Alpha brainwave entrainment as a cognitive performance activator

Violeta Stefania Rotarescu
University of Bucharest

Cognition, Brain, Behavior. An Interdisciplinary Journal

ISSN: 1224-8398
Volume XVII, No. 3 (September), 249-261

ALPHA BRAINWAVE ENTRAINMENT AS A COGNITIVE PERFORMANCE ACTIVATOR

Victor D. CRUCEANU[1], *Violeta S. ROTARESCU*[2*]

[1] Department of Clinical Psychology, "Babes-Bolyai" University, Cluj-Napoca, Romania
[2] Department of Psychology, University of Bucharest, Bucharest, Romania

ABSTRACT

This research investigates the brainwave entrainment process and aims to demonstrate the usefulness of such an approach within the framework of cognitive performance improvements. In the introductory part the theories regarding the neurophysiological structure and the psychological processing of the cognitive system are discussed, for each of their components that are considered to be relevant for this research. The hypothesis states that the stimulation with binaural beats and stroboscopic light, synchronized at 10.2 Hz frequency, will produce a positive change in cognition. The research variables are the cognitive performance (the dependent variable) and the brainwave entrainment (the independent variable). The brainwave entrainment program consists in the synchronized application of Alpha binaural beats and stroboscopic light, at a 10.2 Hz frequency, in a 30 minutes long session. The difference was made by the stroop effect based exercise that was used as a frame. There were 60 participants, divided into two independent samples. The two independent samples t test for the means differences was used in the statistical analysis. The obtained results by evaluations and by statistics confirmed this research's hypothesis, stating that the stimulation with binaural beats and stroboscopic light, synchronized at 10.2 Hz frequency, will produce a positive change in cognition.

KEYWORDS: *brainwave entrainment, binaural beats, stroboscopic light, cognitive performance*

INTRODUCTION

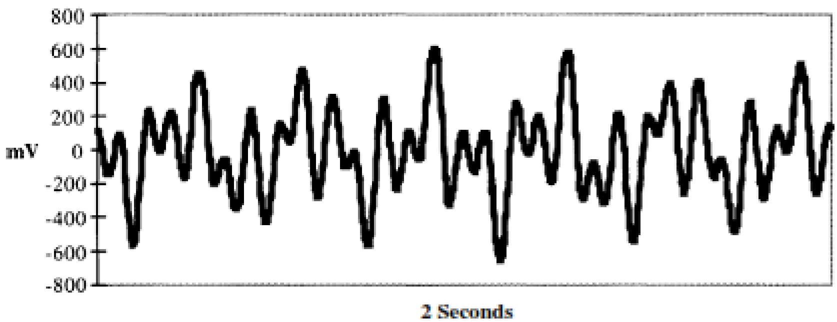
The cognitive system consists in those "*thinking mechanisms on the basis of which information is elaborated, starting from perception, memory and learning and leading to the development of different concepts and logic reasoning*" (Sillamy, 1995, p. 70). The present paper targets performance, at the level of perception, with

* Corresponding author:
E-mail: rotarescu.violeta@gmail.com

implications in the field of implicit perception, of thinking, with implications in the field of comprehension and problem solving, of attention and of memory (Todman & Benson, 2002). We are considering these components of a cognitive system to be essential for a brainwave entrainment process.

A brainwave entrainment process consists in applying on binaural beats, alongside with stroboscopic light, using a high performance and definition audio-video equipment. Binaural beats were discovered by H. W. Dove in 1839 (Oster, 1973). A binaural beat is formed by joining two tones. The lower tone is called carrier and the higher one, offset. The binaural stimuli are administered by high definition stereo headphones, and are perceived by the superior olivary nuclei of each hemisphere. The stimuli perception is determined by the difference in phase of the audio waves' patterns. When the two tones are played together, their frequencies sum up or are subtracted from one another, resulting in a single subsonic wave (WIPO: Thomas Tam, 2013). For example, a 595 Hz tone and a 605 Hz tone produce a subsonic wave of 10 Hz. Then, according to the frequency-following response effect, the brain resonates with the binaural beat and produces cerebral waves that are synchronized with that beat's frequency, thus altering the subject's state of consciousness (Atwater, 1997; Lakatos et al., 2007).

Figure 1.
Complex binaural beat (Atwater, 1997)



Several research sources state the positive effects of a brainwave entrainment program. D. S. Foster (1990) defines Alpha brainwave entrainment as a consciousness management technique, implying a self-adjustment component. Wahbeh, Calabrese, and Zwickey (2007), also Brahmankar (2012), reported considerable decrease in anxiety levels and a raised level in the participants' life quality and overall wellbeing, following a brainwave entrainment program. According to Huang and Charyton (2008), Alpha binaural beats improve the quality of cognitive capabilities, determined by the raised levels of melatonin and DHEA. The relaxed state of alertness determined by Alpha beats facilitates the fast and exact imprinting of images and facilitates connections at a subconscious level. The stable mental state and the raised concentration level determine a higher quality in perception (Lavallee et al., 2011; Padmanabhan et al., 2005).

Stroboscopic light consists in intermittent photic stimulation. It is commonly used in electroencephalography (EEG) in order to determine Alpha frequencies reactivity, and for testing photo paroxysmal reactions. William Grey Walter, one of the pioneers of EEG practice, noted a remarkable effect of stroboscopic light, that is, hallucinations generation (Meulen, Tavy, & Jacobs, 2009; Stevens et al., 2003). In modern neuroscience this kind of phenomena is commonly used in molding hallucinations regarding the altered neuronal activity between the thalamus and the visual cortex, in afflictions such as the Charles Bonnet Syndrome. Nonetheless, in the sixties, when the research was intensely focused on psychedelic effects, Brion Gysin, painter and poet, became highly interested in this field. He designed and built the first stroboscope model, which was primarily destined to brainwave entrainment procedures (Meulen, et al., 2009). A series of theories regarding his device were stated at the time, alongside the one stating that Alpha beats represent a visual scanning mechanism and the hallucinations are caused by the interferences that appeared between the photic stimuli and that scanning mechanism. The shapes of the images can represent different scanning frames, such as parallel lines scanning. Another theory stated that the images are created by spontaneous activity in cortical neurons, which have no idea what the stimulus is, therefore fabricating their own (Meulen et al., 2009; Stevens et al., 2003).

The Stroop Effect has been used in the investigation of the psychological capacities (Peterson et al.,1996; Chen et al., 2013), being a very popular neuropsychological test since its discovery in the twentieth century (Howieson et. al., 2004; Liotti et al., 2000). There is a large array of Stroop test versions that are used in clinical practice, the differences consisting in the number of items, in the type and number of stimuli, in the time necessary for completion and in the scoring procedure (Spreen et. al., 2006; Williams et al.,1996). The items, for example, can consist in color names that differ from the color ink they are printed in, in which case the participant's task is to say the written word. The number of items may vary between 20 and more than 150, this number being interdependent with the scoring system used. Amongst the evaluation criteria we mention the number of correct and/or incorrect answers and the total response time (Howieson et. al., 2004). It is considered that the tests based on the Stroop Effect measure selective attention, cognitive flexibility and processing speed, regularly being utilized in the evaluation of the cognitive system's executive functions (Spreen et. al., 2006; Chen et. al., 2013).

RESEARCH OBJECTIVES

We intend to verify if a long exposure (30 minutes) to a 10.2 Hz brainwave entrainment determines psychological effects, by entraining cortical frequencies and if such a procedure has a positive effect on cognitive performance.
Our hypothesis is that there are statistically significant differences between the results obtained by the sample that underwent a brainwave entrainment procedure, and the results obtained by the other sample, in the sense that in the experimental sample emerged a positive change in cognition.

The participants have ages between 18 and 30 years old and they are part of the same professional environment, following their homogeneity, this approach starting from the premise that people are able to develop similar cognitive styles following similar professional activities. They have been randomly distributed in two experimental samples. All participants were asked for their consent and have been assured for their confidentiality regarding to their participation. The participants haven't been promised material rewards or of another nature.

The instruments used during this experiment, have been: a computer used for the administration of the two variants of the cognitive performance exercise based on the Stroop Effect, a PS24-0X model LED stroboscope with potentiometer adjustable frequency, used for applying stroboscopic light to the participants and a pair of American Audio HP550 professional headphones with a wider playing band, of 5-30000 Hz and a higher rendering output, of 3,500mW, utilized for applying the 10.2 Hz Alpha binaural beats.

The brainwave entrainment consisted of synchronized application of Alpha binaural beats and of stroboscopic light, both with a frequency of 10.2 Hz, having an event time of 30 minutes. The stimuli have been created by the researcher, with the help of some specialized software applications.

The results have been registered in Excel. For the processing of the results it has been used the statistic software SPSS v19.0. The experiment has taken place at the headquarters of the Faculty of Psychology and Education Sciences. Related to the experiment, it is worth mentioning the fact that in the lab has been established and maintained an atmosphere of tranquility with a diffuse light, avoiding as much as possible the presence of another person with the exception of the researcher and of a single subject.

The experimental design

The variables we worked with are the cognitive performance level and the brainwave entrainment procedure.

The dependent variable is represented by the cognitive performance level, quantifiable by the results that are obtained from the Stroop Effect exercise, on three levels: number of correct answers, number of incorrect answers and total work time. Cognition is defined as "the mental action or process of acquiring knowledge and understanding through thought, experience, and the senses" (Soanes, et al., 2006).

The independent variable is represented by the brainwave entrainment procedure. It consists in the exposure to two types of stimuli: binaural beats and stroboscopic light. The two stimuli are synchronized at 10.2 Hz frequency, having an exposure time of 30 minutes.

Data collection procedures

The exercise based on the Stroop effect is computerized. The test consists of three sections: the first section aims for the connections between the chromatic identifications and the labels associated to them, the second section aims for the numerical identifications and the labels associated to them and the third section aims for the derived identifications from the bidimensional spatial orientation and the labels associated to them. There are 56 items. The participants have been shown congruent stimuli as well as the incongruent ones, randomly. The participants have been announced that at the beginning of each section they will be briefed with the proper training and that at the end of the test the total response time and the number of correct and wrong answers will be displayed. Upon completion of the test, the software generates a table where the total number of correct answers, the total number of wrong answers and the total time of completion of the test are registered, for each individual section, as well as the sum of the results of those three sections.

The participants in the control sample, to whom have been presented only the cognitive performance exercise, have been told that the test targets correctness, as well as the rapidity of the answers. The participants in the experimental sample, whom have been first showed the stimuli during a time of 30 minutes and afterwards have been presented with the cognitive performance exercise, have been told the fact that they have to be relaxed and that they don't have to focus on certain thoughts, and that if they have any reason to be afraid, they can stop the procedure at any given time by pressing the ESC button on the keyboard. In addition, the participants in this sample have been asked to follow the following instructions: to stay with their face towards the device which generates the stroboscopic light, to stay in a relaxed position, with their back against the seatback, with their hands around the body, to place the headphones carefully on their ears, so that they stay comfortable while ensuring the direct contact between the speaker and ear, and to keep their eyes closed during the presentation of the stimuli. All of the 60 participants have cooperated during the tests and have been receptive towards the instructions of the researcher.

The results obtained during the experimental procedure have been introduced in Microsoft Excel and processed with the help of the statistic software SPSS v19.0; the independent samples t-test was used in order to determine the difference between the means of the two samples.

RESULTS AND DISCUSSIONS

The data obtained after the experimental procedure was carefully registered and then statistically processed using the independent samples t-test. We targeted the differences between the means of the two independent samples, on three levels: number of correct answers, number of incorrect answers and total work time.

The scores obtained were processed using the independent samples t-test in SPSS. We first analyzed the descriptive statistics, such as the means, the standard deviations and the standard error means. Table 1 illustrates the differences between the means on each of the dependent variable's level. Thus, for "incorrect answers", m=1.93 for the „control sample" and m=1.17 for the „experimental sample, for "correct answers", m=54.07 for the „control sample" and m=54.83 for the „experimental sample, and for "total work time", m=86.80 for „control sample" and m=74.97 for „experimental sample".

Table 1.
Descriptive statistics of scores, for the three levels of independent variable

	Groups	N	Mean	Std. Deviation	Std. Error Mean
Incorrect answers	Control sample	30	1.93	.828	.151
	Experimental sample	30	1.17	.379	.069
Correct answers	Control sample	30	54.07	.828	.151
	Experimental sample	30	54.83	.379	.069
Total work time	Control sample	30	86.80	10.340	1.888
	Experimental sample	30	74.97	7.069	1.291

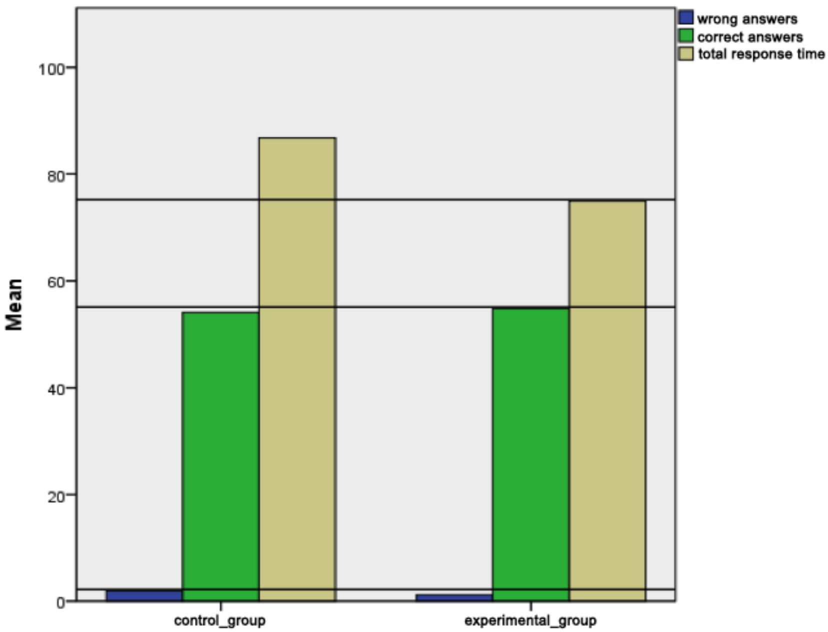
Parametric statistical procedures, such as the independent samples t-test, must test positive for distribution normality, when quantitative variables are implied, meaning that the distribution of these variables' scores are not significantly different from those of a normal distribution. We verified the distribution normality criterion by testing if the Skewness and Kurtosis parameters are within their normality interval of [-1; +1] (Table 2). For "correct answers" and "incorrect answers", Skewness is 0.96 and Kurtosis is 0.51, and for "total work time" Skewness is 0.71 and Kurtosis is 0.02.

Table 2.
Skewness și Kurtosis parameters analysis.

	incorrect answers	correct answers	total work time
Mean	1.55	54.45	80.88
Skewness	.963	-.963	.716
Kurtosis	-.514	-.514	.024

Also, the differences between the values of the dependent variable's three levels are presented in Figure 2.

Figure 2.
Histogram of the scores, on every level of the dependent variable



The independent samples t-test, used for "wrong answers", "correct answers" and "total response time" indicators, reveals a statistically significant change, at $p < 0.05$ (Table 3). This difference ($p = 0.0001$, $p < 0.01$) between the two groups used, "control", on which no treatment has been applied before the testing procedure and "experimental" on which the 30 minutes 10.2 Hz brainwave entrainment treatment was applied, before the testing procedure.

Table 3.
t Test for mean differences, for the two independent samples, for "wrong answers", "correct answers", and "total time of response"

	Levene's Test		t-test						
	F	Sig	T	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Wrong answers	18.772	.000	4.613	58	.000	.767	.166	.434	1.099
Correct answers	18.772	.000	-4.613	58	.000	-.767	.166	-1.099	-.434
Total time of response	3.828	.055	5.175	58	.000	11.833	2.287	7.256	16.411

Therefore, between "wrong answers", "correct answers" and "total response time" indicators, differences are statistically significant, leading to the rejection of the null hypothesis (H0) and to the confirmation of the research hypothesis. From the test's statistical power standpoint, we used Cohen's d coefficient. In the present research, Cohen's d coefficient is d = 1.18 for levels "wrong answers", d = 1.18 for "correct answers", and d = 1.33 for "total response time."

Both the significance level and the effect size registered values confirm that a 10.2 Hz brainwave entrainment program, when instructions are strictly followed, influences the cognitive performance in a positive manner. The significance level is p = 0.0001, and Cohen's d coefficient is bigger than 1, concurring that the difference between the two areas is more than one standard deviation and the effect size was very large.

The results prove the validity of an alternative cognitive performance improvement method, one that addresses the entire cognitive system in a holistic vision, and one that goes beyond merely providing the means to facilitate knowledge. By the means of a brainwave entrainment program, consisting of binaural audio waves, synchronised with a strobe light flicker, at a frequency of 10.2 Hz, the whole cognitive system is stimulated and put in a state of mental preparedness, which allows the individual who followed this program to operate according to his normal routine, but at a much higher processing level (Howieson et al., 2004; Brahmankar, 2012). Also, the proposed method allows a "jump" in performance, without creating limitations or difficulties with the time, financial or logistical availability of the user, that is, because it does not requires algorithmic, heuristic, converging or diverging mechanisms, because the effectiveness does not depend on the type and structure of the material to be stored, and because is not time consuming.

This research aimed to achieve a set of objectives, including proving the fact that long-term exposure brainwave entrainment (30 minutes) involve cortical frequencies. It also determines effects for psychological processes. Such a program has therefore been proven to have a positive effect on cognitive performance, and could provide itself as an efficient alternative method of self-improvement.

The results of the experimental procedure revealed significant increases in the performance of the experimental group which, before starting the Stroop effect exercise, had undergone brainwave entrainment with binaural waves and strobe light, synchronised at the 10.2 Hz frequency ($p < 0.01$, $p = 0.0001$). The recorded results indicated an increase in performance of 118% for the capacity to discriminate between correct and error responses while solving an advanced workload, and an increase in performance of 133% in the ability to faster solving an advanced workload ($d = 1.18$ for "wrong answers", "correct answers", $d = 1.33$ for "total response time").

There were a number of difficulties encountered during the research. The most important one was the availability of the participants. For the participants in the experimental sample the duration of the experimental procedure ranged between 35 and 50 minutes. Another difficulty was the reaction to the stimuli of three of the participants. Those subjects wanted an immediate end to the experimental procedure, accusing a number of somatic aversive reactions such as headache, dizziness, nausea. According to them, these reactions were caused by the strobe light, reactions already noticed in other studies, too (Stevens et al., 2003; Wahbeh et al., 2007). The experimenter tried to determine a link between aversive reactions and the medical history of the participant, demanding information on history of sudden loss of balance, inner ear disorders, epileptic visual disorders, but without success.

We also noticed a number of limitations in our research. A limit is the pseudo-randomised selection of participants. A randomised selection is more desirable, because this type of selection has the potential to build samples that can more accurately capture the peculiarities of the targeted population. Another limitation noted is the lack of quantification of the degree of activation of cortical frequencies (Goodin et al., 2012; Kennerely, 2004). A procedure that would involve the use of electroencephalography (EEG) could collect data to bring more information to this research, meaning it could determine brain areas in which Alpha waves are activated, could quantify the degree in which Alpha waves were activated, and could help determine the degree of remanence of working frequency of 10.2 Hz rank, during the task and after its completion. Another limitation observed is related to the number of items in the Stroop effect exercise utilized to assess cognitive performance. There are 56 items, and, although the exercise is not a psychometric test, a larger number of items would be of a greater relevance, as a standard in the experimental work.

In solving the difficulties and limitations encountered, we propose a set of development guidelines.

On somatic aversive reactions of headache, dizziness and nausea experienced by three participants to the stimuli applied, a future research should provide data on the possibility of recurrence of such events. Specifically, we wish to determine whether such events are random, or if the applied stimuli could determine, as side effects, such aversive reactions, even to the subjects that did not experience them at first.

As concerning the impossibility of determining the degree in which the Alpha waves were activated, and the degree of remanence of 10.2 Hz working frequencies, during the task, and after its completion, the recommendation is that an equipment that could determine this to be utilized, such as an electroencephalograph (EEG), or, much better, neuroimaging equipment, such as a functional magnetic resonance imaging (fMRI). In this last case, the experimental procedure must be reorganised, in order to properly apply stimuli using high fidelity equipment, given that binaural waves can only be transmitted by high-fidelity stereo headset, that works with the help of electromagnets. These headset electromagnets could interfere with fMRI electromagnets. The main task should also be accommodated for the same conditions.

In addition, a longer exposure (30 minutes) for the neural training is targeted, while data collected in other studies, such as those developed by Kennerely (2004) and Goodin et al. (2012), argue that the duration of exposure to stimuli in neural training is irrelevant. According to the literature, there were a number of studies that have claimed that brainwave entrainment procedures require a minimum of 5 minutes to activate (Kennerely, 2004). Goodin et al. (2012) were able to determine the electrophysiological activations using binaural sounds, which led to higher frequencies Theta waves, ranking after 2 seconds after application. However, the authors argue that the above mentioned relatively short periods of binaural stimuli presentations, especially of Beta and Theta types, are insufficient in generating neural training process and also have no effect on vigilance (Goodin et al., 2012). Considerations behind the proposal to use long-term exposure (at least 20 minutes) in applying the brainwave entrainment procedures arose from the experimental observation of conducting the proceedings recorded in data sheets. First of all, a large majority of participants (26 out of 30 subjects in the experimental sample) had changes in nonverbal communication after about 15 minutes (+/- 5 minutes) of exposure to the stimuli - facial, back and shoulder muscles relaxations, and posture repositioning to accommodate a more relaxed seating position in the chair. In the second place, the large exposure time of 30 minutes is suggested in order to act proactively, and to prevent errors in the frequency of cortical activation.

In conclusion, we were able to formally demonstrate that a 10.2 Hz brainwave entrainment procedure has a significant effect in the cognitive area. More specifically, it brings an increase of performance in cognitive processing. The original contribution is ensured by using a Stroop effect based exerciseas a cognitive performance test method, and by using the 10.2 Hz frequency of the stimuli used in the brainwave entrainment procedure to make improvements in cognitive processing. In addition, although in the pre-experimental phase of this study, a comprehensive approach in the scientific databases was conducted, no similar research was found. This result might attest that the present research is the one of the firsts in this direction, testing the hypothesis that 10.2 Hz brainwave entrainment improves the natural capacities of a cognitive system.

As other development directions, beyond those discussed above, would be that of creating an extensive file, based on behavioral anchors, that could be used in behavioral profiling of cortical predominant frequencies of individuals. We point out that such a profile has the potential to maximize a brainwave entrainment process because it works on the principle of taking an individual from his or her natural cortical activation level (the one before a brainwave entrainment program) and the conversion of the degree of activation based on the desired frequency. Therefore, the brainwave entrainment would be facilitated because of the possibility of easily determining the starting point (the natural cortical activation status). Moreover, we want to strongly emphasize the usefulness such a file could have, both in therapeutic and in the clinic practice, allowing the psychologist to adapt the treatment according to the particularities of cortical activation status of the client or patient.

Also, another proposed development direction is to verify the theoretical frame according to which the repeated and systematic use of the same type of brainwave entrainment method influences the development of new neural networks and thus forms new synaptic connections. Also, to verify if these new networks, once formed, increase the intelligence coefficient (IQ). Thus, our proposal would be to test these two complementary parts of the theory, following a longitudinal study, using arrays based IQ tests.

REFERENCES

Atwater, F. H. (1997). Accessing anomalous states of consciousness with a binaural beat technology. *Journal of Scientific Exploration, 11*(3), 263-274.

Atwater, F. H. (1997). Complex Binaural Beat [Photograph]. Copyright 1997 by Society for Scientific Exploration.

Brahmankar, D. A. (2012). The Effect of Resonance on Human Consciousness. *International Journal of Computer Applications, 3*(5).

Chen, Z., Lei, X., Ding., C, Li., H., & Chen, A. (2013). The neural mechanisms of semantic and response conflicts: An fMRI study of practice-related effects in the Stroop task. *NeuroImage, 66*(1), 577-584.

Foster, D. S. (1990). *EEG and subjective correlates of alpha frequency binaural beats stimulation combined with alpha biofeedback*. Ann Arbor, MI: UMI.

Atwater, F. H. (1997). Complex Binaural Beat [Photograph]. Copyright 1997 by Society for Scientific Exploration.

Goodin, P., Ciorciari, J., Baker, K., Carrey, A. M., Harper, M., et al. (2012). A High-Density EEG Investigation into Steady State Binaural Beat Stimulation. *PLoS ONE, 7*(4,) 34789.

Howieson, D. B., Lezak, M. D., & Loring, D. W. (2004). *Orientation and attention. Neuropsychological assessment* (pp. 3365–3367). Oxford: Oxford University Press,.

Huang, I., & Charyton, C. (2008). A comprehensive review of the psychological effects of brainwave entrainment. *Alternative Therapies in Health and Medicine, 14*(5).

Kennerely, R. (2004). QEEG analysis of binaural beat audio entrainment: A pilot study. *Journal of Neurotherapy, 8*, 122.

Irving, K. (2011). Suggestibility and suggestive modulation of the Stroop effect. *Consciousness and Cognition, 20*(2), 335-336.

Lakatos, P., Chen, C. M., O'Connell, M. N., Mills, A., & Schroeder, C. E. (2007). Neuronal oscillations and multisensory interaction in primary auditory cortex. *Neuron, 53*(2), 279-292.

Boenke, L. T., Ohl, F. W., Nikolaev, A. R., Lachmann, T., & van Leeuwen, C. (2009). Different time courses of Stroop and Garner effects in perception — An Event-Related Potentials Study. *NeuroImage, 45*(4), 1272-1288.

Lavallee, C. F., Koren, S. A., & Persinger, M. A. (2011). A quantitative electroencephalographic study of meditation and binaural beat entrainment. *Journal of Alternative and Complementary Medicine, 17*(4), 351-355.

Liotti, M., Woldorff, M. G., Perez III, R., & Mayberg, H. S. (2000). An ERP study of the temporal course of the Stroop color-word interference effect. *Neuropsychologia, 38*(5), 701-711.

Meulen, B. C., Tavy, D., & Jacobs, B. C. (2009). From Stroboscope to Dream Machine: A History of Flicker-Induced Hallucinations. *European Neurology, 62*(5), 316–320.

Oster, G. (1973). Auditory beats in the brain. *Scientific American, 229*(4), 94-102.

Padmanabhan, R., Hildreth, A., & Laws, D. (2005). A prospective, randomised, controlled study examining binaural beat audio and pre-operative anxiety in patients undergoing general anaesthesia for day case surgery. *Anaesthesia, 60*(9), 874-877.

Peterson, B., Anderson, A., Skudlarski, P., Zhang, H., & Gore, J. (1996). An fMRI study of the Stroop effect. *NeuroImage, 3*(3), Supplement, 195.

Sikstrom, S., & Soderlund, G. (2007). Stimulus-dependent dopamine release in attention-deficit/hyperactivity disorder. *Psychological Review, 114*(4), 1047-1075.

Sillamy, N. (1998). *Dicționar de psihologie*. Bucharest: Univers Enciclopedic Printing House.

Soanes, C., Hawker, S., & Elliott, J. (2006). *Oxford Dictionary of Current English*. New York: Oxford University Press Inc.

Spreen, O., Strauss, E., & Elisabeth, M. S. (2006). *A compendium of neuropsychological tests: administration, norms, and commentary* (477–499). Oxford: Oxford University Press.

Stevens, L., Haga, Z., Queen, B., Brady, B., Adams, D., Gilbert, J, Vaughan, E., Leach, C., Nockels, P., & McManus, P. (2003). Binaural Beat Induced Theta EEG Activity and Hypnotic Susceptibility: Contradictory Results and Technical Considerations. *American Journal of Clinical Hypnosis, 45(*4), 295 - 309.

Todman, M. G., & Benson, P. J. (2002). Cognitive neuroscience. *Current Opinion in Neurobiology, 12*(2), 129.

Wahbeh, H., Calabrese, C., Zwickey, H., & Zajdel, D. (2007). Binaural beat technology in humans: A pilot study to assess neuropsychologic, physiologic, and electroencephalographic effects. *Journal of Alternative and Complementary Medicine, 13*(2), 199-206.

Williams, J. M. G., Mathews, A., & MacLeod, C. (1996). The emotional Stroop task and psychopathology. *Psychological Bulletin, 120*(1), 3-24.

WIPO publishes patent of Thomas Tam for "TONG REN BRAINWAVE ENTRAINMENT" (AMERICAN INVENTOR). (2013, May 17). US Fed News Service, Including US State News.