Quality Assessment for Delta and Theta Binaural Beats

Fatin E.M. Al-Obaidi and Ali Jassim Mohamed Ali
Department of Physics, College of Science, Mustansiriyah University, Baghdad, Iraq

Abstract: Due to brain’s internal wiring, a beating effect will be created in it as soon as two sine waves with slightly different frequencies be applied to each ear. Brain’s response to such beat remains controversial; therefore and in addition to author’s desire toward investigate the role of beat and carrier frequencies upon the brain, this research introduces a new way for quantifying such phenomenon by using an objective methods of quality assessment. In such method, the criteria of error visibility (differences) between tones had been tested. Delta and Theta waves had been used here to investigate their beat and carrier frequencies inside the brain. Results show a similarity behavior for both Delta and Theta waves. Delta wave appeared to be better effect than Theta due to its highest structural dissimilarity metric (DSSIM) which indicates a greater similarity between tones than Theta wave.

Key words: Binaural beat, Structural Similarity Index Metric (SSIM), Structural Dissimilarity Metric (DSSIM), beat frequency, carrier frequency

INTRODUCTION

The dichotic presentation of two nearly equivalent pure tones with slightly different frequencies lead to what we called ‘beat’ in the brain. The beat in this case generated within the brain and is referred to as a ‘binaural beat’ (Jirakittayakorn and Wongsawat, 2017; Chaieb et al., 2015). When a tone of 410 Hz presented to the right ear as an example and a 420 Hz one to the left, then a beat of 10 Hz shall be perceived and located in the brain with carrier frequency of 415 Hz (Chaieb et al., 2015; Anonymous, 2017). In general, binaural beat can occurred if the carrier frequency of the left and right stimulus is no longer than 1500 Hz with a difference of the two tones which not exceed 50 Hz (Mihajloski et al., 2014; Anonymous, 1997). In 1839, H.W. Dove discovered the concept of binaural beat and then outlined with more details by G. Oster over five decades ago (Kneidinger, 2015; Padmanabhan et al., 2005). The researchers by Padmanabhan et al. (2005) found that binaural beat audio has the role in decreasing acute pre-operative anxiety affectively. For inducing a meditative state, Jirakittayakorn and Wongsawat (2017) suggested that 6 Hz binaural beat on a 250 Hz carrier tone can be regard as a good stimulus. Mihajloski et al. (2014) developed a new procedure of evoking transient auditory evoked potentials to binaural beats by adopting frequency modulated stimuli. Table 1 summarizes brain wave with its four bands.

An attempt to visualize delta and theta brain waves has been chosen to test by utilizing quality assessment. The latter is a crucial need which is closely related to signal differences assessment in which quality is based on the differences between left and right tones (Al-Obaidi, 2017; Varnan et al., 2011). Due to certain considerations related to its cost, an objective method is seems to be more preferable than the subjective one in the quality process (George and Prabavathy, 2014).

MATERIALS AND METHODS

Objective quality assessment

Human Visual System (HVS) feature based metrics

Structural Similarity Index Metric (SSIM): This measure compares two signals using information about luminous, contrast and structure as follow (Al-Obaidi, 2017; Varnan et al., 2011):

\[
I(x, y) = \frac{2\mu_x(x, y)\mu_y(x, y) + C_1}{\mu_x^2(x, y) + \mu_y^2(x, y) + C_1}
\]

(1)

\[
C(x, y) = \frac{2\sigma_x(x, y)\sigma_y(x, y) + C_2}{\sigma_x^2(x, y) + \sigma_y^2(x, y) + C_2}
\]

(2)

\[
S(x, y) = \frac{\sigma_{xy}(x, y) + C_3}{\sigma_x(x, y)\sigma_y(x, y) + C_3}
\]

(3)

| Table 1: Brain waves types (Anonymous, 2017) |
|---------------------------------------------|
| Brain wave      | Frequency range (Hz) |
| Delta           | 0.5-4               |
| Theta           | 4-7.5               |
| Alpha           | 7.5-14              |
| Beta            | 14-40               |
| Gamma           | >40                 |

Corresponding Author: Fatin E.M. Al-Obaidi, Department of Physics, College of Science, Mustansiriyah University, Baghdad, Iraq
Where:

\[ x \text{ and } y = \text{Two different positions in two separate signals} \]

\[ \mu_x(x, y) = \sum_{p=-P}^{P} \sum_{q=-Q}^{Q} w(p, q) x(p+q, y+q) \]  

(4)

\[ \sigma_x^2(x, y) = \sum_{p=-P}^{P} \sum_{q=-Q}^{Q} w(p, q) \left[ x(p+q, y+q) - \mu_x(x, y) \right]^2 \]  

(5)

\[ \sigma_{xy}(x, y) = \sum_{p=-P}^{P} \sum_{q=-Q}^{Q} w(p, q) \left[ x(p+q, y+q) - \mu_x(x, y) \right][y(p+q, y+q) - \mu_y(x, y)] \]  

(6)

where, \( w(p, q) \) is a Gaussian weighting function such that:

\[ \sum_{p=-P}^{P} \sum_{q=-Q}^{Q} w(p, q) = 1 \]  

(7)

And \( C_1, C_2, \) and \( C_3 \) are constants given by Al-Dalawy (2013), Wang and Li (2011):

\[ C_1 = (K_1 L)^2 \]  

(8)

\[ C_2 = (K_2 L)^2 \]  

(9)

\[ C_3 = C_2 / 2 \]  

(10)

\( L \) is the dynamic range for the sample data and \( K_1 \) and \( K_2 \) are two scalar constants. Throughout this research a value of 0.01 and 0.03 are set to parameter \( K_1 \) and \( K_2 \) respectively (Al-Dalawy, 2013). The structure similarity can be written as (Wang and Li, 2011):

\[ \text{SSIM}(x, y) = \left[ l(x, y) \right] \left[ c(x, y) \right] \left[ s(x, y) \right] \]  

(11)

SSIM is a decimal value between (-1, 1) (Nisha and Kumar, 2013).

**DSSIM:** This is the structural dissimilarity metric which is derived from SSIM as follows (Nisha and Kumar, 2013):

\[ \text{DSSIM}(x, y) = \frac{1}{1-\text{SSIM}(x, y)} \]  

(12)

The greater values of SSIM and DSSIM refer to greater similarity between signals (Varnan et al., 2011).

**RESULTS AND DISCUSSION**

In this research, Delta and Theta sine tones had been adopted through the web site found by Anonymous, (2017). A general preview for the used tones can be

![Fig. 1: a- d) Delta brain wave relationships with carrier and beat frequencies; Blue series for range (1000.75-1002.25) and Red series for range (1001.5-1003)](image_url)
Fig. 2: a-d) Theta brain wave relationships with carrier and beat frequencies; Blue series for range (1003.5-1004.5)

Table 2: Delta and Theta brain waves generated by Anonymous (2017)

| Brain wave | 1st wave | 2nd wave | Carrier frequency | Beat frequency |
|------------|----------|----------|------------------|---------------|
| Delta      | 1001.0   | 1002     | 1001.50          | 1.0           |
|            | 1003     | 1002.00  | 2.0              |               |
|            | 1004     | 1002.50  | 3.0              |               |
|            | 1005     | 1003.00  | 4.0              |               |
|            | 1000.5   | 1000.75  | 0.5              |               |
|            | 1002     | 1001.25  | 1.5              |               |
|            | 1003     | 1001.75  | 2.5              |               |
|            | 1004     | 1002.25  | 3.5              |               |
| Theta      | 1001.0   | 1006     | 1003.50          | 5.0           |
|            | 1007     | 1004.00  | 6.0              |               |
|            | 1008     | 1004.50  | 7.0              |               |

CONCLUSION

A binaural beat is a beat phenomenon generated by dichotic presentation of two nearly equivalent pure tones with slightly significant different frequencies. Among the used Delta and Theta waves, one can noticed the similarity behavior for the two brain waves with increasing the carrier and beat frequencies. According to results, Delta wave appeared to be better effect than Theta due to its highest DSSIM values which indicates a greater similarity between signals than Theta wave.

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