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Quality Assessment for Delta and Theta Binaural Beats

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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.

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

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):

$$l(x, y) = \frac{2\mu_x(x, y)\mu_y(x, y)+C_1}{\mu_x^2(x, y)+\mu_y^2+C_1} \quad (1)$$

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

$$S(x, y) = \frac{\sigma_{xy}(x, y)+C_3}{\sigma_x(x, y)\sigma_y(x, y)+C_3} \quad (3)$$

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Where:

x and y = Two different positions in two separate signals

F_x and F_{xy} = Are the average of x

standard deviation of *x* and the covariance of x and y, respectively where (Al-Dalawy, 2013):

$$\mu_x(x, y) = \sum_{p=-P}^{P}\sum_{q=-Q}^{Q} w(p,q)\,x(x+p, y+q) \quad (4)$$

$$\sigma_x^2(x, y) = \sum_{p=-P}^{P}\sum_{q=-Q}^{Q} w(p,q)\left[x(x+p,y+q)-\mu_x(x, y)\right]^2 \quad (5)$$

$$\sigma_{xy}(x,y) = \sum_{p=-P}^{P}\sum_{q=-Q}^{Q} w(p,q)\left[x(x+p,y+q)-\mu_x(x,y)\right]\left[y(x+p,y+q)-\mu_y(x,y)\right] \quad (6)$$

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

$$\sum_{P=-P}^{P}\sum_{q=-Q}^{Q} w(p,q) = 1 \quad (7)$$

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

$$C_1 = (K_1L)^2 \quad (8)$$

$$C_2 = (K_2L)^2 \quad (9)$$

$$C_3 = C_2/2 \quad (10)$$

L is the dynamic range for the sample data and K_1++1 and K_2++1 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):

$$SSIM(x,y) = [l(x,y)].[c(x,y)].[s(x,y)] \quad (11)$$

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):

$$DSSIM(x,y) = \frac{1}{1\text{-}SSIM(x,y)} \quad (12)$$

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

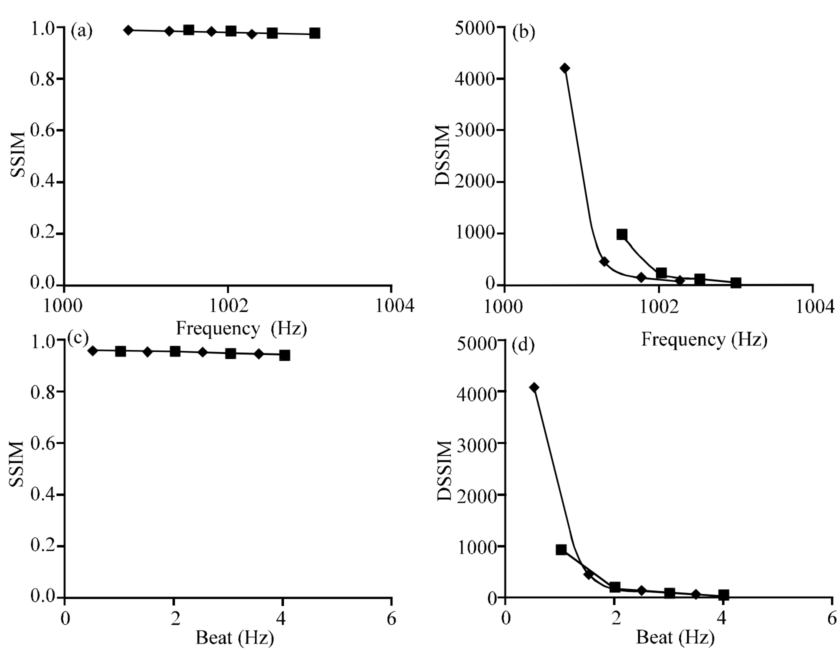

Fig. 1: a- d) Delta brain wave relationships with carrier and beat frequencies; Blue series for range (1000.75-1002.25) and Red series for range (1001.5-1003)

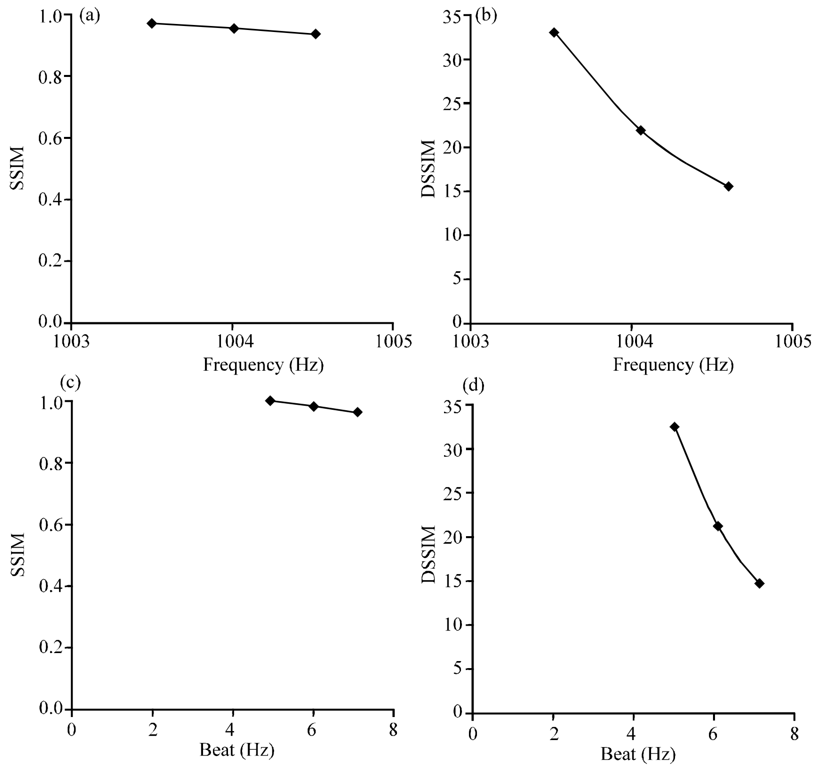

Fig. 2: a-d) Theta brain wave relationships with carrier and beat frequencies; Blue series for range (1003.5-1004.5)

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	1001	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

summarized in Table 2. Figure 1 and 2 show SSIM and DSSIM relationships with beat and carrier frequencies, respectively.

Results show a similarity behavior for both Delta and Theta waves. A descent state appeared for DSSIM relations with increasing carrier and beat frequencies respectively while a nearly straight decreased one occurred in the case of SSIM relationships with increasing carrier and beat frequencies, respectively. In each used brain wave, the lower end seem to be the best one to handle. DSSIM measure is much better in detecting the similarity between signals than SSIM.

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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