffic noise on human physiology and well-being.

SUPPLYMENTRY MATERIAL

See supplementary material at [URL will be inserted by AIP] for more details on the processing of wave files, psychophysiological signals, and the significance of statistical tests adopted.

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AUTHOR DECLERATIONS

Conflict of Interest

All authors declare that they have no conflicts of interest.

Ethics Approval

This experiment was conducted according to the Indian Council of Medical Research National Ethical Guidelines, and ethics approval was provided by the UCL BSEER Ethics Committee (Dated 12/11/21).

DATA AVAILABILITY

The data that support the findings of this study are available on request from the corresponding author.

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