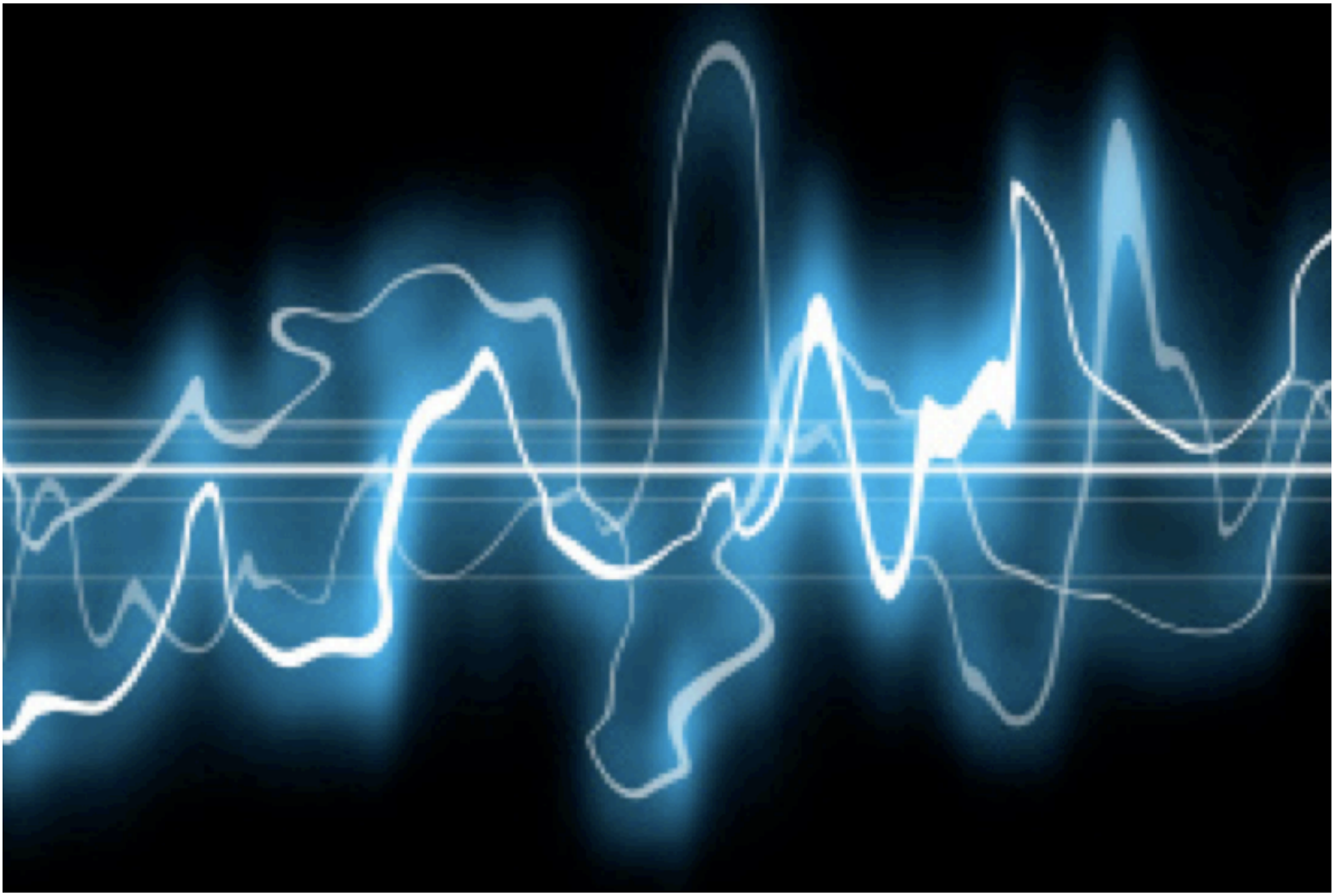
ICC Group Project:

The Influence of Binaural Beats on Brain Wave Activity



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Introduction

In recent years, researchers have exposed various neuroscientific mechanisms related to perceiving sight, sounds, smells and various other cognitive functions. Of great contribution to this growing understanding has been the emergence of neuroimaging techniques such as MRI, fMRI, PET and the EEG, allowing researchers to gather empirical data associated with observable results concerning cognition.

With the growing understanding of cognitive processes also emerges a variety of other related opportunities. One of these opportunities has been exploited in the past years by a great number of commercial organizations in the form of "Binaural Beats". These binaural beats are used to alter one's brain wave frequency, and by doing so, altering one's state of mind. The underlying mechanism relies on the fact that our brain produces certain frequencies of brain waves when exposed to two separate tones with slightly different frequencies. In other words; binaural beats entrain brainwaves by their specific frequencies. Exploiting this fact, various organizations have made claims ranging from reducing anxiety, improving health, reducing pain and increasing alertness or concentration through the exposure to binaural beats.

Of course, when companies make such claims, proper scientific research has to be conducted to verify the reliability and assess possible risks. Fortunately, researching binaural beats should be very feasible with the proper utilization of an EEG device, as the most important variable that needs to be measured is the alteration of brain wave frequencies. Therefore, this research will focus on whether listening to binaural beats has a greater effect on cognition than listening to monaural (normal) beats. The effect will be measured by using EEG device.

This leads to the following research question:

Does listening to binaural beats have a significant effect on brain wave activity compared to normal sounds?

Hypothesis:

Due to the great number of companies claiming to be able to induce positive effects through binaural beats and the number of people who claim to have benefited from binaural beats, it seems plausible to assume that listening to binaural beats will indeed show a change in brain wave patterns.

The subjects of this experiment will listen to binaural beats while their EEG is measured simultaneously. These results will be compared to the results derived from subjects listening to normal beats. This set up and procedure is similar to a matched pair study in which one subject receives two 'treatments' after which the results of both treatments are compared and conclusions made. The experiment will be conducted using multiple subjects to acquire significant data and to avoid possible random change results.

Since binaural beats is still a rather experimental concept with limited scientific research conducted on the actual effect on humans, our research has the potential to be of great value by either verifying or rejecting the effects of binaural beats through brain wave entrainment.

Background

Various literatures about the mechanisms behind binaural beats and its effects in humans has been conducted to obtain an improved understanding about the workings of binaural beats and the possible outcome of this research.

A binaural beat is the result of a modulation in sounds that gets produces when two sounds with slightly different pitch interfere (Oster, 1973)
The frequency of this beat is the same as the initial difference between the frequencies of the original sounds; e.g. if a certain tuning fork with a pitch of 450 hertz is struck at the same time as a tuning fork with a frequency of 444 hertz, a beat will be produced that has a frequency of 6 hertz. All in all, this article serves as a useful source to increase the understanding of what binaural beats are and how they arise, but it does not elaborate on possible brainwave entrainment by binaural beats.

Pratt et al. (2010) compared cortical brain responses evoked by acoustic beats and binaural beats using an EEG device. It was concluded that differences between acoustic beats and binaural beats were not significant. Both gave similar cortical activity, therefore indicating similar cortical processing.
It is not hard to notice the similar nature of above experiment conducted by Pratt et. al (2010) and the experiment described in this report. The fact that Pratt et. al (2010) did not find a significant difference might indicate that a similar result might be achieved here, but this can only be concluded at the end of this experiment.

Lane et. al (1998) have performed research on the effects of binaural beats on vigilance (concentration) tasks. The results indicate that beta-frequency beats caused the subjects to be more alert and their moods to be less negative. However, no EEG's or other quantitative measurement devices to detect brain activity were used in this research; the mood assessment was by self-reporting and targeting-tests before/ after exposure to the binaural beats. A control factor with non-binaural was included.
Despite the limitations of this research (self-reporting), the results do show a significant reaction to binaural beats in the form of increased alertness & improved moods compared to simple non-binaural beats.
These results showing affected psychomotor performance and mood enhancement by binaural beats do indicate that there might be measurable alteration in brain wave activity.

Another study performed by Carter (2008) measured the effect of binaural beats on heart rate and blood pressure. First Carter (2008) explain how binaural beats are processed in the superior olivary complex in the brain, a collection of nuclei in the brainstem important in multiple aspects of hearing. Nonetheless, results showed that neither the binaural beats nor the control sounds influenced blood pressure or heart rate.
However, the beats were only listened to for a short time period (7 minutes) and the subjects were all older people, which might explain the lack of results as older brain do not perceive sounds as well as younger brains and binaural beats might require a certain period before they exert their effect.

Wahbeh, Calabrese, & Zwickey (2007) measured the psychological and physiological effects resulting from listening to delta (0 – 4 Hz) binaural beat frequencies daily for a 60 day period. Results showed that binaural beats have a positive effect on self-reported psychological attribute, as well as a decrease in the insulin and dopamine growth factor. However, this study followed a non-controlled design, and whether or not the responses correlated with EEG measureable brain activity is not reported.

In conclusion, it can be observed that various researches have been performed on the effects and nature of binaural beats, including the response of cortical activity, the change in heart rate & blood pressure, and the effect on various psychological and physiolical attributes.
Of these studies, the controlled studies conducted by Pratt et. al (2010) measuring changes in cortical brain activity in response to binaural beats is most relevant to the experiment described in this report. The similar set-up, consisting of a controlled design with EEG measurement to detect changes in brain activity, might indicate a similar outcome. Nonetheless, the various physiological and psychological responses to binaural beats derived from controlled studies do indicate that there is some mechanisms at work, which might be detectable in brain activity.

Methods & Materials

The intention of this experiment is to measure the effect of binaural beats on brainwave activity, also referred to as brainwave entrainment. This particular purpose leads to the emergence of a straight-forward, yet effective experiment in which subjects listen to binaural beats, while brain activity is measured with an EEG device before, during and after exposure.

The EEG device

The EEG device, called 'Emotiv Epoc', is a wireless device and has 16 sensory electrodes, including two reference sensors, which measure the base resistance of the skin and skull instead of an actual EEG. The electrodes measuring EEG are placed across the skull, specifically 8 electrodes on Frontal, 2 electrodes on Temporal, 2 electrodes on Parietal and 2 electrodes on Occipital lobe. The EEG device collects raw data which are then converted from signal segments into four wavebands (alpha, beta, delta, and theta) for their respective electrode.

Controlled set-up

In order to derive empirical conclusions, a controlled set-up needs to be applied to ensure that the possible results are not forthcoming from other random events. Fortunately it is possible to control this experiment very effectively by exposing the test subjects to the same beat in a mono-audio configuration, which does not allow for differences in pitch required for the effects of binaural beats. If binaural beats can indeed induce brainwave entrainment, then hearing the same beat in a mono-configuration, which is not consciously distinguishable from a binaural beat, should not have the same effect as listening to the actual binaural beat.

The sound files

In order to increase the probability of obtaining significant results, the binaural beats that will be used in this experiment have been selected on basis of the following criteria:

-*specificity of brainwave frequency*: To measure the efficiency of a binaural beat, it is essential for us to know the proposed effect of the binaural beat on brainwave frequency (e.g. a beat could target either alpha or beta brainwaves)

-*customer recognition*: Claims of noticeable effects by a wide audience indicates effectiveness, and thus measurable outcomes.

-*immediate effect*: The beat and effects have to be tested and measured during a feasible time-span.

After extensive research the following commercial binaural beats have been selected:

Audio Training-Sync - Meditation Centerpointe - Holosync - Oasis (Theta); this binaural beat claims to increase theta brain wave patterns related to creativity.

Audio Training-Sync Meditation Centerpointe - Holosync - Quietude (Alpha): this binaural beat claims to increase alpha brain wave frequency patterns related to relaxation and concentration.

Holosync is one of the most popular commercial organizations selling brainwave entrainment programs in the form of binaural beats. Centerpointe (the producer) claims that over a million people worldwide have used Holosync, which indicates effectiveness.

Moreover, the 2 selected tracks should have immediate effects, allowing for the direct measurement of brain wave alteration. The duration of both tracks is 30 minutes each, which seems necessary as another research using 7-minute long binaural beats failed to obtain results (Carter, 2008)

Subjects

Subjects in the same age category should have similar processing and thus reaction to binaural beats; therefore a small group of young test subject will be most efficient. Our own research group consisting of 6 people in the age range 18-21 is ideal for this purpose.

Brainwave activity in the subjects will be measured during exposure to binaural beats in order to observe and compare the direct change in brain wave activity of both the binaural beat and the mono-sounds. Measuring brain activity only at the beginning and ending of binaural beat seems more convenient, but measuring during the entire track is still preferred due to the sensitive nature of the EEG device and in order to avoid the influence of random change.

Both binaural-and mono beats will be listened to on separate days in order to avoid possible interference of brain activity.

Experimental conditions

Part of the binaural beat 'guidelines' is to be in a comfortable position and to avoid any distractions. To achieve this, comfortable chairs will be required as well as a room in which the subject will not be distracted.

Furthermore, it has to be assured that any possible observed changes in brain wave activity are not the results of the interference between the EEG device and headphones. Therefore, a ball will be equipped with both EEG and headphones in order to observe possible interference.

Experiment

The experiment is designed to measure changes in brainwave activity caused by so-called 'binaural beats', sound waves that can possibly induce brain-wave entrainment.

This has led to a straight-forward outline in which the brain activity of 4 subjects (2 subjects were unable to participate due to 'EEG-inappropriate' haircuts and illness) with the 'Emotiv Epoc' EEG device while listening to binaural (stereo)/mono sound.

The experimental procedure

4 tracks have been listened to in total (alpha & theta in both binaural- and mono-configuration) Therefore, each subject was required to listen to 4 tracks in total.
Each track has duration of 30 minutes. This is a long time for an EEG measurement and leads to a tremendous amount of data collection. It has been decided that, in order to maintain a manageable amount of data, a measurement interval of 10 seconds would be optimal. This provided 180 measurements for each track.

30 minutes is a long time to concentrate and listen to single sound. Nonetheless, in order to to avoid distractions that might influence the measurements, subjects were instructed to sit still and close their eye while focusing on their breathing. This should have provided the most accurate reflection of the binaural beats' effects.

Results

Do binaural beats really have an effect on brain waves? Can binaural beats alter our state of mind and our productivity through the entrainment of brain waves? In other words: is there a significant difference in brain activity while listening to a binaural beat and while listening to a 'normal beat'?

As stated before, the data has been derived through the measurement of brain activity while listening to a stereo beat, enabling the effect of binaural beats, and through listening to mono beat, which renders the effect of binaural beats non-existent.

The hypothesis that has been exposed to rigorous testing is that listening to certain binaural beats increases the activity of targeted brain waves, leading to a desired state of mind.
In terms of data analysis, this would mean that the data derived from the stereo beat would show a significant increase in brain wave activity in the specific frequency range (theta & alpha) targeted by the binaural beats.

Because the objective is to observe the overall difference of brain activity change between the binaural and mono sounds, taking the average of all data together is most effective.
This leads to 4 raw data sets; alpha mono, alpha stereo, theta mono and theta stereo.

To observe the different effects of both the mono and stereo tracks, both data sets have been translated into a column graph. This creates two graphs, alpha and theta, which shows the difference in brain wave activity between the mono and stereo track.

Standard deviation

In order to take possible measurement errors in account, the standard deviation has also been analyzed. This led to the discovery of a number of measurements in which the standard deviation was relatively high. Analysis of the particular data category led to the discovery of a significant number of outliers

affecting the standard deviation. These outliers were too high to be derived from brain activity; some kind of error related to the extremely sensitive nature of the equipment is most likely responsible for the observed outliers. After deleting the majority of outliers, the standard deviation dropped to more favorable values for the extreme cases.

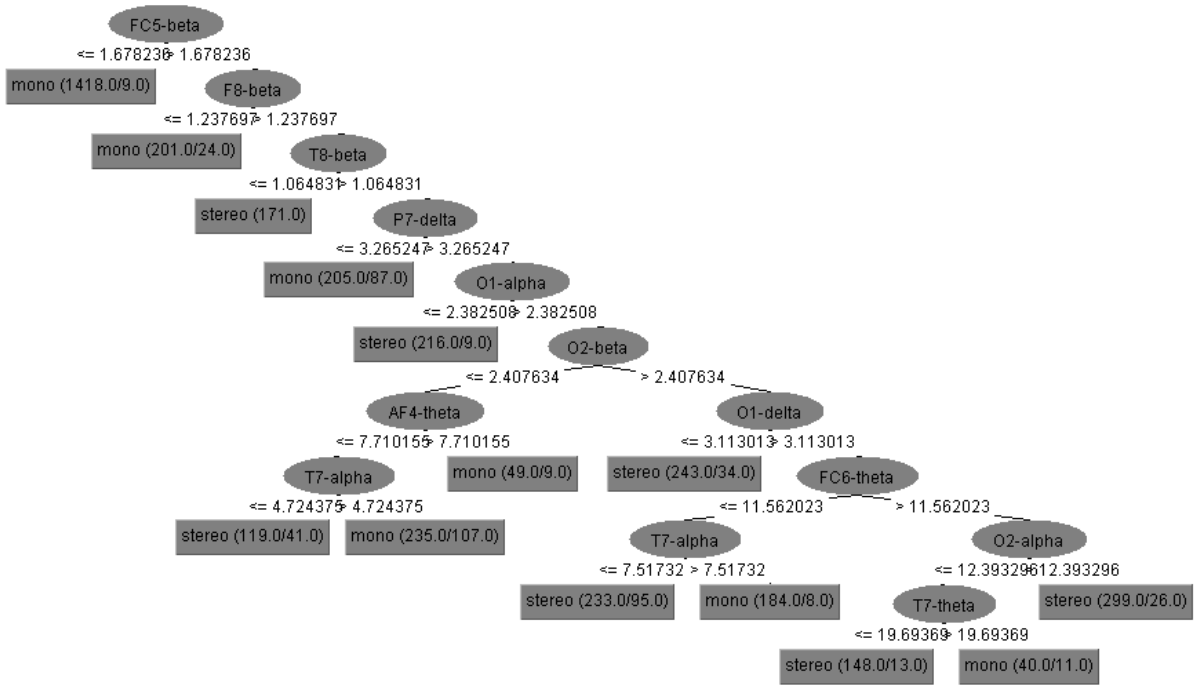
T-test

Furthermore, t-tests have been conducted to test the significance of the differences between the binaural beats and the mono version. The averages of the different subjects were calculated, after which the t-test was performed. The outcome of this was that the differences between the two samples are significant, since for all data sensors α was clearly below 0,05. Therefore, we could reject the null-hypothesis which stated that there was no difference between the samples, and proved an existing difference between the samples.

Classifiers

Finally, a classifier has been utilized to further assess the derived data. A classifier, basically a pattern-discovering algorithm, is a very useful tool to indicate the significance of the differences in measurements between two classes, in this case thus stereo & mono.
The decision tree has been used, leading to the following outcome:

Correctly Classified Instances	3135	83.3555 %
Incorrectly Classified Instances	626	16.6445 %
Kappa statistic	0.648	
Mean absolute error	0.1863	
Root mean squared error	0.3191	
Relative absolute error	39.1652 %	
Root relative squared error	65.4286 %	
Total Number of Instances	3761	

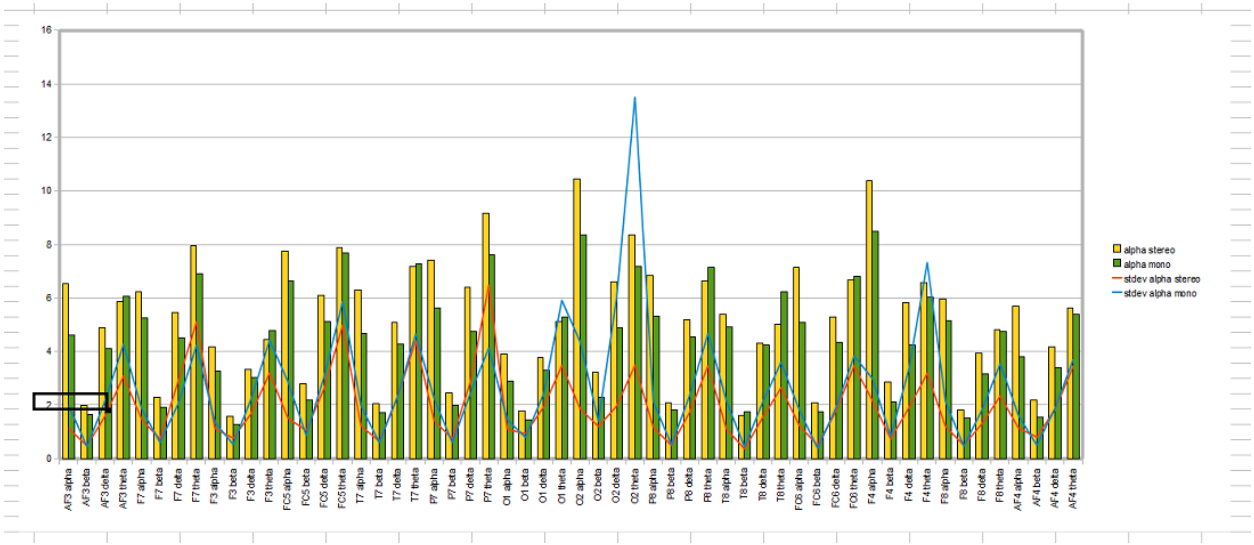


The high proportion (83.3555 %) of correctly classified instances to their corresponding mono or stereo class further indicates the significant difference between the mono and stereo measurements.

Conclusion

Alpha

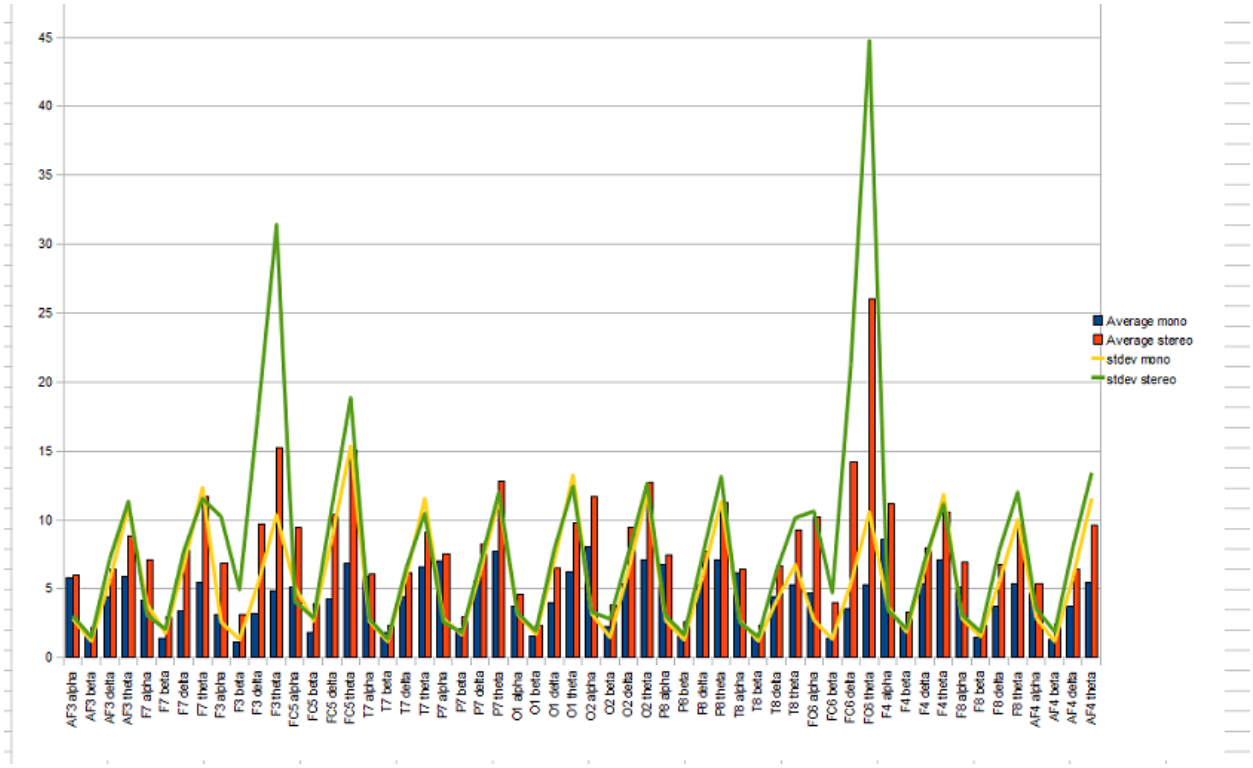
Based on the results of the measurement derived from listening to the alpha binaural- and mono-beats it can be derived that there is indeed a significant increase in alpha-frequency brain wave activity while listening to the binaural beat that targets alpha waves.



It can be observed from the graph that for every single alpha sensor the brain activity during the stereo-beat is higher than during the mono-beat. This is less obvious or not the case at all for other frequencies.

Theta

The same line of reasoning applies to the results derived from listening to the theta binaural- and mono-beats.



For all theta frequency sensors the brain activity is higher while listening to the stereo-beat than while listening to the mono-beat. Despite being less obvious, this also seems to be the case for the other frequencies, indicating that this binaural beat increases brain activity for a wide spectrum of frequencies. Nonetheless, the increase in theta activity while listening to binaural beats is distinctly higher than for the other frequencies.

The results seem to positively answer the research question:

'Does listening to binaural beats have a significant effect on brain wave activity compared to normal sounds?'

In other words, the binaural beats indeed affect the specific brainwaves they were designed to affect, as was also predicted in the hypothesis.

For both alpha and theta stereo/mono comparisons, the alpha and theta values were consistently higher while listening to the stereo beat than while listening to the mono sounds. Significance of the measured differences has been tested and verified by applying t-tests and utilizing a classifier to assess and classify the different data sets.

Furthermore, by deleting extreme outliers and thus reducing the standard deviation, the possibility that the results are derived by random change measurements is minimized.

Implications

The fact that binaural beats are indeed able to induce an increase in targeted brain activity might bear some important implications. Whereas other research, such as the study performed by Pratt et. al (2010), has failed to discover a significant difference in brain activity between binaural and normal beats, this experiment shows that there is a significant difference in brain activity caused by binaural beats.

These results, which possible provide empirical evidence that there is indeed a significant difference caused by binaural beats, might prove to be useful as scientific support for the various claims of personal improvement caused by binaural beats made by their producers. Nonetheless, more research will have to be performed before empirical conclusions can be drawn, as there are various limitations which one has to take into account before interpreting the results of this experiment. These limitations are discussed below.

Discussion

Indeed, no research is without limitations, and this experiment is no exception in that sense. The major factors that require the results of this experiment to be approached with careful consideration are the following:

Small sample size

Despite the overall significant increase in brain activity while listening to stereo sounds, the small sample size of 4 subjects limits the conclusions which one can draw from these results. Situational factors, such as a more aroused or focused state caused by better sleep or nutrition can influence brain activity. A sample size of 4 people is too small to completely exclude the option that the results are merely the result of circumstances.

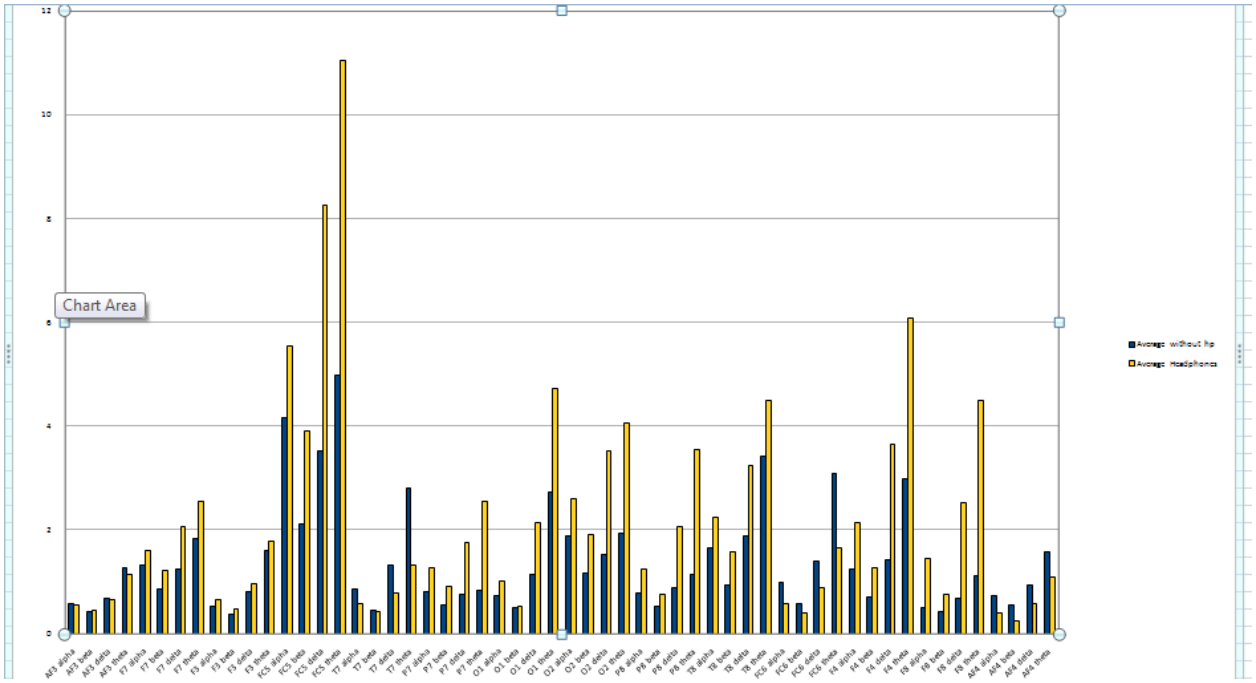
EEG measurements

The EEG device is very precise instrument, but this also means that it is a very sensitive instrument. This implies that a small distortion of the device can lead to undesired variation in the results, which expresses itself in the form of a high standard deviation. Especially when conducting 30 minute measurements such as in this experiment, a small distortion can significantly disrupt measurements, as was also experienced during this experiment. In order to counter a large standard deviation caused by outliers, most outliers were deleted. In most cases this did not significantly influence the measurements since outliers usually applied to a single interval and to all frequencies.
However, in one instance an entire data set from a single test subject was flawed at various frequencies due to measurement errors which lasted an extended period of time. Deleting the entire data set would influence the overall result of the experiment. Therefore, this data has been taking into account, which resulted into the large standard deviations observable in the graph of the theta measurements. For these frequencies, the results are flawed. Fortunately this is only encountered in two instances, which still leaves the validity of the majority of results intact.

The standard deviation is overall within reasonable boundaries for the alpha measurements; the few observable peaks indicating a high standard deviation are from the mono-data files, something which only favors the difference between stereo and mono in this case.

Headphone interference

In order to assess the interference of the electrical signal from the headphones used in this experiment a ball was equipped with headphones and an EEG device. Measurements were conducted with and without a headphone playing the theta inducing binaural beat.



It can be observed that the theta values while the ball is exposed to active headphones are higher than the values derived from the ball without headphones. This indicates that the headphones possibly also interfere with the EEG while measuring human brain activity. Nonetheless, this result cannot influence the measured difference between binaural- and mono-sound activities in the human brain, as the auditory and electrical signal of binaural and mono sounds files does not change.
The observed increase in theta measurements might be a result from the low frequency bass line which is present in the theta track.

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