Analysis And Evaluation Of Audio Induced Acoustic Fatigue Using Infrared Imaging

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Abstract: Every system whether living or non-living has a threshold of time for which it can work efficiently. If the system is used beyond its threshold, a fatigue is developed and the efficiency reduces. Any acoustic activity, including continuous listening or speaking also introduces fatigue called acoustic fatigue within the human beings and some time, it is responsible for several problems even not directly related to input audio stimulus. The treatments available for tackling fatigue related problems in the human body may be categorized as chemical compounds balancing, surgical practices, and application of special acoustic vibrations based techniques. The objective of the paper is to investigate the effect of acoustic vibrations in the form of pure tone frequencies on reduction of the fatigue introduced due to some unknown stimuli within the human subjects by using infrared (IR) imaging. In the proposed research, IR images obtained as a result of applying acoustic vibrations have been used for estimating the acoustic fatigue. The images were analyzed with respect to 3D and linear spatial temperature profiles. In most of the cases,the analysis of the temperature profiles of different subjects showedleft side of the brainis activated corresponding to 174Hz pure tone suggesting unpleasant perception (i.e. fatigue) within the subjects for prolonged durations of stimuli. On the other hand, 432Hz activates the right side of the brain indicating relaxed state of mind (lower fatigue). Evaluation of the entropy of the thermal images also reveals the reduction in fatigue due to 174 Hz and 432 Hz tones..

Key Words: Acoustic energy, sound vibrations, acoustic induced fatigue, sound therapy, acoustics, entropy, thermal imaging, IR imaging.

1. Introduction

One of the most important reasons of medical anomaly in human body is the development of fatigue in certain part of the body, especially containing hormonal glands. The treatments for reducing the fatigue andits secondary effects may be categorized into three major groups. The first group consists of the techniques involving the use of medicines for balancing chemical compounds responsible for introduction of the fatigue. Second group uses surgical practices for the treatment of the developed fatigue. Third group uses internal or external acoustic vibrations for stimulating the brain or the targeted organ directly to enhance the release of desired hormones for reducing the fatigue. Effect of acoustic vibrations in the range of 13.5 kHz to 20.0 kHz at sound pressure level between 82 dB to 92 dB was investigated by Fletcher et al [1] on the development of fatigue in human subjects with reference to 1 kHz stimulus at 25 dB. It was reported that highly frequency stimulus introduced visible discomfort (fatigue) with in subjects.

The acoustic vibrations do not require any invasive technique to help the human organs for reducing the fatigue. This technique has recently been used in several developed countries for detecting, analyzing, and treating the fatigue related problems.Cakmak et al [2] investigated the effect of electric stimulation of intrinsic auricular muscle zones and demonstrated that gait of Parkinson disease patient improves as compared to the response shown by medication, which suggests that vibrational stimulus can also help in improving the condition of the patients of Parkinson disease. Similar improvements were reported by Jakobs et al for the patients having Alzheimer disease [3]. Another area of acoustics called photo acoustics has also been employed for detecting medical anomalies particularly cancer and atherosclerosis [4].

The facial expressions developed due the muscular changes are indicative of the present state of mind and the information about the state, particularly, emotional state can be estimated from the visual image of the face of the subject. In [5],a facial expression integrated sign language has been developed with emotional state estimation to an accuracy of 94.6% [5]. Even investigations have also been carried out to access the future state of the subjects using thermal imaging. For example, in [6], thermal imaging has been employed predicting the future state of the plants for reducing the impact of predicted diseases before actual inception of the symptoms.

Imaging techniques have also been used for the assessment of physiological parameters of plants without any contact non-destructively. The processes photosynthesis, transpiration, stomatal conductance, accumulation of salicylic acid, cell death, etc., are altered because of any plant-pathogen infection leading to differences in temperature distribution between the leaves infected and the non-infected leaves. In [7], IR thermal imaging has been used for investigating pre-symptomatic disease in leaves on the basis of temperature profile. It was found that the temperature of the infected leaves was in the range of 0.5°C - 1.3°C lower than that of the healthy leaves. The temperature difference discriminated the infected and healthy leaves even before the visible appearance of the disease and hence, IR thermal imaging can play an important role in predicting disease related anomalies.

Vascular disorders can also be analyzed using IR thermal imaging as the abnormal flow of blood in the affected areachanges temperature profile in the vicinity of the abnormality which can easily be detected by the IR imaging device. It has been reported that the temperature change in the affected regions range from 0.7°C to 1°C above that of the normal regions, due to slow blood circulation [8].

Thermal imaging has also been used for investigating the seriousness of diabetic patients from the images of hands, feet, and skin. It provides an accurate and reliable method with the advantages of lesser analysis time, lesser human intervention along with fast processing [9].

Various audio signals (acoustic vibrations) have different effects on the fatigue developed within the human subjects. The scope of this paper is to analyze the effect of pure tone frequencies 174 Hz and 432 Hzon the fatigue developed within human subjects using thermal imaging. The detail of the thermal imaging is presented in the following section. Section 3 discusses the methodology of the investigations. The results are presented in Section 4. Conclusions and future scope are discussed in Section 5.

2. Thermal Imaging

Each disease has a specific temperature profile and the same can be assessed using a thermal sensor. Hence it can be an efficient and convenient diagnostic tool to detect most of the diseases if they result in temperature variations within the skin or the tissue [10][11]. Generally, thermocouples, thermistors, and thermopiles are used for recording body temperatures. The limitation of these sensors is uncomfortable size, slow response, and inconvenience of attaching to the patient skin [12]. Thermal imaging or IR imaging maps the surface temperature of a body in a form of an image. It is generally used to study the flow of blood, the detection of various cancers, and muscular performance of our human body [13][14]. Thermal images have been used to quantify and measure sensitive changes in skin temperature because of certain diseases [15].

Fig 1. Fluke Ti480 Pro thermal camera.

The energy radiated by an object at *T* temperature is given by Stefan Boltzmann law $E = \sigma T^4$, where σ is Stefan Boltzmann constant. Infrared imaging is used in clinical diagnosis to record slight physiological changes caused by fractures, burns, prostate cancer, dermatological diseases, lymphomas, rheumatoid arthritis, liver disease, bacterial infections, etc. These conditions are associated with various processes which generates a high-temperature heat source.

Several types of thermal cameras are available with different features and capabilities. For the present investigations, Fluke Ti480 PRO thermal camerawhich is based on IR imaging is used. It may be used for several applications like equipment troubleshooting, preventive and predictive maintenance,diagnostics of buildings, research and development activities involving thermal radiations,etc.It has various features like IR-Fusion,auto focus, image enhancement,digital zoom (2X and 4X),image annotations,auto capture,wireless connectivity,HDMI connectivity,relative humidity adjustment, and temperature compensation. The camera also has a touch LCD for displaying the images with high-visibility. The images can be saved to internal or external memory. All thermal imagers need sufficient warm-up time for accurate temperature measurements and bestimage quality.Its temperature measurement ranges from -20°C to1000°C and has optical wide angle smart lense of 1.31 mRad.The images along with the metadata can be transferred to a PC having SmartView for further analysis.

3. Methodology

The methodology for analysis and evaluation of audio induced acoustic fatigue using infrared imagingwithin human subjects has been divided into the following two sections:

Synthesis of stimuli

Effect of acoustic vibrations applied to human subjects on the fatigue is investigated by applying 174 Hz and 432 Hz pure tone frequencies. The reason for selecting these two specific pure tones was their historical significance. These two frequencies have been reported as beneficial with respect to creating a perception of calmness in human brains. For comparison, 185 Hz pure tone was also used as reference. In our investigations the pure tones were synthesized in software. The amplitude of the tones was fixed at 10,000.the sampling frequency was kept at 16,000 kHz.

Recording of the response

For the investigations,50 subjects were taken. Out of these twenty four were males and twenty six were females in the age group of 20-30 years. No psychological and physiological problem was visible within the subjects. All the subjects belong to same region and social strata. The set up was made in an acoustically treated room with the appropriately positioned Fluke Ti480 Prothermalcamera on stand to take images. Before recording of the thermal images the known sources of thermal energy in the vicinity of the camera were switched off for reducing the interference .Precautions were taken to position the image of the subject within a specific area on the LCD. Before the application of the pure tone, the image of the subject was focused first and then image was taken.A waiting time of around 2 minutes was ascertained before actual application of the acoustic stimuli(185 Hz, 174Hz, and 432Hz) through headphones. The volume of the sound adjusted within a comfortable level of 72dB the duration of stimuli was fixed as 60sec to reduce the chances of psychological interference due to the lack of the concentration of the subjects if any existed during the presentation of the stimuli.Between any two consecutive sessions the time gap was fixed more than one hour for reducing the fatigue of the previous session, if any.

Analysis of the response

SmartView was used for the analysis of thermal images. First the images from the thermal camera were downloaded to the PC where the analysis software SmartView was installed. The emissivity was kept constant at 0.65 and the dynamic temperature range was kept fixed as(30^0C -42^0C). Investigations were carried out by visually viewing the 3D temperature and linear spatial temperature profiles. Investigations were also carried out using the changes in the entropy the thermal images, before and after the application of the stimuli.

4. Results and Discussions

The effect of 174 Hz and 432 Hz with reference to 185 Hz on fatigue in human subjects was investigated using Fluke Ti480 Pro, as explained in methodology. The effect on the subjects was almost similar except in case of few subjects. For reference, the 3D temperature profiles for the subject (code M01)corresponding to pure tone stimuli of 174Hz and 432Hz are shown in Fig 2. Column 1 displays the images for stimulus of 174 Hz and Column 2 displays for 432Hz. First row corresponds to the images before applying the stimuli and third row after applying the stimuli. Second row shows the 3D temperature profiles before applying the stimuli and fourth row corresponds to the 3D temperature profiles after applying the stimuli.

The analysis of the 3D temperature profiles obtained before the application of stimuli (Fig.2b, Fig. 2f) and after applying the stimuli shows that the shape of the temperature profile corresponding to the facial area shifts towards a rhythmic regular and smooth shape. The reason for the shifting of the shape may be due to the changes in the temperature of the specific points on the face having active muscles or blood vessels in the vicinity of area under consideration.Our earlier studies shows that rhythmic patterns corresponds to relaxed state of mind and hence the patterns obtained after applying the pure tone of 432Hz results in relatively more rhythmic 3D temperature profile in comparison to that of 174Hz. Relatively more changes are observed on the right side of the face indicating more activities within the left side of the brain, representing emotional changes within the brain.

The analysis of linear spatial temperature profile shown in Fig 3 of the face at three different positions indicates that on application of the 174 Hz tone the relaxation(reduction in fatigue) is not appreciably visible resulting in some distracting effect within the brain. The same effect was communicated by some of the subjects when asked about the experience of listening to the tone of 174Hz.It was observed that 432 Hzreduces the temperature variations on left and right side of the face indicating relaxation of brain.It may also be observed that the relaxation effect of 432 Hz is relatively more as compared to that of 174Hz tone.

In few subjects, 174Hz tone showedsome rise in the temperature in central portion of the face giving an indication of some destructive effect (increased fatigue) produced within the brain. Application of 432 Hz stimuli resultedin calmness within the brain. In some case, the facial region containing the nose showed low temperaturemay be due to some medical anomaly in that part of the face. Linear spatial temperature profile showed that 174Hz results in activation of the emotional part of the brain and 432Hz results in activation of

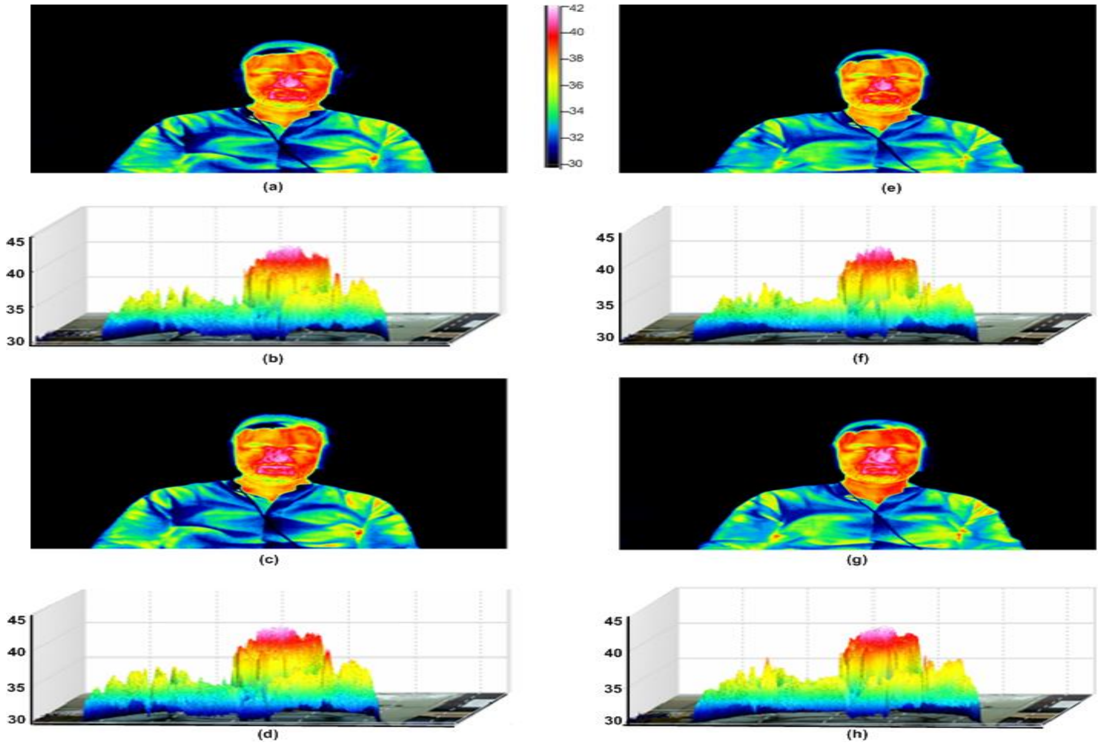

Fig 2.3D temperature profiles of the subject M01 corresponding to pure tone stimuli 174 Hz (first column) and 432 Hz (second column). First row corresponds to the images before applying the stimuli and third row after applying the stimuli. Second row shows the 3D temperature profiles before applying the stimuli and fourth row corresponds to the 3D temperature profiles after applying the stimuli.

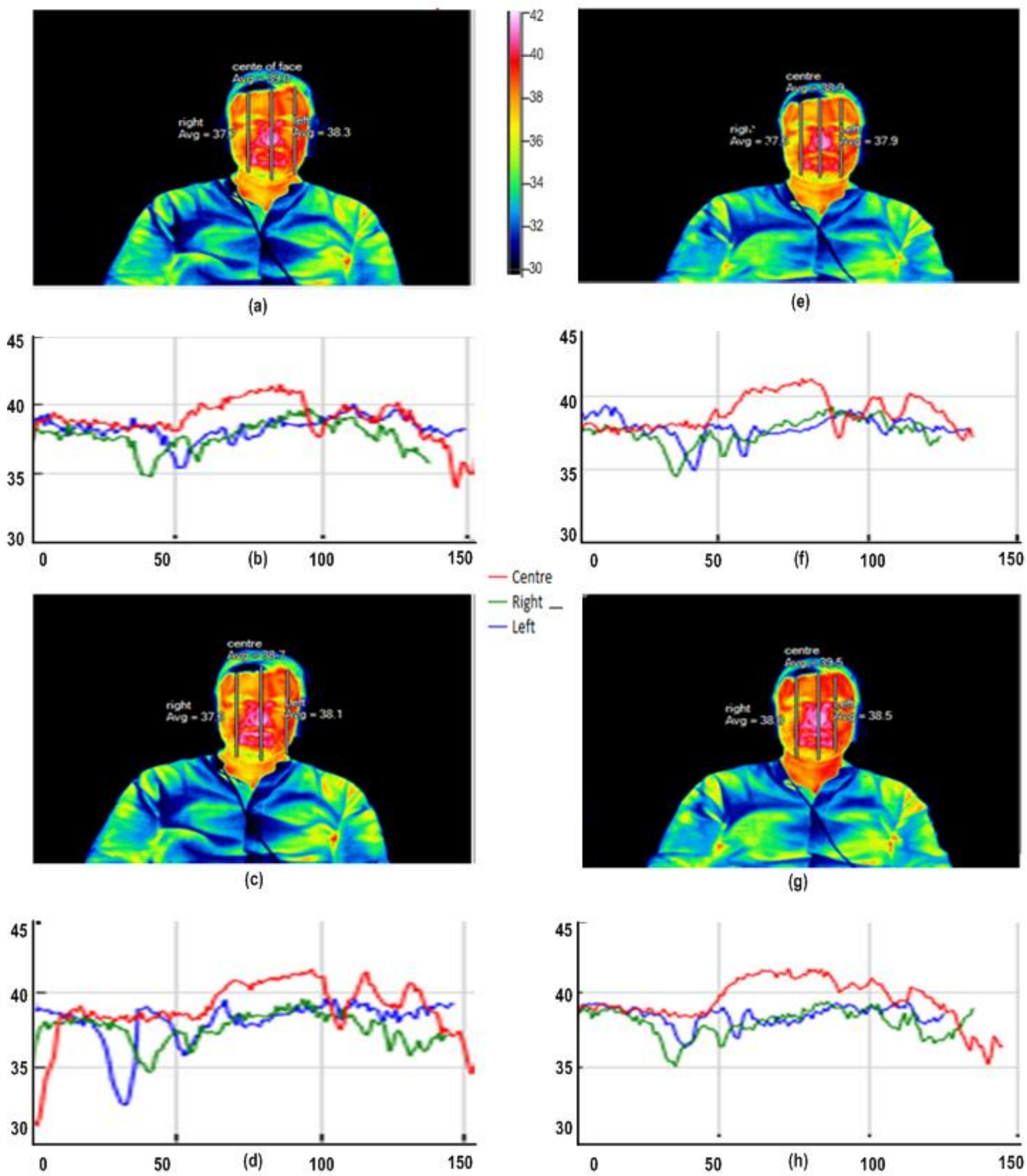

Fig 3. Linear spatial temperature profiles of the subject M01 corresponding to pure tone stimuli 174 Hz (first column) and 432 Hz (second column). First row corresponds to the images before applying the stimuli and third row after applying the stimuli. Second row shows the Linear spatial temperature profiles before applying the stimuli and fourth row corresponds to the Linear spatial temperature profiles after applying the stimuli.

the logical section of the brain. The closeness of the linear temperature profile corresponding to the left and right side of the face suggests calmness within the whole brain, particularly, when the stimulus is 432.

The 3D profiles temperature profiles and linear spatial profiles for the reference stimulus of 185 Hz is shown in Fig 4. The analysis of the profiles shows that the application of 185 Hz stimuli raises the temperature of the right brain indicating distracting effect. Similar effects were observed in the temperature profiles of other subjects also.

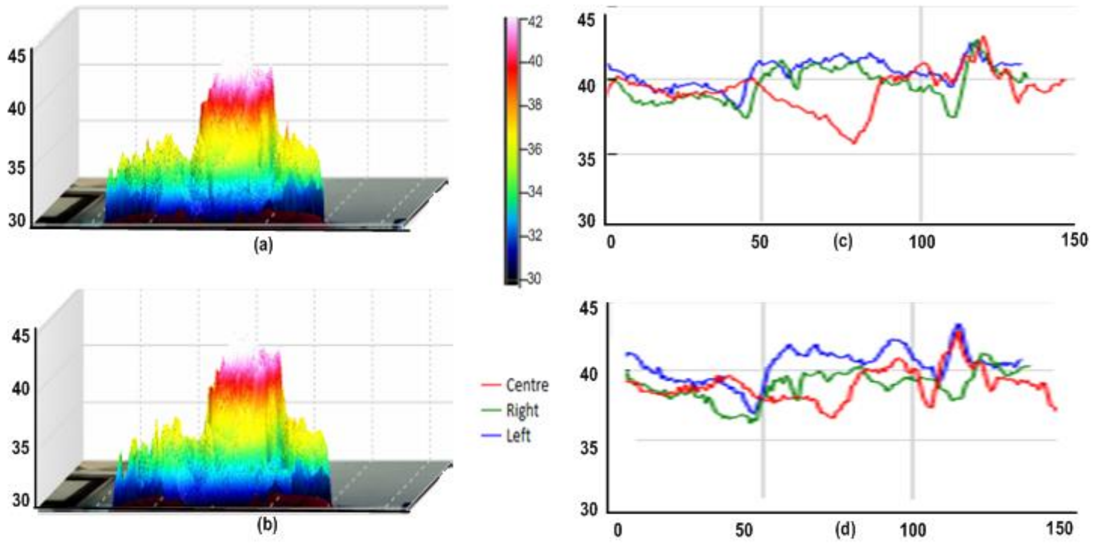

Fig 4.3D and linear spatial temperature profiles of the subject M16 corresponding to pure tone stimuli 185 Hz. First row corresponds to the images before applying the stimuli and second row after applying the stimuli.

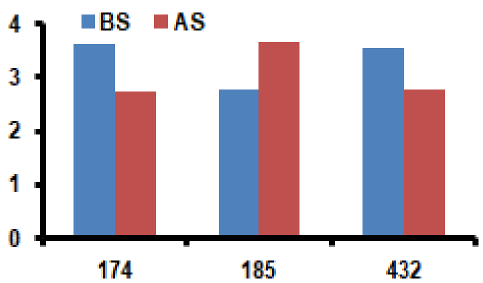

Fig 5. Average entropy (y-axis) for different pure tones (x-axis) before and after the stimulus.

Average entropy ($\hat{E}$) of each image (T)before and after the application of pure stimuli was also evaluated across all the subjects (M) and analyzed to assess the fatigue present in the images, using the following equation

$$\hat{E}(T) = \frac{1}{M}\sum_{i=1}^{M}\sum_{j=1}^{N} p(g_j^i)\log_2 p(g_j^i)$$

where N is the number of gray levels in the image and $p(g_j^i)$ is the probability of occurrence of the *j*th gray level g_j^i for the *i*thsubject.The average entropy across all the subjects is shown in Fig 5 as histograms. It is clear from the plot that the entropy decreases in response to 174 Hz and 432 Hz tones. The entropy increases for 185Hz, suggesting, relative increase in the randomness.The range of standard deviation was observed in the vicinity of 0.90, indicating the confidence on the performance of investigations. Hence, 432Hz and 174Hz are useful for reducing the stress,but, 185 Hz does not provide any relaxation in the mind.The analysis of 3D temperature profiles, linear spatial temperature profiles, and entropy obtained from the images of the subjects in response to pure tones suggests that the pure tones 174 Hz and 432 Hz, especially 432 Hz have a definite effect on the reduction of fatigue with in human subjects.

5. Conclusions and Future Scope

Investigations were carried out to study the effect of pure tone frequencies 174 Hz and 432 Hz on reduction of fatigue in reference to the pure tone frequency 185 Hz on human subjects. The results showed that 432 Hz stimulus resulted in relatively more relaxation within the subjects as compared to that of the reference frequency 185 Hz. It may be noted that 174 Hz was also perceived as distracting by some of the subjects. In conclusion it is certain that 432 Hz is really a pure tone for reducing fatigue in most of the subjects. Almost same conclusions were derived from the analysis of entropy. Detailed analysis of the effect of these tones on MRI, ECG,and blood pressure is on our future program.

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