Effects of Varying Audio Frequencies on Reaction Time and Muscular Activity

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Abstract

Audio perception is a key component in every individual's ability to react to alarms in the case of an emergency. There have been few studies done which utilize human perception and physiological responses aimed to optimize alarms. Our study aimed to determine the audio frequency which would illicit the fastest and most volatile response, observing both reaction time and electromyographic activity. We predicted that higher frequencies would lead to faster reaction times and more muscular activity. However, we found that there was no significant difference between the reaction times or the electromyographic activity between the varying auditory frequencies. Although there was no significant difference between these reaction times, we found that 37.9% of participants reacted fastest to 880 Hz. Future studies should focus on extending the range of frequencies in order to incorporate a larger portion of participants' audio range, sampling a larger variety of the population other than college students, and incorporating a more mobile version of the electrodes with the electromyography to more accurately measure the true reaction time of the subject.

Introduction

Warning sounds have an extremely important function in society, allowing us to quickly become aware of life-threatening situations like fires, chemical spills, and severe weather such as tornadoes. "The Human Factor's Design Guide" is an extensive compilation of work that takes into consideration human factors in order to design and optimize equipment. The guide defines an alarm warning as "a signal that indicates the existence of a hazardous condition requiring immediate action to prevent loss of life, equipment damage, or a service interruption" (Ahlstrom & Longo, 2003). Optimization of these alarms is extremely important in emergencies. Optimization of warning sounds elicits more urgency, which in turn, increases the probability of an appropriate response and a reduced reaction time (Bliss, Gilson, & Deaton, 1995). Reaction time is defined as the amount of time it takes to physiologically respond to a stimulus (Shelton and Kumar, 2010). Our study focuses on the physiological responses specifically to different auditory frequencies.

There has been a multitude of research studies conducted on auditory stimuli and their effect on reaction time, heart rate, and muscular activity. In Pain and Hibbs' 2007 study on auditory reaction time, they found that auditory reaction time can be as fast as 100 ms, and is thus one of the body's fastest reaction times, even faster than reaction time to visual stimuli. In one study, greater reduction in heart rate was linked with decreased reaction time (Lovallo et al. 1986). Additionally, a study done by Andren and colleagues suggests that varying levels of both noise and frequency have a significant effect on certain aspects of cardiological function, including increased heart rate and increased arterial pressure (1980). Muscular activity can also have adverse responses to auditory stimuli. In a study that examined how varying audio stimuli affected muscular activity, five subjects whose faces and necks were attached to an electromyograph showed increased muscular activity when subjected to an auditory stimulus (Bisdorff et al. 1994).

In our study, we will measure reaction time, heart rate, and muscle activity in response to five different audio frequencies all corresponding to the same musical note A. By altering audio frequency, will reaction time, heart rate, and muscular activity change from their baseline activity? We predict that increasing audio frequencies will decrease reaction time, and increase muscular activity.

We plan to test our question by using GarageBand to measure reaction time, a pulse oximeter to examine heart rate, and a BIOPAC© electromyograph (EMG) to examine muscular activity under five different auditory frequencies. A repetitive pitch will act as our negative control in order to determine the baseline response.

Materials

We developed an audio track with the five auditory frequencies. The corresponding frequencies were chosen in a way that they could each be categorized as the same note ("A"). The five frequencies were: (A4) 440 Hz, (A5) 880 Hz, (A6) 1760 Hz, (A7) 3520 Hz, (A8) 7040 Hz, which are all different octaves of the same note. The use of a single note negated any musical predisposition participants may have had for specific tones. The audio track was composed of each frequency at four random times; 20 sounds in total.

The specific sequence of these frequencies was made using a random number generator denoting A4-A8 as 1-5. Randomization reduced any preference participants may have had for certain frequencies. The volume of the sounds was held constant at volume level 5 on Garageband. In addition to randomizing the tones, we randomized the time interval between each tone (see Fig. 1). These time intervals ranged from 3-6 seconds and were also determined by a random number generator. These time intervals allowed for measurements betweens tones on the EMG to be distinct, and also were used to reduce anxiety of the participants based on an initial trial.

Our means of measuring reaction time was through a computer mouse whose functionality and consistency between subjects was of utmost importance. Garageband facilitated the ability to record reaction time to the millisecond. The cursor of the mouse was placed over the pause button on the interface of Garageband, so upon each click the audio track would be paused. This gave us enough time to record data and press play on the audio track. To prevent movement of the cursor, the sensor at the bottom of the mouse was taped. Additionally, the mouse was securely fastened to the table by tape to keep the distance the subject's hand moves consistent. A line of masking tape was placed 20 cm horizontally below the tip of the left button on the mouse, indicating where each subject was to place their hand after each tone.

The electromyograph used in this experiment is a component of Biopac (©1998-2010 BIOPAC Systems, Inc. Goleta, CA) software. Three electrodes comprise an EMG: VIN-, VIN+, and ground. Each of these electrodes were first attached to a 4mm electrode adhesive disk then Signa Electrode Gel was applied in the center of the electrode. The VIN- was attached to the central forearm near the elbow on the opposite side of the thumb. The VIN+ was attached above the wrist on the thumb side, and the ground electrode adhered above the wrist on the pinky side without any of them touching (Figure 2). The rate of muscular activity was graphed on the Biopac© software interface in milliVolts per second (mV/s). The Biopac© software has a function which allows its users to calculate the maximum rate of muscular activity.

A pulse oximeter was also used to measure heart rate in beats per minute (bpm). This device was attached to the tip of the pointer finger of the non-dominant hand and was used both before the experiment and after the experiment.

To transmit audio to the participants, noise-cancelling audio headphones were used which fit around the ear. To further reduce external sound the experiment was performed in a room solely occupied by lab members and the subject.

Methods

Preparation

In the winter of 2014, at the University of Wisconsin-Madison Medical Sciences Center, a study was conducted to measure physiological responses to various auditory frequencies. The physiological tests conducted were reaction time, muscular activity, and heart rate.

Testing subjects were told to sit down and place both hands on a table. Three electrodes of the electromyograph (EMG) were connected to the subject's dominant arm which would be active in the experiment (Fig.1). Subsequently, we calibrated the EMG on the Biopac Software by determining each subject's baseline muscular activity. Calibration was achieved by the subject remaining still for two seconds, then clenching their dominant fist for two seconds, and finally relaxing that fist. Next, we placed a pulse oximeter on the pointer finger of the subject's non-dominant hand and told them to place that hand flat on the table. We allowed 10 seconds for the pulse oximeter to give a steady reading and then recorded their heart rate. We then asked the participants if they had any hearing problems and also the amount of sleep they received the prior night. After this initial preparation was completed, we told the subject their task.

Task

A mouse was placed 20 centimeters in front of the tip of the subject's hand (Fig. 2). Each subject was told to click the left button of the mouse every time they heard a sound. Next, we placed the audio headphones over the subject's ears. We then played the highest, medium, and lowest tones in a sequence to make sure the audio headphones worked properly.

One lab member started the audio recording while two other members of the lab group recorded the times and observed the EMG. After each "click" occurred, the audio track on Garageband paused. One member recorded reaction times to each tone on a spreadsheet to the millisecond by comparing the time the tone was stopped to the time the tone sound was activated. Another member continued the recording after the time had been recorded after each measurement. If for any reason the subject missed the mouse, we omitted the data for that tone on the spreadsheet. Upon finishing all 20 tones, we removed the headphones and placed the pulse oximeter back on the subject's non-dominant pointer finger using the same method as previously mentioned and recorded their final heart rate.

Analysis

Due to encountering an error upon saving each file separately, analysis of the muscular activity was required immediately after each subject's completion of the testing procedure. We utilized a Biopac© option which calculated the maximum rate of muscular activity (Fig. 3). The same sequence of audio frequencies was used for each subject which enabled us to couple muscular activity with the corresponding frequency, and compare averages between frequencies amongst all subjects.

As noted in the task section, once each subject heard the sound, they subsequently paused the audio track. When the subject clicked, reaction time was determined by the difference between the time they paused and the time the predetermined time the tone had begun. The reaction times for each frequency were then averaged for each participant by each frequency.

A statistical T-Test was performed using the software RStudio that allowed for comparison between mean values of both reaction time and muscular activity at five various auditory frequencies. The first series of two sample t-tests analyzed if auditory frequency had a treatment effect on reaction time (ms). This test compared the mean values of reaction times at auditory frequencies of 440 Hz, 880 Hz, 1760 Hz, 3520 Hz, and 7040 Hz for 28 subjects. A separate series of two sample t-tests analyzed if auditory frequency had a treatment effect on muscular activity (mV/s). This test compared muscular activity at the five different auditory frequencies. A linear regression analyzed the relationship between reaction time (ms) and heart rate (BPM) prior to the experiment.

Results

28 individuals from the University of Wisconsin-Madison participated in this study. On average, participants slept 6.9 hours per night with a standard deviation of 1.16 hours and none of the participants reported to have hearing problems.

The mean reaction time for the tones A4-A8 were as follows: 440 Hz (A4): 0.699 ± 0.014 Seconds, 880 Hz (A5): 0.679 ± 0.123 Seconds, 1760 Hz (A6): 0.686 ± 0.123 Seconds, 3520 Hz (A7): 0.682 ± 0.105 Seconds, 7040 Hz (A8): 0.683 ± 0.111 seconds. Participants reacted fastest to 880 Hz and slowest to 440 Hz (Fig 4).

The mean max EMG peak readings for the tones A4-A8 are as follows: 440 Hz (A4): 0.447 ± 0.581 mV/s, 880 Hz (A5): 0.441 ± 0.538 mV/s, 1760 Hz (A6): 0.450 ± 0.533 mV/s, 3520 Hz (A7): 0.455 ± 0.582 mV/s, 7040 Hz (A8): 0.428 ± 0.538 mV/s (Fig. 4).

The series of two sample t-test analyses of the treatment effect of auditory frequencies on reaction time yielded 10 P-values, all highly insignificant. The P-values are as follows: 440 Hz and 880 Hz is .277, 440 Hz and 1760 Hz is .335, 440 Hz and 3520 Hz is .302, 440 Hz and 7040 Hz is .377, 880 Hz and 1760 Hz is .547, 880 Hz and 3520 Hz is .680, 880 Hz and 7040 Hz is .782, 1760 Hz and 3520 Hz is .634, 1760 Hz and 7040 Hz is .787, and 3520 Hz and 7040 Hz is .765 (Fig 5a). There were 27 degrees of freedom for this series of two sample t tests.

The series of two sample t-test analyses of the treatment effect of auditory frequency on muscular activity yielded 10 P-values, all of which were highly insignificant. The P-values are as follows: 440 Hz and 880 Hz is .466, 440 Hz and 1760 Hz is .808, 440 Hz and 3520 Hz is .670, 440 Hz and 7040 Hz is .377, 880 Hz and 1760 Hz is .516, 880 Hz and 3520 Hz is .362, 880 Hz and 7040 Hz is .425, 1760 Hz and 3520 Hz is .518, 1760 Hz and 7040 Hz is .302, and 3520 Hz and 7040 Hz is .211 (Fig 5b). There were 27 degrees of freedom for this series of two sample t tests.

The linear regression utilized heart rate as the predicting value of the explanatory variable reaction time. The relationship was not significantly correlated, $r=.135$.

Discussion

The results of our study indicate that an increased audio frequency does not have a significant effect on reaction time or muscular activity relative to audio tones of smaller frequencies. Therefore, we can reject our alternative hypothesis which stated that increasing audio frequencies will decrease reaction time, and increase muscular activity. Additionally, heart rate was a poor measurement to predict reaction time evident in our small r value of .135.

A salient result of our data is that more than 37.9% of participants reacted fastest to the second lowest pitch, 880 Hz. 31% of participants reacted slowest to the lowest pitch, 440 Hz (Fig. 6). This data might suggest a preference for certain auditory frequencies over others.

We postulated we could use an EMG as a means of measuring muscular activity in response to reaction time because multiple published studies utilized this technology for similar objectives (Benesch et al., 2000; Shultz et al., 1989). We used peak EMG values because we hypothesized more movement would correspond with a faster reaction time and a more volatile response.

According to “The Human Factor’s Design Guide,” the recommended frequency of a warning signal should range from 500 to 3000 Hz. Signals intended to travel around obstacles or distances greater than 300m should exhibit frequencies between 500 and 1000 Hz (Ahlstrom & Longo, 2003). Other research suggests that a higher pitch is correlated with a faster response (Edworthy, Loxley, and Dennis, 1991). This data recommends warning signals to have as high a frequency as possible. Another study found significant differences between fundamental frequencies of 200 Hz to 500 Hz but found no difference between 500 Hz to 800 Hz (Haas and Edworthy, 1996). For this reason, this experiment used a broad range of frequencies in order to investigate the discrepancies between past studies. However, a major limitation of the present study is that it examined only one of many parameters of warning signals that can affect perceived urgency (i.e. the ability to react and remove oneself from the area of danger). The study “Evaluating Warning Sound Urgency with Reaction Times” indicates that some parameters can communicate perceived urgency more effectively than others. Frequency, repetition rate, sound volume, harmonic content and rate are all factors that can affect perceived urgency. Hellier concluded that rate was “the most efficient parameter to communicate urgency” (Hellier et al., 1993). This might serve as a possible explanation for the lack of significance in our data because we analyzed audio frequency alone. Future studies should include repeated experiments with both frequency and rate which would more accurately simulate an alarm.

Several confounding variables existed in our experiment which could have influenced our results. One point of interest to note was that approximately 35.7% (10/28) participants stated that they received six hours of sleep or less the night before they were tested. There have been a multitude of studies conducted that demonstrate the importance of sleep in locomotor tasks such as reaction time. Moreover, past studies indicate that more than six hours of sleep are needed in order for subjects to experience performance improvement and memory consolidation in specific tasks. One such study suggests that an increase in reaction time is observed as sleep loss increases (Williams *et al*, 1962). Therefore, participants who suffered from a lack of sleep (6 hours or less) the night prior to testing could have displayed an impaired ability to perform on a reaction time test in response to an auditory stimulus. Another confounding factor was the inconsistency in the amount of effort put towards the reaction time test. While most subjects clicked the fastest to their capability, other subjects demonstrated lack of enthusiasm, which increased their reaction time.

If this experiment were to be replicated in the future, a few aspects of the methodology should be altered. A larger sample size with a wider age distribution, and gender discrimination of the subjects would enhance the data by representing the population more appropriately. This would limit the effects of outliers and a lack of effort exhibited by some subjects. Concrete and standardized instructions given to each participant should more clearly outline our expectations of the experiment (i.e. to click the mouse as fast as possible when prompted to by the auditory sound). A more mobile version of the electrodes with the electromyography would be useful because there were issues with electrodes detaching from the participants skin as they moved their arm to click the mouse. Extending the range of frequencies in order to incorporate a larger portion of participants' audio range would also strengthen the data.

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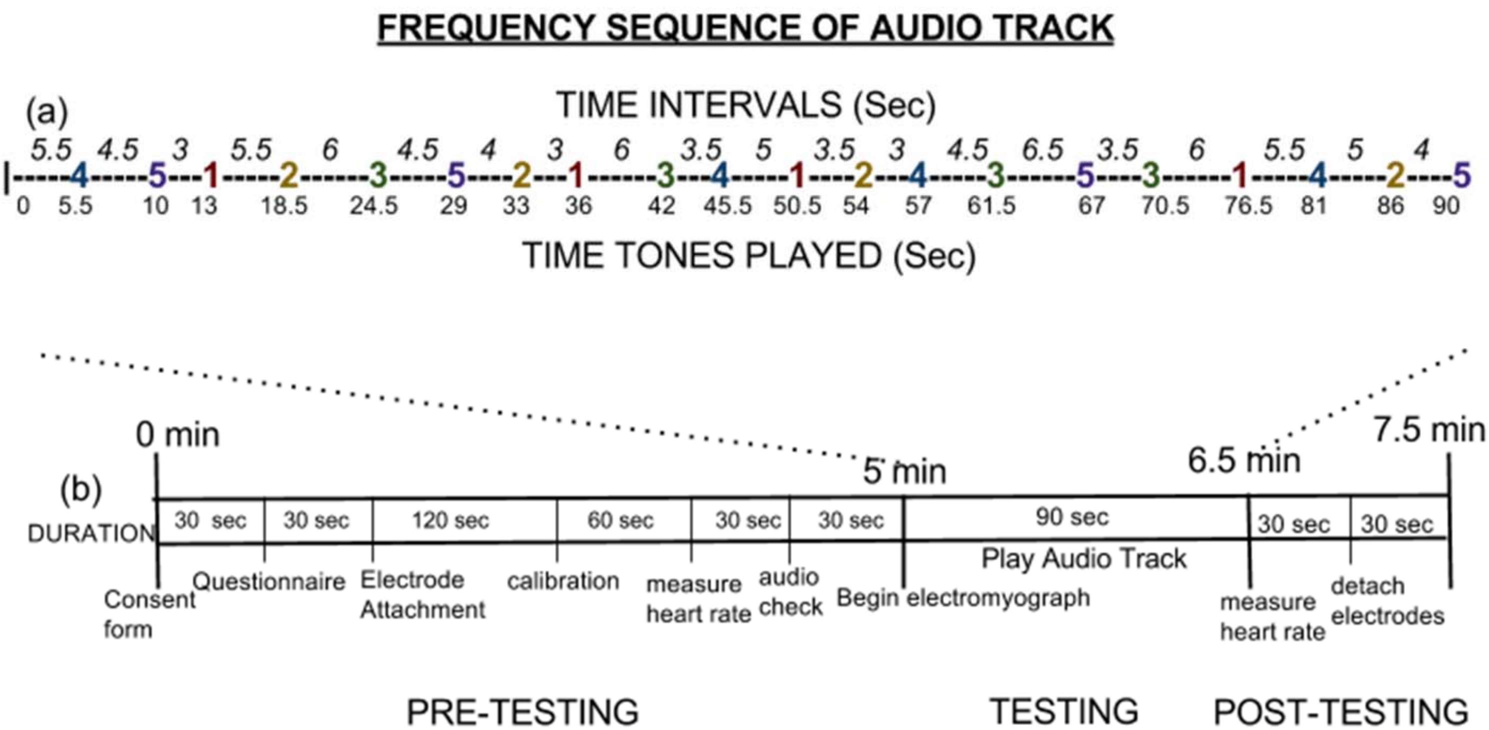
Appendix



(c)

TONE	1	2	3	4	5
FREQUENCY (Hz)	440	880	1760	3520	7040

Figure 1*: *(a) The sequence of the varying frequencies during the audio track. Frequencies were mixed using computer randomization divided into subsections of 4 so each tones would be evenly distributed throughout the audio track; ***(b)*** The timeline of the experiment procedure of a single participant; ***(c)*** The key showing the representation of each frequency as a number from 1 to 5 in order to be input into the random number generator.

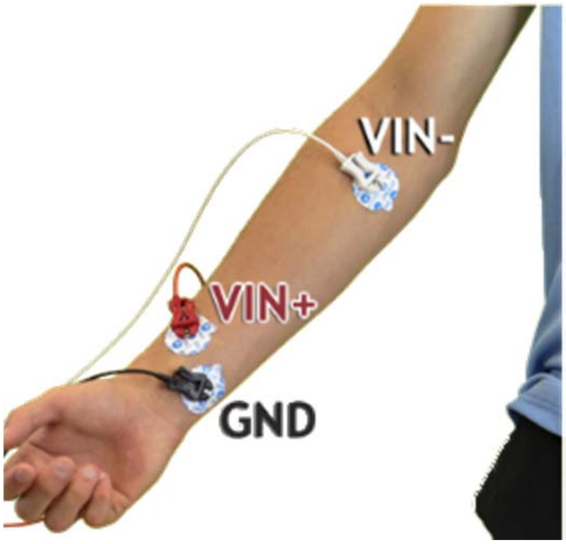


Figure 2: The configuration in which the three electrodes from the EMG were attached to each subject's arm (source: Biopac manual).

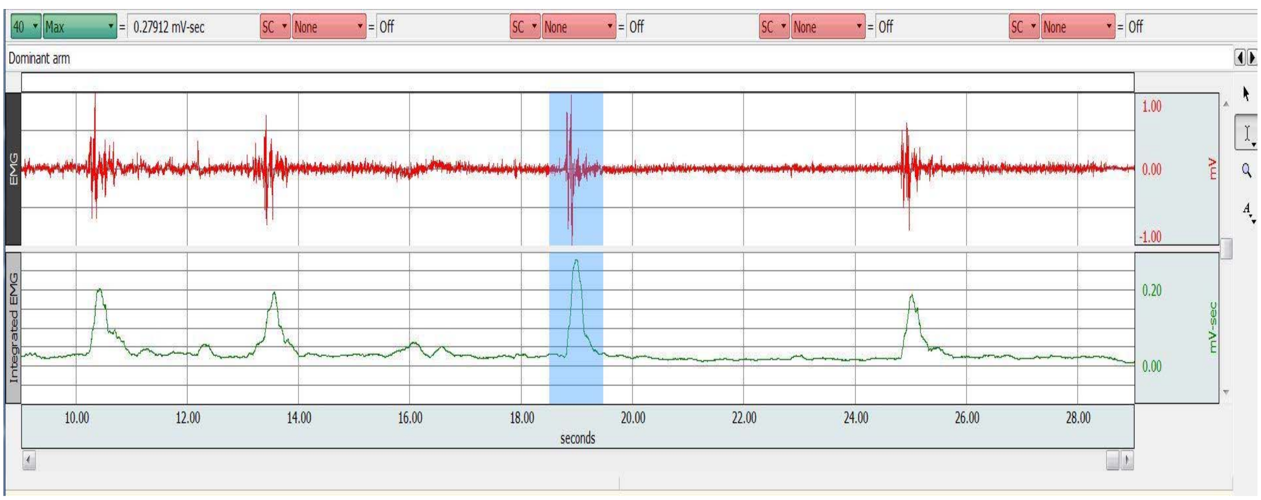


Figure 3: A sample graph of an EMG on Biopac with the calculated the maximum rate of muscular activity

Frequency	**Mean Reaction Time (sec)**	**Mean max EMG peak (mv/sec)**
440 Hz (A4)	0.699 ± 0.144	0.447 ± 0.581
880 Hz (A5)	0.679 ± 0.123	0.441 ± 0.538
1760 Hz (A6)	0.686 ± 0.123	0.450 ± 0.533
3520 Hz (A7)	0.682 ± 0.105	0.456 ± 0.582
7040 Hz (A8)	0.683 ± 0.111	0.428 ± 0.538

***Figure 4*:** A table with the mean reaction times and mean max EMG peak EMG for each frequency across all participants' trials.

(a)

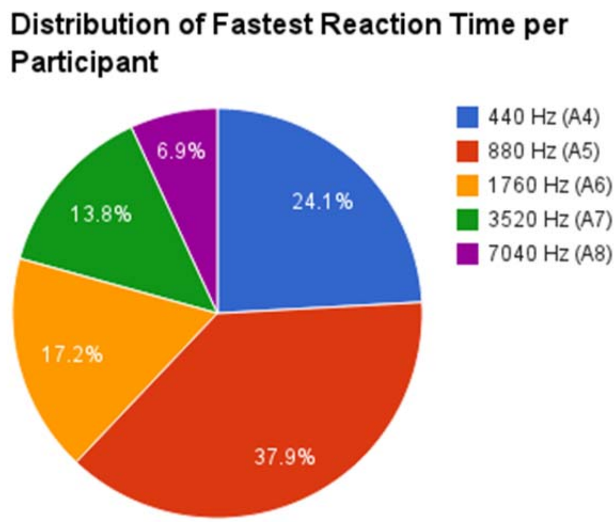
P-values of Reaction Times	880 Hz (A5)	1760 Hz (A6)	3520 Hz (A7)	7040 Hz (A8)
440 Hz (A4)	.277	.335	.302	.377
880 Hz (A5)		.547	.680	.782
1760 Hz (A6)			.634	.787
3520 Hz (A7)				.765

(b)

P-values of EMG	880 Hz (A5)	1760 Hz (A6)	3520 Hz (A7)	7040 Hz (A8)
440 Hz (A4)	.466	.808	.670	.377
880 Hz (A5)		.517	.362	.425
1760 Hz (A6)			.518	.302
3520 Hz (A7)				..211

Figure 5*: *(a) A table with the p-values calculated from numerous t-tests between the average reaction times between two frequency groups. There were no significant differences between reaction time of any two different frequencies. Overall, audio frequency had no significant effect on reaction time; ***(b)*** A table with the p-values calculated from numerous t-tests between the average EMG reading between two frequency groups. There were no significant differences between muscular activity of any two different frequencies. Overall, audio frequency had no significant effect on muscular activity.

(a)



(b)

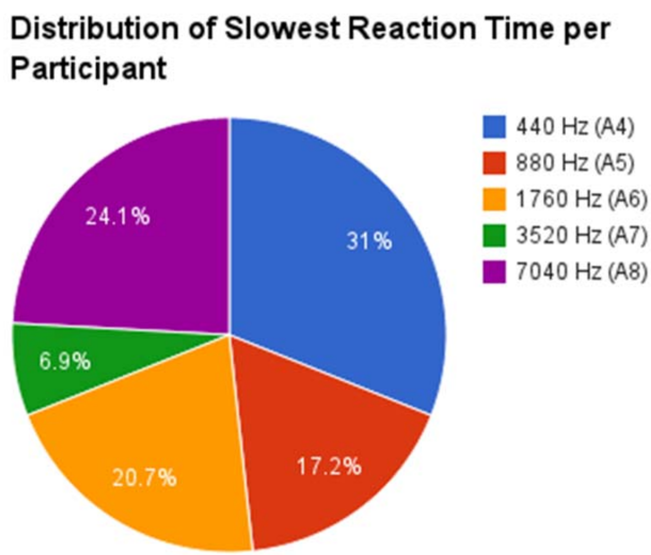


Figure 6: (a) The distribution of the frequencies that produced fastest individual reaction times per participant; ***(b)*** The distribution of the frequencies that produced slowest individual reaction times per participant***.***