An Investigation on the Effects of Brainwave Entrainment through Binaural Beats on Verbal Recall

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Objective

This study aims to evaluate how verbal recall is affected by binaural beats stimulation, and the influence of different personality traits in the effects. The study involved four stages, analyzing personality traits, a verbal recall test, listening to the binaural beats stimulus and another verbal recall tests. Separately, EEG data for four participants was collected during the stimulus presentation and analyzed in Matlab to detect entrainment.

Keywords: binaural beats, brainwave entrainment, electroencephalogram (EEG), Five Factor Model, Verbal Recall

1. Introduction

1.1 Terminology

1.1.1 Binaural beats & brainwave entrainment

Binaural beats are auditory processing artifacts, the perception of which arises in the brain for specific physical stimuli. These binaural beats can be generated by present two different frequencies to the left and right ears. The frequency difference should generally lie below 30Hz, or the beats cannot be perceived. It is proposed that binaural beats can effect brain activity and induce brainwave entrainment (also known as frequency following response). Binaural beats have been shown to reduce anxiety and facilitate easier rehabilitation for drug

addicts. It is proposed that binaural beats can trigger out-of- body experiences, lucid dreaming and other paranormal states.

1.1.2 Five Factor Model

The Big Five personality traits are five broad domains or dimensions of personality that are used to describe human personality. The theory based on the Big Five factors is called the Five Factor Model (FFM). The five factors are:

1. *Openness* - Openness involves active imagination, aesthetic sensitivity, attentiveness to inner feelings, preference for variety, and intellectual curiosity. It can be viewed as a global trait; a cluster of patterns of traits, habits and tendencies.

2. *Conscientiousness* – It is a property that is associated with thoroughness, self-organization and carefulness.

3. *Extraversion* – It describes outgoing, talkative and energetic behavior.

4. *Agreeableness* – Its characteristics are perceived as kind, sympathetic, warm and considerate.

5. *Neuroticism* – It is manifested in anxiety, moodiness, worry, envy and jealousy.

A correlation between personality and brain activity is thought to exist, which could affect brainwave entrainment as well. For example, a subject who scored higher on the '*openness*' measure could probably be affected faster by the binaural beats than one who scored less, assuming this to be their first exposure to binaural beats.

1.1.3 Electroencephalogram & EEGLAB

Electroencephalography (EEG) is the electrical activity recorded from multiple electrodes placed on the scalp. A routine clinical EEG recording typically lasts 20–30 minutes. An ERP, or event related potential is the graph of oscillation in the voltage of EEG data that shows specific response to a time-locking event

EEGLAB is a MATLAB toolbox and GUI to analyze recorded EEG data. It includes a set of functions to import EEG data, channel and event information importing, data visualization, independent component analysis etc. More details on EEG and EEGLAB are discussed in a future section.

1.2 Literature review

Holmes [1] measured the changes in ongoing brainwave activity associated with complex binaural-beat stimuli in occipital alpha and central delta band by using free-running EEG. They concluded that binaural beats can engender changes in cortical arousal. P. Goodin [2] et al used steady state binaural beats for a relatively short time (two minutes) to measure the effect of personality traits on entrainment and find no significant difference. M. Gocmen [3] investigates the effect and impact of binaural beats with a beating frequency of 6 and 10Hz at a base frequency of 440Hz on the cognitive states of patients with varying deficits of consciousness and healthy subjects. He indicated that the 6Hz binaural beat stimuli had a significant effect on the post-stimuli theta band compared to the pre-stimuli theta band over all frequencies with $p=0.02$. While the 10Hz binaural beat stimuli had no significant effect.

2. Experiment Design

The study involved two separate experiments.

The first was a study on the effect of personality and binaural beats on verbal recall scores, and the second aimed to detect brainwave entrainment through EEG measurements.

2.1 Task One

The task can be divided into two sections, a pre-stimulus and the stimulus. The participants were not monitored in this task, and were allowed to perform the experiment remotely and at their own convenience.

2.1.1 **Pre-stimulus**

The participant will be asked to perform two tests before the stimulus presentation.

1. **Five Factor Model –** This test is used to determine personality traits in five dimensions. They are openness, conscientiousness, extraversion, agreeableness and neuroticism. This test consists of the participant answering a set of questions (usually 40-60), and receiving a score (usually normalized from 0-5) on each dimension. The participant answers this test only once, as the results are not expected to change in the duration of the experiment. The purpose of this test is to correlate behavioral traits with the results of our study (for example, Open-minded people entrain faster than less open-minded). The test we used is available here.

2. Verbal Recall – This is a simple test where the participant is given some time to memorize a large number of words (40 in our case), and asked to recall as many as possible. The participant will undergo this test twice per sitting, once before the stimulus and once after. Helane et al. [5] have reported a significant correlation between immediate verbal recall and binaural beat stimulus. We originally intended to explore a possible correlation between recall scores and learning, but due to time constraints we could only attempt to replicate their results. The test we used is available at here.

2.1.2 Stimulus

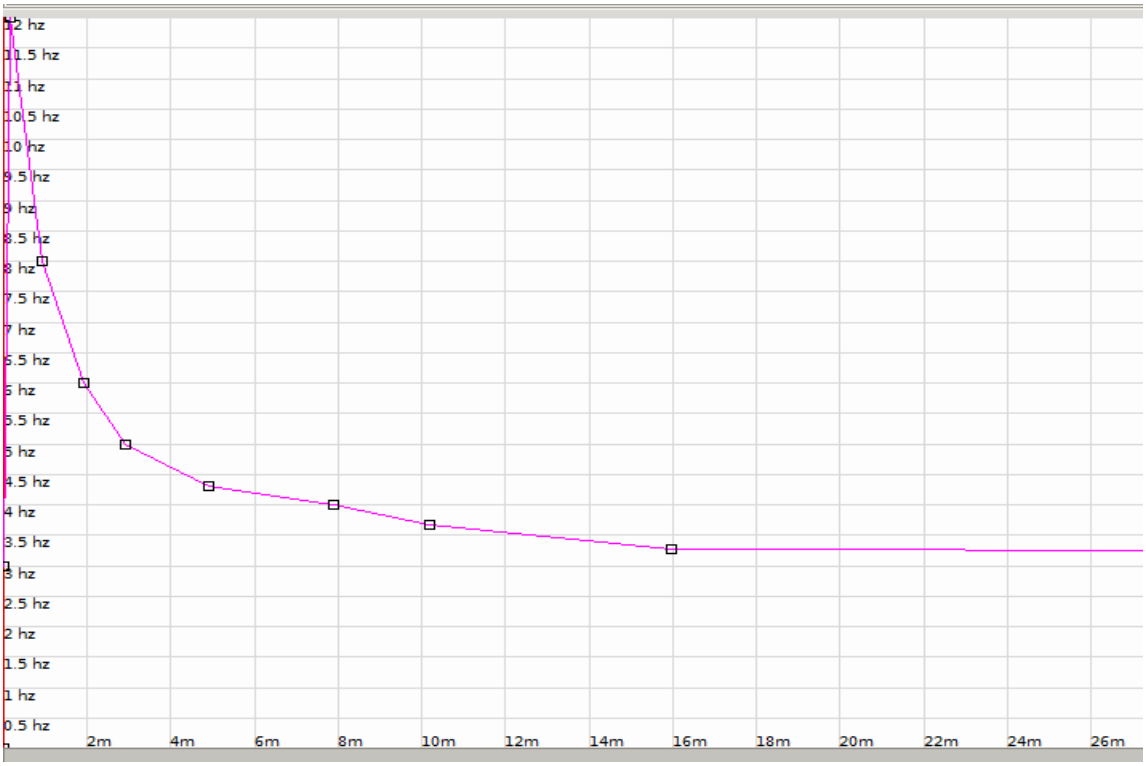
Each participant taking a particular task will be presented with the same stimulus. A few studies have proposed that 400 Hz is the 'optimum' carrier or base frequency for binaural beat stimulation, citing that beats at this frequency are most easily heard. Licklider et al. have proposed a theoretical background to this that combines elements of the Hill-Rashevsky theory of the excitation of neurons with elements of Wever's volley theory.

At low frequencies neurons can discharge in some degree of synchrony with the stimulus wave form, yet fail to coincide within the time interval necessary for synaptic summation. At high frequencies the neurons must take turns discharging, and relatively few can participate in any given volley. At intermediate frequencies, however, each neuron participates

in many volleys and the neurons participating in each volley fire almost simultaneously. The result is that at intermediate frequencies synchrony is relatively precise in each afferent pathway and, when the two afferent streams join in a common neural center, beats appear.

However, some researchers reported no measurable entrainment with 400 Hz carrier stimulus in the theta band. The Oster curves [7] depict some optimum carrier frequencies for each beat frequency. This is considered a “best practice” and not a rigid rule.

The beat frequency of our stimulus varied gradually from 12 Hz to 3 Hz, reducing from 12 Hz to 4 Hz in about five minutes, and gradually reducing to 3Hz during the rest of the stimulus. A plot of beat frequency vs time (in minutes) presented in the following page. In order to remove the effect of carrier frequency variations, we chose a carrier frequency of about 256Hz, which is approximately equal to the optimum frequency specified by the Oster curve. The beats are embedded in white noise, as it is believed to improve the perception of the beats themselves. There is contradicting research about the effect of the duration of the stimulus on entrainment; we approximated the length of our stimulus to about 15 minutes. The stimulus was be generated using the open source application ‘Gnaural’.



Plot of beat frequency vs time of the stimulus

2.2 Task Two

In the second task, we attempt to detect brainwave entrainment through an EEG. An Emotive EPOC, a commercially available 16 channel EEG unit was used to monitor the participant while they are presented with the stimulus. The stimulus was an extended version of the previous stimulus, lasting about 25 minutes. The recorded EEG data is analyzed using the Matlab package EEGLAB. The procedure and visualizations of the data is presented in the following section.

2.3 Data Analysis and Results

2.3.1 Task 1

The participants were requested to report the results of their personality and verbal recall scores. We initially search for the effect of binaural beats on verbal recall scores, and later explore the effect of personality on the change in verbal recall scores. The personality scores were reported in percentiles, and the normalized percentiles are reported in the table below, along with the verbal recall scores.

Key:

VR_PRE = Verbal recall, before stimulus

VR_POST = Verbal recall, after stimulus

P_E = Personality, Extraversion

P_C = Personality, Conscientiousness

P_N = Personality, Neuroticism

P_A = Personality, Agreeableness

P_O = Personality, Openness

Descriptive statistics for the results are displayed in the following page:

Type	Mean	Standard Deviation	Max	Min
VR_PRE	11.95	4.84	23	4
VR_POST	11	4.98	23	5
P_E	.55	.20	.86	.03
P_C	.58	.29	.96	.05
P_N	.58	.28	.91	.03
P_A	.54	.24	.94	.11
P_O	.36	.25	.82	.01

The mean pre-stimulus verbal recall score was 11.95 and the post stimulus average was 11. The verbal recall scores were reported out of 40, and users were awarded one point for a correct word and penalized one point for a wrong one. The scores were mapped from a range of 0-40 to a range of 0-1 for computation. We tabulate the acquired data below.

Serial No.	VR_PRE	VR_POST	P_E	P_C	P_N	P_A	P_O
1	4	7	0.53	0.94	0.91	0.45	0.52
2	6	8	0.65	0.8	0.49	0.26	0.22
3	7	5	0.53	0.09	0.07	0.11	0.18
4	14	18	0.78	0.52	0.91	0.94	0.65
5	16	13	0.41	0.8	0.89	0.83	0.59
6	16	6	0.72	0.05	0.4	0.63	0.42
7	13	10	0.57	0.2	0.44	0.22	0.15
8	12	17	0.03	0.57	0.03	0.51	0.01
9	11	14	0.53	0.92	0.75	0.78	0.27
10	10	12	0.45	0.96	0.89	0.94	0.15
11	5	8	0.38	0.52	0.19	0.39	0.12
12	14	13	0.45	0.62	0.52	0.3	0.65
13	17	12	0.24	0.52	0.63	0.64	0.18
14	15	7	0.86	0.37	0.75	0.51	0.52
15	23	23	0.72	0.28	0.22	0.34	0.76
16	7	8	0.61	0.94	0.64	0.83	0.52
17	18	18	0.49	0.8	0.75	0.52	0.27
18	10	8	0.65	0.8	0.84	0.63	0.12
19	11	5	0.75	0.33	0.64	0.34	0.09
20	10	8	0.83	0.53	0.58	0.67	0.82

Our null hypothesis could be simply stated as “The binaural beat stimulation presented does not affect verbal recall scores”. A repeated measures t-test was used to check the effect of binaural beats in verbal recall scores, t(19)= 1.0435, p = 0.3098, but no significant difference was found. We also used ANOVA on the data, and the similar results (displayed below) are obtained. We therefore conclude that our results were statistically insignificant.

ANOVA Table

Source	SS	df	MS	F	Prob>F
Columns	9.025	1	9.025	0.37	0.5445
Error	916.95	38	24.1303		
Total	925.975	39			

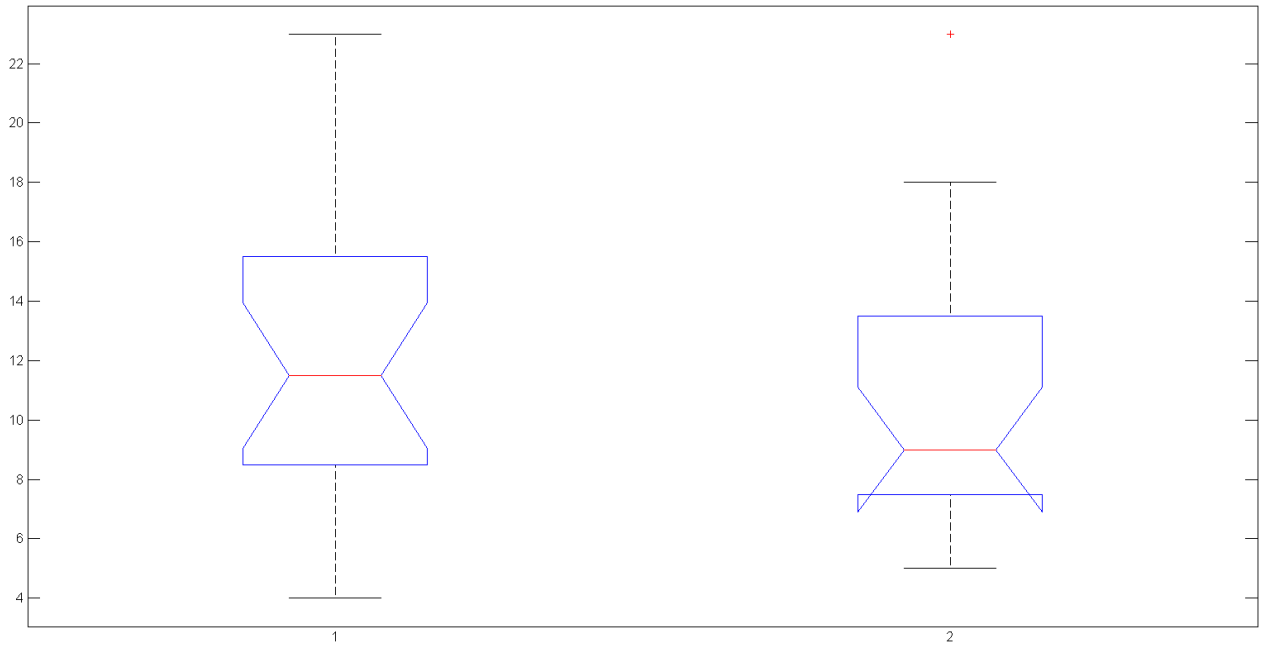


Table of Correlation Coefficients

	Delta	P_A	P_C	P_E	P_N	P_O
Delta	1	-0.1492	-0.5815	.3917	.0360	0.739
P_A	-0.1492	1	0.5140	0.0131	0.6327	0.2319
P_C	-0.5815	0.5140	1	-0.2519	0.5984	0.0015
P_E	.3917	0.0131	-0.2519	1	0.3014	0.5023
P_N	.0360	0.6327	0.5984	0.3014	1	0.2436
P_O	0.739	0.2319	0.0015	0.5023	0.2436	1

Table of p-values

	Delta	P_A	P_C	P_E	P_N	P_O
Delta	1	0.5302	0.0072	0.0876	0.8803	0.7568
P_A	0.5302	1	0.0204	0.9562	0.0028	0.3251
P_C	0.0072	0.0204	1	0.2840	0.0053	0.9951
P_E	0.0876	0.9562	0.2840	1	0.1966	0.0240
P_N	0.8803	0.0028	0.0053	0.1966	1	0.3008
P_O	0.7568	0.3251	0.9951	0.0240	0.3008	1

The p-values lower than 0.05 are highlighted in green. From the above table, we can conclude that conscientiousness is one of the only five personality traits which could cause a change in scores. However, we feel a more thorough study should be conducted before this statement could be verified.

Goodin et al [4] have explored this as well, and have concluded that personality measured in the big five scale does not seem to effect vigilance based binaural based tasks. To the best of our knowledge, there is no published study with conclusive results stating an influence yet.

Our study this far has produced largely inconclusive results, and we believe this may be due to several reasons:

- Nature of binaural beats – The psychophysiological nature of binaural beats is not yet fully understood. Many studies have failed to reproduce previous findings and research.

- Subjects not monitored – The subjects were not monitored during the experiment. Many participants admitted not to have listened to the entire stimulus. It is a highly subjective and situational phenomenon; the environment and situation could have perturbed the results.

- Character of stimulus – The choice of carrier and beat frequencies may not have the predicted effect on verbal recall.

- Background noise – The presence of white/pink noise could affect brainwave entrainment, there have been no studies on this to the best of our knowledge.

- Length of stimulus – The fifteen minute stimulus might not be sufficient to induce the intended effects

2.3.2 Task 2

In this section the effect of binaural beats on the human brain are studied using an EEG.

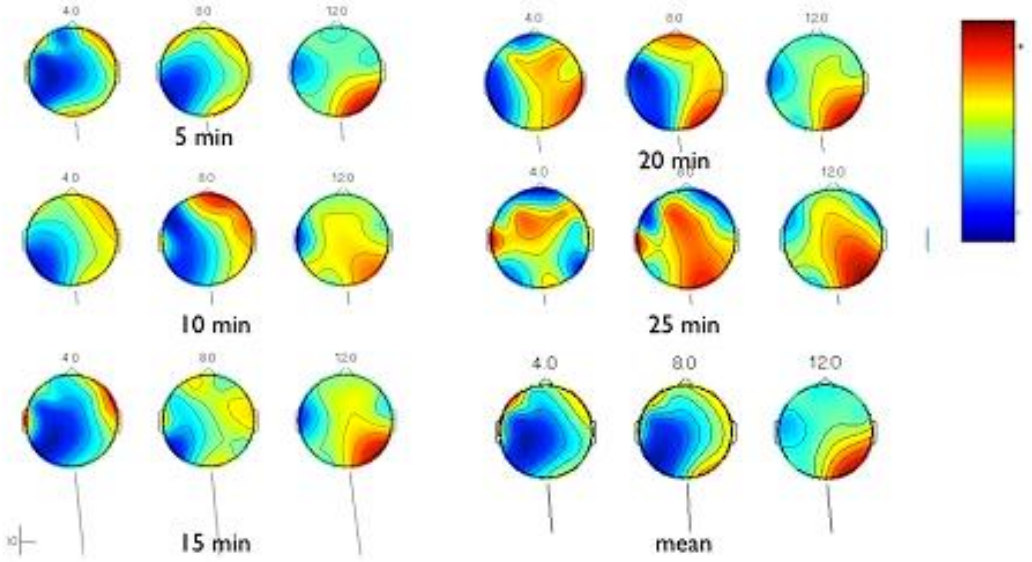
Data preprocessing and Acquisition

The Emotiv testbench software provides a good interface for visualization, but it is not capable of analyzing the data on its own. Therefore, the data is imported into Matlab using the EEGLAB toolbox. First, the EEG data is mapped to its channel location; 14 for EEG data channels and 1 for event related information. The sampling rate of acquisition is set to 128 Hz, and a High Pass filter at 1Hz a Low Pass Filter at 20Hz are applied to reduce errors.

Before data analysis, it is important to pre-process the data to suppress eye blink or muscle movement artifacts. Independent Component Analysis (ICA) algorithms are usually used for this purpose, and produces good results.

The following figure displays the brain activity of a subject at specific intervals of time (5, 10, 15, 20, 25 minutes) and at frequency bands (4, 8 and 12 Hz). Through this figure, we can see that the energy in the theta band (4 Hz) increases with time. This is consistent with the assumption that the theta brainwave stimulus increases energy at that frequency. The mean activity however, does not show much activity in the theta band, this is probably because the beat frequency of our stimulus varies with time. Similar results were obtained for the other subject.

The distribution of energy is tabulated in the following page, along with their verbal recall scores pre and post stimulus.



ID	Theta band (4-8Hz) normalized energy (t/min)						VR Test
	5	10	15	20	25	mean	Pre/Post
1	0.023	0.062	0.128	0.552	0.525	0.262	16/13
2	0.045	0.096	0.314	0.478	0.506	0.288	11/9
3	0.016	0.053	0.139	0.397	0.484	0.217	10/13
4	0.033	0.022	0.235	0.245	0.388	0.185	12/12
5	0.085	0.106	0.433	0.457	0.575	0.331	9/8

Results

Primarily, the second task was to detect changes in the EEG spectrum over time, and compute the energy in the theta band. The results do corroborate our hypothesis, but this could probably be the result of the subject relaxing during the course of the stimulus.

The second task also involved listening to a longer stimulus, to detect if the length of exposure to binaural beats affected their verbal recall scores. However, their scores are similar to the ones in the previous task.

2.4 Conclusion

The study aimed to explore the effect of brainwave entrainment through binaural beats on verbal recall tests. The results were inconclusive, and this could be due to a large number of reasons like length and frequency of stimulation. The study also sought a correlation between personality (from the Big Five model) and change in verbal scores. Though conscientiousness was found to be significant mathematically, we believe that a more comprehensive study should be performed to verify this statement. We detected brainwave entrainment through the EEG study, but did not have enough data to correlate this with the big five personality traits. The longer duration of the second task did not show a drastically different pattern of verbal scores than the first task, but we do not have enough data to make a conclusive statement.

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