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Article

A Preliminary Investigation on Frequency Dependant Cues for Human Emotions

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Abstract: The recent advances in Human Computer Interaction and Artificial Intelligence has significantly increased the importance of identifying human emotions from different cues, and has hence become a subject of study for various scholars from diverse background including Acoustics, Psychology, Psychiatry, Neuroscience and Biochemistry. This study is a preliminary step towards investigating cues for human emotion on a very fundamental level by aiming to establish relationship between tonal frequencies and emotions. For that, an online perception test was conducted, in which participants were asked to rate the perceived emotions corresponding to each tone. The results shows that a crossover point for four primary emotions lies in the frequency range of 417 - 440 Hz, thus consolidating the hypothesis that frequency range 432 – 440 Hz is neutral from human emotion perspective. It was also observed that frequency dependant relationship between emotion pairs Happy - Sad and Anger - Calm are approximately mirror symmetric in nature.

Keywords: Emotion recognition; Emotion cues; Pure tone; Frequency dependent relationship

1. Introduction

Our emotions play a crucial role in modulating our experiences and the way we interact with others, along with driving our perception and cognitive processes. Hence, endowing machines to replicate basic sensing capabilities like humans has remained a long-pursued goal for various Bio-medical, Engineering and computer science disciplines [1][2][3][4]. Ideally, we expect our machines or computing devices to be smart enough to rapidly sense their immediate surroundings and develop the most appropriate response for a given operational environment[5] [6]. For this quest, the two basic senses that can play a significant role are audio and vision, out of which audio senses are well known for stimulating emotion cues [7][8][9][10]. Nevertheless enabling computing devices to detect emotion cues from acoustic signals is a daunting task because of reasons like [11][7],

- diverse nature of possible audio inputs and their application scenarios,
- presence of high background noise, and
- poor performance of source localisation and separation algorithms.

Hence, in order to sense acoustic environments, this research investigates cues for human emotions on a very fundamental level by focusing on identifying physical sound determinants of emotional responses. In the past, there have been few research studies to establish perceptual determinants for physical parameters in sound such as mapping emotional reactions to auditory events onto a pleasantness-unpleasantness (Lust-Unlust) dimension [12], preference for tones as a function of frequency and intensity [13], Valence and potency/control cues in the vocal expression of emotion [14], relating everyday emotional reactions to both sound characteristics and the appraisal of sound/sound source [15] and emotional reactions to sounds without meaning [16].

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However, to the best of our knowledge, there have been no research in the past aiming to establish a frequency (one of the most important physical parameters of sound) dependent relationship amongst perceived human emotions. Thus, establishing such a relationship between physical parameters of sound and emotional responses can be important for various applications such as emotion induction with sound, development of new sound abatement approaches, sound and auditory interface design and prediction and assessment of subjective noise experiences [17] [18] [19]. The findings of this research can also be helpful in establishing perceptual determinants for physical parameters in sound, along with setting directions for other research in emotion recognition such as detecting emotion cues from non-musical, non-vocal sounds.

Overall this paper is organized as follows: Section 2 presents initial information and research methodologies, Section 3 presents results and discussion, Section 4 presents conclusions and future work.

2. Materials and Methods

In this study, we intend to establish a relationship between pure tone frequencies and perceived human emotions. For that, an online (Qualtrics software based) perception test was conducted, with approval from ANU Human Research Ethics Committee (Protocol 2021/418). Here, the participants were asked to rate 12 different pure tones (frequency range 110 - 963 Hz) on a scale of 1 to 10, corresponding to each emotion class.

2.1. Participants

Thirty adults in the age group of 21 – 55 yrs. from Canberra, Australia participated in the research on a voluntary basis. The gender distribution among participants were equal (i.e., 15 male and 15 female), with median age 27 yrs. (SD 8.041). All participants had normal hearing and technical acumen required for understanding basic acoustic signal processing terminologies such as spatial audio, pure tones, frequencies etc. Also, the test didn't have any specific requirements for participants to represent the general population. Instead, it favors those having prior experience in critically listening to audio.

2.2. Stimuli

The Solfeggio frequencies (174 Hz, 285 Hz, 396 Hz, 417 Hz, 528 Hz, 639 Hz, 741 Hz, 852 Hz and 963 Hz) and the standard tuning frequency along with its harmonics (110 Hz, 220 Hz and 440 Hz) were used to generate pure tones (using MATLAB). The main reason for choosing Solfeggio frequencies was their claimed capability to balance our energy and keep our body, mind, and spirit in perfect harmony [20][4]. Also, using pure tones as a stimuli allowed us to identify direct relationship between frequency and the perceived emotion class, as emotions are typically very complex conscious mental responses that may depend upon various factors such as previous emotional state, past experiences, personal biases and other socio-geographic factors [21][1]. However, with pure tones as stimulus, the chances of emotional responses being convoluted with other factors will be minimal and will only be the resultant of present stimuli.

2.3. Emotion rating mechanism

Each participant had to listen to all 12 Solfeggio frequencies. For each primary emotion class (Happy, Sad, Calm & Anger) they were required to rate these pure tones on a scale of 1 to 10 by using a comparative analysis. Here 1 represents "least significant emotion" and 10 represents "most significant emotion". The detailed instructions for completing emotion rating test were as follows:

- For each emotion category, participants should listen to all 12 pure tones, perform a comparative analysis, and rate the significance of highlighted emotion on a scale of 1 to 10.
- For an effective and consistent perception test, participants are asked to use headphones of good frequency responses.

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- Prior to starting the perception test, participants are to adjust their speaker / headphone sound level to a comfortable level (Recommended level : 15 to 20 %).

2.4. Perception test setup

The emotion rating test was conducted online via Qualtrics software as a survey tool. The main reason for opting online emotion rating test instead of in person was COVID related safety measures. Here, each participant received an email-based invitation with a secured link and a password to participate.

3. Results and Discussions

One of the main intention of this study is to establish frequency dependent interrelationship amongst different emotion classes. For that, we only consider primary emotions - Happy, Sad, Anger and Joy, as they almost cover the entire human emotion spectrum [22] [23]. Also, considering only the primary emotions will allow our results to be more generic and broadly applicable.

To establish the required relationship, emotion ratings from all 30 participants corresponding to each emotion class were analysed by using various statistical tools including mean, median, mode, standard deviation and box-plots. This analysis is represented through the line graph in FIG. 1. **The key finding is that the crossover point for all four primary emotion lies in the frequency range of 417 - 440 Hz**. This clearly depicts that the **frequency range 417 - 440 Hz is neutral**, and hence supports the claim of using 432 - 440 Hz as *universal tuning standard* [24].

Also, from FIG. 1, **we conclude that the plot for emotion pairs, Happy - Sad and Angry - Calm are approximately mirror symmetric in nature**. This also supports the Circumplex model based dimensional approach for emotion annotation where the primary emotion pairs, Happy - Sad and Anger - Calm are represented in diagonally opposite quadrants [23].

Apart from that, for higher frequencies ($\geq$ 440 Hz), the **emotion rating tends to dampen continuously for three primary emotions happy, sad and calm**. However, for emotion class - anger, the rating gradually increases with increasing pure tone frequencies ($\geq$ 440 Hz). This clearly reflects the **dominance of anger emotion class in the higher frequency range**.

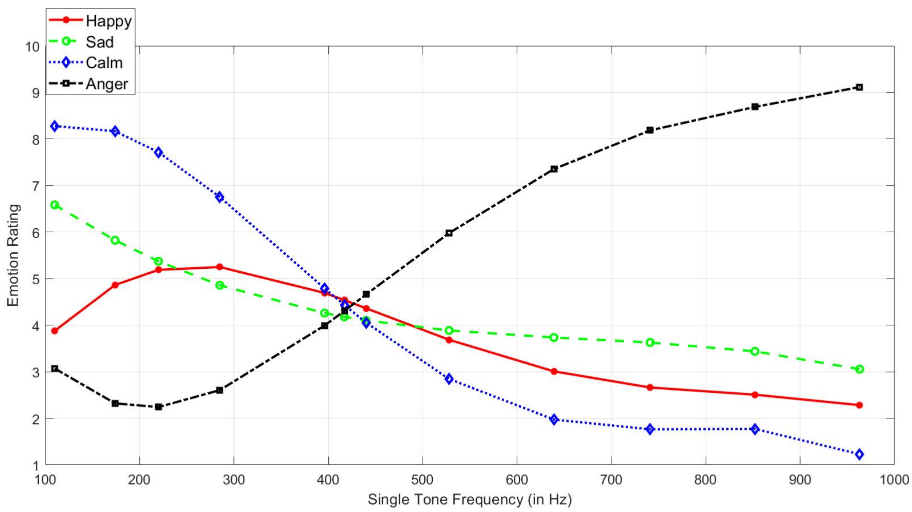

Figure 1. Plot for **Different emotion class rating vs Pure tone frequency.** Here, the line graph for all four primary emotions - Happy, Sad, Anger and Calm are plotted w.r.t pure tone frequency (in Hz).

This study also attempts to identify frequency dependent cues for various emotion classes. For that, a box-plot analysis corresponding to each emotion is thoroughly discussed in the later part of the paper. The prime reason for choosing box-plot as a statistical tool

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for analysis was its capability to visually summarise and convey the level, spread, outliers, and symmetry of data distribution [25].

3.1. Happy

From the happy emotion rating plot (FIG. 2), it can be concluded that the preferred pure tone lies in the frequency range of 210 - 528 Hz. This result also supports the findings of [13]. Apart from that, it can also be concluded that the perception of happy emotion corresponding to higher frequencies is quite contrasting, and hence the appearance of several outliers.

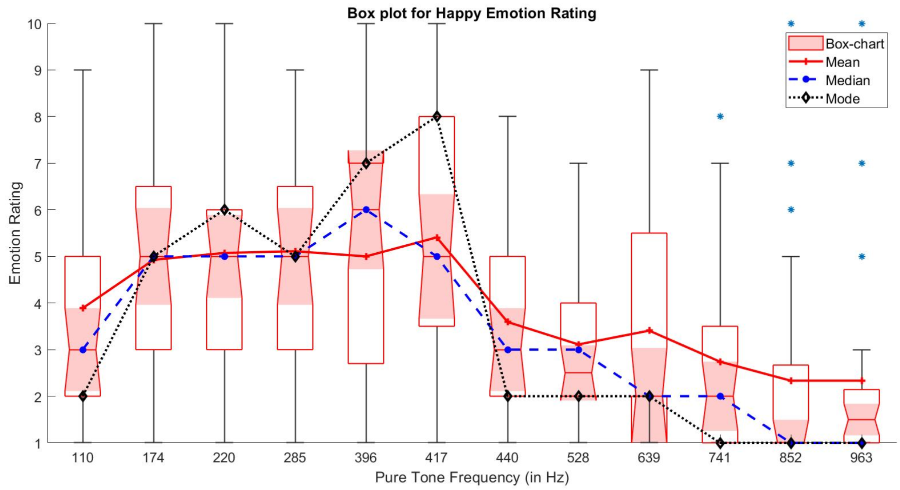

Figure 2. Plot for **Happy emotion rating v/s Pure tone frequency.** Here, the shaded area (red in color) of box chart represents distribution for annotated emotion corresponding to each pure tone frequency. Also, blue dots in emotion rating plot represent outliers data.

3.2. Sad

The sad emotion rating plot (FIG. 3) clearly depicts that the low frequency range corresponds to a higher emotion rating and vice-versa. Also, it can be concluded that the emotion rating corresponding to sad emotion class decreases exponentially with increase in pure tone frequency, and thus reflects the Negative Valence - Low Arousal nature of the sad emotion [23].

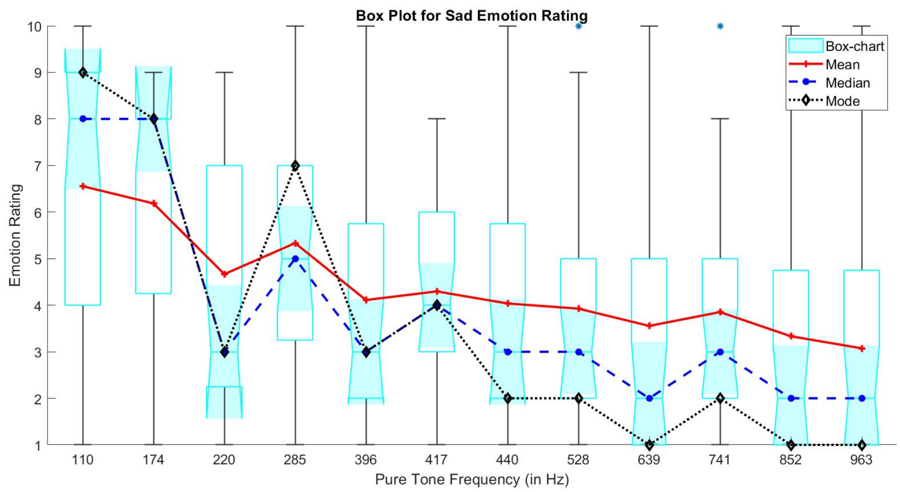

Figure 3. Plot for **Sad emotion rating v/s Pure tone frequency.** Here, the shaded area (cyan in color) of box chart represents distribution for annotated emotion corresponding to each pure tone frequency. Also, blue dots in emotion rating plot represent outliers data.

3.3. Anger

For emotion class - Anger, the rating plot (FIG. 4) clearly depicts that the emotion rating increases exponentially with increase in pure tone frequency. This finding also supports the fact that anger is a Negative Valence - High Arousal emotion [23].

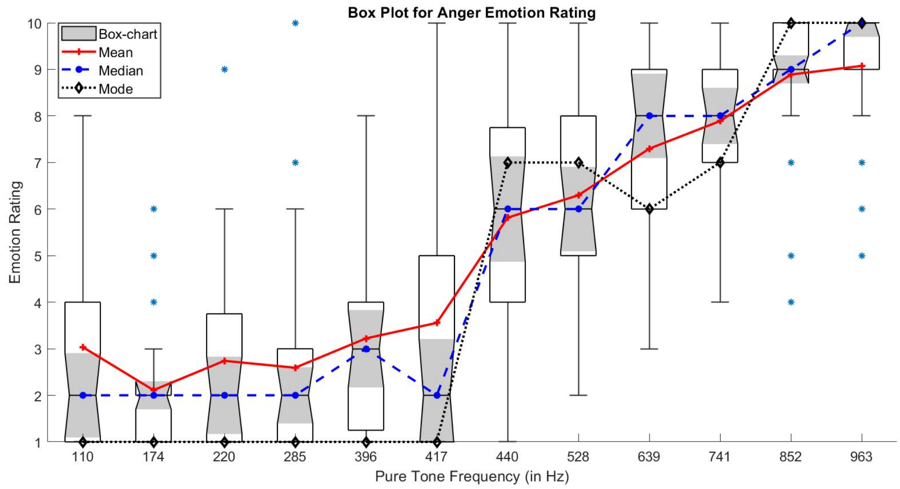

Figure 4. Plot for **Anger emotion rating v/s Pure tone frequency.** Here, the shaded area (grey in color) of box chart represents distribution for annotated emotion corresponding to each pure tone frequency. Also, blue dots in emotion rating plot represent outliers data.

3.4. Calm

For emotion class - Calm, the rating plot (FIG. 5) depicts an interesting relationship between pure tone frequencies and emotion rating. As the emotion rating remained almost constant for both lower and higher frequencies, within the frequency range from 285 - 528 Hz, the rating dips sharply.

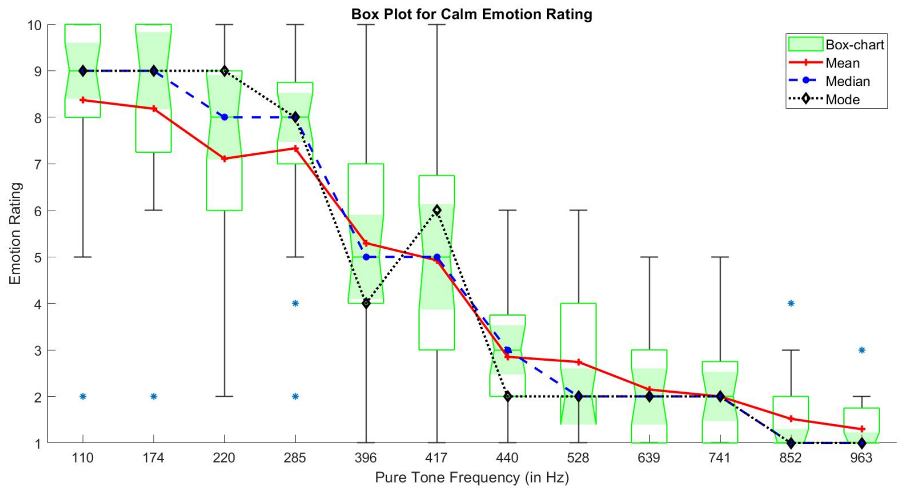

Figure 5. Plot for **Calm emotion rating v/s Pure tone frequency.** Here, the shaded area (green in color) of box chart represents distribution for annotated emotion corresponding to each pure tone frequency. Also, blue dots in emotion rating plot.

Since, emotion rating test was conducted online via Qualtrics software as a survey tool, there is a possibility that differences in testing conditions (i.e., ambiance noise, head phone response and quality) may affected the true stimuli to the listener. To minimize the influence from these variations on the final observations, box-plots are used as a statistical

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tool which is capable of visually summarising and conveying the level, spread, outliers, and symmetry of data distribution [25]. Also, mean, median and mode of emotion rating data is plotted along with box-plot to visualise the overall trend.

4. Conclusions and Future work

Overall, the findings of this research are interesting and establish the relationship between pure tone frequencies (in Hz) and perceived emotions. Specifically, the crossover point for all four primary emotions, Happy, Sad, Anger and Joy, lies in the frequency range of 417 - 440 Hz. The results also consolidates a number of hypothesis with regards to human emotion perception:

- Frequency range 432 – 440 Hz is neutral from human emotion perspective.
- Primary emotion pairs such as Happy - Sad and Angry - Calm are mirror symmetric in nature.
- Preferred pure tones lie in the frequency range of 210 – 540 Hz.

Also, given a rather simple stimuli such as pure tones, the results are still promising thus this work deserves further attention. From future perspective, the findings of this research can lay pathway for further investigation in how pure tone based human emotion perception can vary with respect to other physical parameters such as rate of change in sound intensity, change in direction and other spatial features.

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