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EFFECT OF BINAURAL BEATS ON SACCADIC OCULAR MOTION

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ABSTRACT: Brainwave entrainment can alter an individual's cognitive and physiological responses. This may be used as a noninvasive therapy in medicine and rehabilitation. This study examines the effect of beta-range binaural-beats on saccadic control. This was conducted in Riphah International University, with 25 non-dyslexic subjects (20 male, 5 females. Age 20±1). Subjects generated saccades in a cross pattern to focus on defined targets. An electrooculogram (EOG) was recorded using skin surface electrodes. The test conditions (20Hz binaural-beats) and the control conditions (silence) listened to 1 minute of the audio stimulus. The results of horizontal and vertical movements over short distance (SD) and long distance (LD), before and after sound exposure were statistically analyzed. There was significant ($p< 0.05$) reduction in horizontal erroneous saccades ($p<0.0024$ LD, $p<0.0001$ SD), significant decrease in LD vertical saccadic ($p<0.0067$), no significant change in SD vertical motion ($p<0.3$). Exposure to binaural-beats reduced the largest angle of ocular deviation by 36.3%. This may help in rehabilitation by improving saccadic control and reading in dyslexics.

Keywords: Binaural beats, Distance, Dyslexia, Entrainment, Motion, Plane, Saccades, Treatment.

INTRODUCTION

The purpose of this study is to investigate the effects of brainwave entrainment, using beta range (12-38Hz) binaural beats as the stimulus, on saccadic motion control of non-dyslexic subjects, as a means to establish a correlation, with potential further applications as a treatment option for people with Special Learning Disabilities. This paper discusses the apparent effects of such entrainment on saccadic ocular motion control over a range of fixed distances in both the horizontal and vertical dimensions. This is followed by a discussion of its clinical significance and recommendations for further study.

A Specific Learning Disability (SLD) refers to a disorder in which one or more of the basic processes involved in understanding or using spoken or written language are disrupted at a cognitive level. They may manifest as impairment in the ability to listen, speak, read, write, spell, perform mathematical calculations, process information and/or use reason and logic.

A survey conducted by the University College London in 2013 concluded that up to 10% of the general population is affected by some form of learning disability, equating to roughly two to three children per classroom. One such disability is dyslexia, which lies in the top five most common learning disabilities. Dyslexia makes it difficult for a child to learn, read and write. Since dyslexia is not of one specific type, there are a variety of factors, associated with cognitive tasks such as learning, affected by it to different extents in each case.

Previous studies find that dyslexics perform differently in saccadic tasks than people without SLDs.

Saccades are rapid, voluntarily or reflexive, ballistic movements of the eyes that abruptly change the point of fixation. They can be of a wide range of amplitudes. Rapid Eye Movement (REM) during sleep is an example. Voluntary saccades are used to align the fovea with objects and events of interest, and working in tandem with head movement, are a part of a goal-directed orienting response. The saccade-generating system of the eye cannot respond to subsequent changes in the position of the target during the course of the saccadic eye movement, and are thus said to be ballistic. Saccadic reaction time is the time between the onset of a visual stimulus and the onset of the saccadic eye movement.

Previous investigations have found there to be a correlation between dyslexia and saccadic control. One study observed that there exists a significant difference in the saccadic motion and fixation of dyslexic patients when compared to non-dyslexic subjects (Eden, *et al*., 1994). Another study observed abnormal saccadic control in dyslexic patients where they displayed longer saccadic reaction times and the number of late saccades was also significantly increased. It also states that the dyslexic patients had poorer fixation quality, failed more often to hit the target at once, had smaller primary saccades, and had shorter reaction times to the left as compared with the control group in non-cognitive tasks.

Brainwave entrainment is the capacity of the brain to naturally synchronize its brainwave frequencies with the rhythm of periodic external stimuli. Studies have shown brainwaves to be correlated with emotional responses, motor control, and a number of cognitive functions. Furthermore, it has been observed that each cognitive function is associated with a different frequency range. These brain waves can be detected and recorded as micro-electrical activity. The procedure, done by applying electrodes to a subject's scalp, is known as electroencephalography (EEG). Through EEG it has been observed that brainwave frequencies can be entrained to a desired range using external stimuli, which can be audio, visual or tactile in nature. Such entrainment has been shown, in previous studies, to affect an individual's cognitive functioning (Huang and Charyton, 2008).

A binaural beat is an auditory phenomenon perceived when two pure tones below the 1500Hz frequency range, with a difference of less than of 40Hz, is presented to each individual ear of the subject. This results in the subject hearing a tone with a varying amplitude with a frequency equal to the difference between the two tones presented in each ear (McConnell *et al.*, 2014). Binaural beats have been shown to be able to alter vigilance and mood via brainwave entrainment. However, in order to observe noticeable results prolonged exposure to the specific beats is required (Huang *et al.*, 2008).

A majority of the studies done to date have directed their attention towards alpha and delta range binaural beats. This is because they are easily recognized in the frequency domain of an EEG. Some studies show that beta and theta waves tend to have an antagonistic effect and are predominantly observed to affect the temporal lobes of the brain. However further investigation is needed, as certain possibilities have been left unexplored, such as the effects of other ranges of binaural beats.

Such studies have also revealed a correlation between vigilance and wake-full awareness and beta-range and theta-range brainwave entrainment. Subjects that experienced the entrainment displayed an increased awareness and vigilance. These studies however test different ranges of brainwave frequencies, as well as use a variety of methods to achieve the desired entrainment.

Kasprzak *et al*. (Kasprzak *et al.*, 2011) Huang et al. (Huang *et al.*, 2008) all have stated that binaural beats have shown proof of brainwave entrainment via frequency following response under specific conditions and assigned cognitive tasks. This is only possible if the frequency of the binaural beats falls in the range of brainwave frequencies as stated. A study has shown that Binaural beats falling in the set range of a specific brainwave tend to show controlling or instead altering effects to that that specific brainwave. Due to this property it is hypothesized that such an effect can be used to either amplify or diminish certain aspects of that specific brainwave. According to Baumeister et al. (Baumeister *et al.*, 2008), Beta Range brainwaves are associated with high anxiety and strong cognitive activity along with active learning. Hence Beta range binaural beats are believed to have an effect on these characteristics. However, the due lack and the specific nature of the research done in this field the true potential of binaural beats remains undiscovered.

MATERIALS AND METHODS

This section highlights the methods used to acquire appropriate and accurate EOG signals from the designated subjects.

This study was approved by the ethical committee of the Department of Biomedical Engineering, Riphah International University. All subjects were made aware of the protocol and signed a consent form detailing their rights before the study commenced in accordance with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

This study analyses data collected from 25 test subjects, 20 male and 5 female. All subjects were of the age 20 (±1) years, and were enrolled as students in Riphah International University. All Subjects were Pakistani nationals and were not afflicted by any acute or chronic ailments. Subjects were required to have unimpaired vision or corrected vision with the aid of prescription glasses or contact lenses.

Subject EOG data were collected using the BIOPAC® Systems Inc. (USA Version) via an MP36 acquisition unit. To provide anti-aliasing for the digital IIR filters and to reduce high frequency noise it employs approximately 20KHz low pass filter. Furthermore, to accommodate the DC offsets associated with a range of biopotentials and transducer signals, it employs a switchable bank of single pole high pass filters whose options are DC (HP filter off), 0.05 Hz, 0.5 Hz and 5 Hz. It also has a D/A resolution of 16 bits.

20 Hz unfiltered beta binaural beats with a base frequency of 200 Hz were presented to the subjects through standard stereo channel, noise canceling earphones.

Disposable Column Electrodes with pre-existing electrolytic gel were applied. Disposable alcohol swabs were used to cleanse the skin of any impurities that may increase skin impedance ultimately affecting data acquisition before the application of electrodes.

A dual channel 6-electrode lead system was used: 3 leads for each, the vertical and the horizontal dimensions. A power line filter (50 Hz) was applied to reduce interference by live power cables in the testing room.

The subjects were informed of the protocol before the testing began. The protocol required subjects to sit still while facing a chart comprising of 8 colored dots and a central reference point. This point was denoted using a shiny metal thumbtack, which was kept at eye level.

The dots were lined in the shape of a cross, with one vertical arm and one horizontal. They were placed at distances of 5.77cm from the reference point (SD) and at

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14.05cm from the reference point (LD). The short-distance points were colored sea green and the long-distance a sky blue. Lighter colors were preferred so as to reduce the contrast between the dots and white background of the chart itself in order to reduce eye strain and to ease the shift from short and LD, as vivid colors have the possibility to produce anticipatory or regressive saccades.

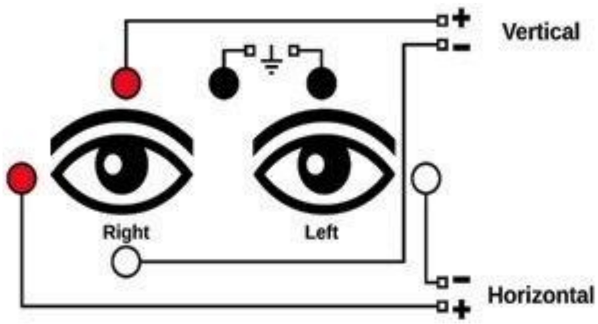

Figure-1: EOG Dual Channel 6-Electrode Lead Placement. Each channel is dedicated to detecting deviations in one specific dimension.

These dots covered a visual deviation angle of 3.6^0 (SD) and 8.82^0 (LD) when viewed from a distance of 3 feet (91.44 cm) away from the chart. These angles were chosen as they cover the range of ocular deviation when reading a standard A4 (210mm × 297mm) from 2 feet away (Shin Y, et al. 2016) so as to replicate a normal reading experience.

Subjects were attached with electrodes and lead wires leading to the BIOPAC® systems lab to record their EOG.

Subjects were kept in isolation during the testing, save for the test supervisor. They were wearing noise isolating earphones. Subjects were instructed to blink as little as possible during the data recording process, as blinking produces interferences in EOG data.

The subject kept their focus on the central reference point until instructed to do otherwise. Instructions to shift their focus were delivered via a timed physical stimulus to uniformly maintain the duration of the saccade. Upon receiving the stimulus, subjects would shift focus without moving their heads. They were instructed to shift from the reference point to first the short-distance dot in the plane (horizontal or vertical) being tested. Upon a second stimulus delivered after a delay of one second the subject would return focus to the reference point. The next stimulus indicated a shift of focus to the long-distance dot in the same direction, and the next stimulus returned focus to the reference. Subjects were made aware of which plane to focus on before testing began.

Figure-2: BIOPAC® MP36 Windows Acquisition Unit used for bio potential acquisition. It has three sets of leads i.e. one for reference aka ground (black), one for positive deflection (red) and one for negative (white) as it alternates with the red lead. (courtesy of BIOPAC® MP36 Student Manual)

Individual readings were taken for movements in the vertical and horizontal plane. On average, each patient was required to produce at least 4 saccades in each plane. These were the “Control” conditions.

The above protocol was repeated once more with each test subject now being exposed to beta range binaural beats through the earphones. For the purpose of this study, unfiltered beats with a frequency of 20Hz (left channel 150Hz, right channel 130Hz) was used. These were the “Test” conditions.

The subjects were allowed a period of rest in between the “Control” and “test” readings. This was done to provide the subject with time to blink and relax the eye.

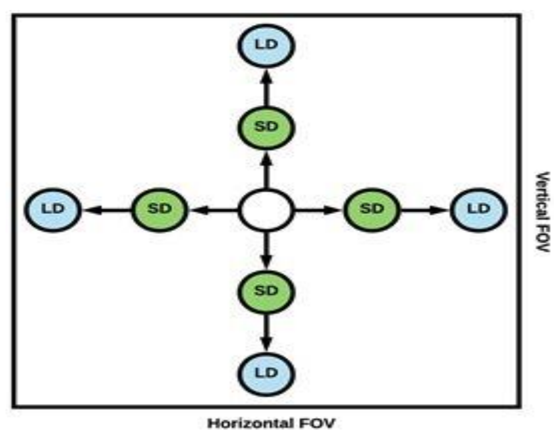

Figure-3: Dot Plot chart designed to produce saccadic movements by the eye.

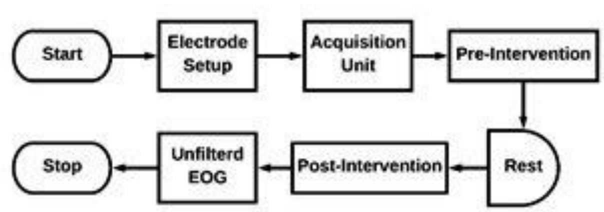

Figure-4: Data Acquisition Flowchart

The EOG recording started while the subject focused on the reference point in order to acquire a baseline for reference.

Saccadic movement of the eye in response to the stimulus resulted in a peak deviation from the baseline. The amplitude of the peak was proportional to the distance moved by the eye. Larger saccades produced peaks with greater amplitudes. Each saccadic movement produced a large initial peak which then stabilized over time spent focusing on the dots. This exaggerated peak represented the overshot eye movement, which occurs due to an inability to stop the saccadic motion immediately. This study focuses on these overshot peaks.

For each subject, the potentials at their horizontal and vertical baselines were recorded, along with the largest magnitude of the overshoot peaks for each saccade. The mean deviation for both SD and LD was measured with and without the beats. The values were then plotted on a graph.

All measured parameters were statistically analyzed using SPSS 13.0 (INC. CHICAGO, IL) software system and their results are displayed in tables 7 – 10 in the Results section.

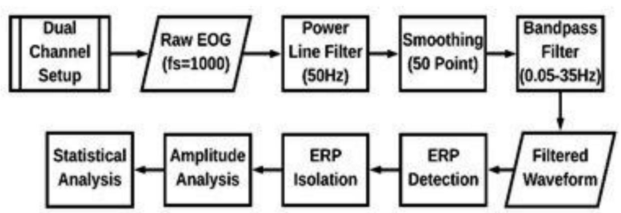

Figure-5: Data Analysis Flowchart

RESULTS AND DISCUSSION

The EOG signals acquired via the MP36 acquisition unit were filtered and denoised by the default settings of the unit.

A total of 16 saccades were recorded from each subject. The first 8 saccades represented the millivolt deviation from the base line under silent conditions while the remaining 8 were recorded in the presence of binaural beats.

Individual readings were taken from each saccade and were tabulated accordingly to their origin and conditions. Furthermore, the baseline was acquired from in between each set of saccades to give us an accurate measure of the deviations under those conditions. The baseline used and the deviation measured was specific to each set of saccades for every subject.

These readings were taken with respect to the plane in consideration (i.e. horizontal and vertical), while direction of motion (i.e. left, right, up and down) were not taken into account. In each plane, movements were recorded on the basis of whether they were SD, or LD.

As such, eight sets of data were acquired per individual subject; namely: horizontal SD deviation without beats, horizontal SD deviation with beats, horizontal LD deviation without beats, horizontal LD deviation with beats, vertical SD deviation without beats, vertical SD deviation with beats, vertical LD deviation without beats, and vertical LD deviation with beats.

Further statistical processing was performed by inputting acquired data into the SPSS 13.0 (INC. CHICAGO, IL) software system which was sued to obtain the mean deviation of each individual in each plane, the overall mean deviation of all subjects in each plane (plotted in graph 1), the pairwise comparisons. Lastly the comparison of mean deviation for each case in the presence and absence of binaural beats was also taken.

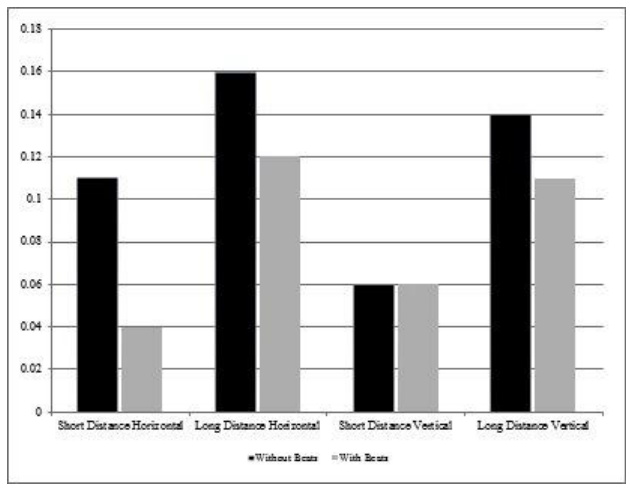

Figure-6: P Values (for cross validation ANOVA through SPSS 13.0 (INC. CHICAGO, IL) software system was used.)

	Horizontal	Vertical
Long Distance	0.0024	0.0067
Short Distance	0.0001	0.2976

Figure-7: Overall Mean comparison chart

Subjects showed no change in SD vertical tracking, while all other parameters saw a significant reduction in overshot saccades. The greatest difference was seen in SD horizontal tracking (63.6% reduction). Other parameters showed smaller reductions: 25% reduction in LD horizontal; 21.4% reduction in LD vertical tracking.

Subjects with poor eyesight displayed an overall poorer control of saccadic movement and had rather erratic fixation patterns. This was regardless of whether or not they used their corrective eyewear, particularly in the vertical plane.

In light of the above results, it can be concluded that brainwave entrainment via binaural beats does have an effect on the saccadic motion control. Further study using prolonged exposure to binaural beats of a variety of ranges may provide even better results. Continuing this investigation may help determine its clinical significance as a possible aid for saccade related Specific Learning Disabilities.

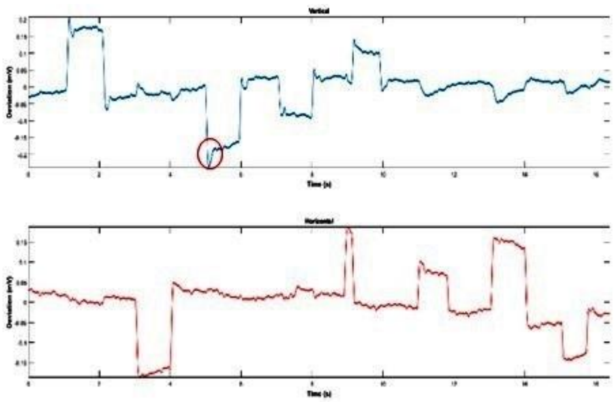

Figure-8: Filtered EOG Waveform. The red circle highlights the exact location of an overshot peak of a saccade.

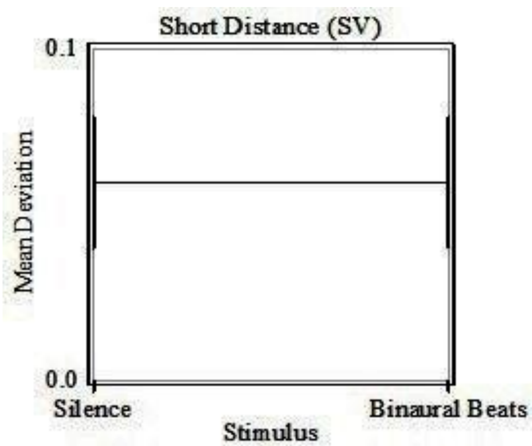

Figure-9: SD Vertical (Silence v/s Beats).

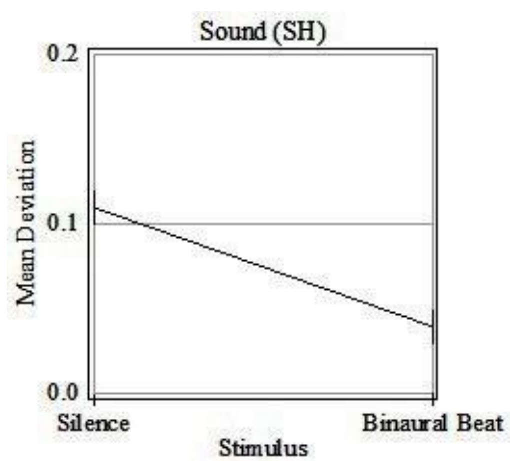

Figure-10: SD Horizontal (Silence v/s Beats)

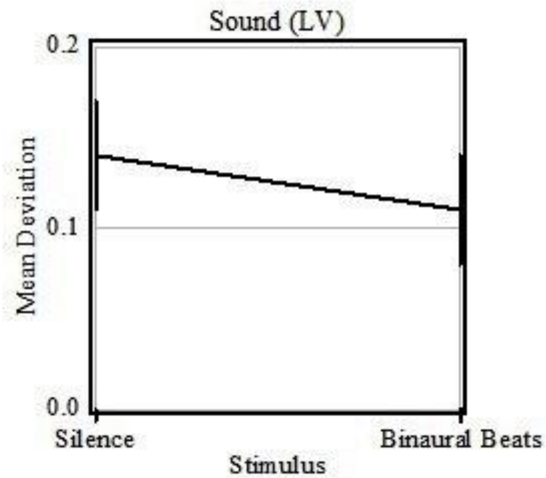

Figure-11: LD Vertical (Silence v/s Beats).

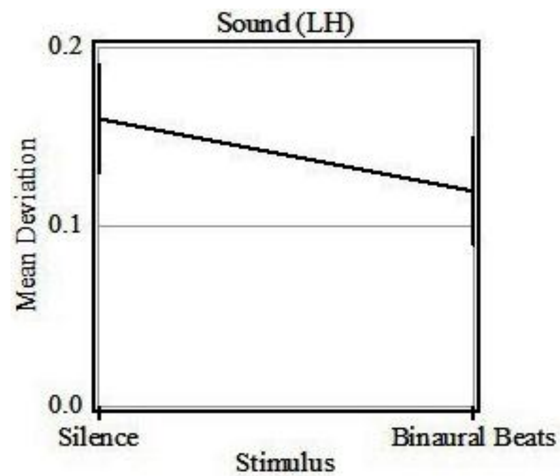

Figure-12: LD Horizontal (Silence v/s Beats)

From the above data it may be inferred that there is a positive correlation between beta range brainwave entrainment and increased saccadic control for SD horizontal movements.

Significant results were reproduced in three out of a total of four scenarios. It was noted that saccadic control improved, with reductions in overshot saccades by 63.6% in SD horizontal tracking, 25% in LD horizontal and 21.4% reduction in LD vertical tracking.

Conclusion: Since a correlation between SLDs and poor saccadic control has been observed as stated in Biscaldi et al. (Biscaldi M, et al. 2000) Paylidis et al. (Pavlidis G, et al. 1981), these effects could possibly help improve reading and learning skills.

The tendency to induce a frequency following response in the brain can also tend to have other higher physiological effects throughout the body excluding the brain as shown by (Reedijk *et al.,*2015; Shin *et al*., 2016). In this way the indirect effects produced due to brainwave entrainment can serve a clinical purpose that remains untapped to this date.

Further study into the use of binaural beats for brainwave entrainment can help diversify the knowledge about potential therapeutic uses. Investigations using different ranges of binaural beats, varying amounts of exposure time and also by using a combination of multiple frequencies of beats as proposed by (Huang *et al.*, 2008) are required to identify the most effective use of such strategies.

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