ALPHA AND LOW GAMMA EMBEDDED WITH WHITE NOISE BINAURAL BEATS MODULATING WORKING MEMORY AMONG MALAYSIAN YOUNG ADULT: AN EXPLORATORY fMRI STUDY

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by

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LIST OF SYMBOLS

α	Alpha
$\eta 2$	Effect size
μD	Population Mean Weight Gain
σB	Inter-subject variability
σw	Intra-subject variability

LIST OF ABBREVIATIONS

AWN	Alpha embedded with white noise
BB	Binaural beats
BOLD	Blood oxygen level dependent
DMN	Default mode network
EEG	Electroencephalography
fMRI	Functional magnetic resonance imaging
GWN	Gamma embedded with white noise
Hz	Hertz
IPS	Institut Pengajian Siswazah
PN	Pink noise
RT	Reaction time
SMA	Supplementary motor area
USM	Universiti Sains Malaysia
WM	Working memory

LIST OF APPENDICES

RENTAK BINAURAL ALPHA DAN GAMMA RENDAH DILAPISI HINGAR PUTIH MEMODULASI INGATAN KERJA DALAM KALANGAN BELIA MALAYSIA : KAJIAN PENEROKAAN PENGIMEJAN RESONANS MAGNET KEFUNGSIAN (FMRI)

ABSTRAK

Pengenalan: Pendedahan kepada rentak binaural alpha dan gamma (BB) mendapati penemuan yang tidak selaras dalam peranan memodulasi memori kerja (WM). Hingar putih telah dilaksanakan sebagai keadaan kawalan dalam kajian terdahulu. **Objektif:** Kajian ini bertujuan untuk mengenal pasti impak beban kognitif ke atas keberkesanan rentak bunyi binaural auditori alpha dan gamma yang dilapisi hingar putih (AWN/GWN) terhadap prestasi WM menggunakan pengimejan resonans magnet kefungsian. **Metodologi:** Penyelidikan ini merupakan eksperimen yang menggunakan reka bentuk blok paradigma tugas n-back. **Hasil:** Enam belia (3 lelaki dan 3 perempuan) dari sekitar kawasan Kota Bharu telah menyertai kajian ini dengan umur min 23.5 ± 0.84. ANOVA dua hala pengukuran berulang (p<0.05) pada ketepatan tindak balas menunjukkan tidak ada kesan utama yang signifikan bagi keadaan dan beban kognitif. Kesan interaksi bagi keadaan dan beban kognitif ($\eta 2$=.171) menujukkan sedikit peningkatan pada ketepatan tindak balas. ANOVA dua pengukuran berulang (p<0.05) pada masa reaksi tindak balas menunjukkan bahawa terdapat kesan utama yang signifikan bagi beban kognitif, khususnya semasa keadaan 1-back selepas pendedahan BB. Tiada kesan interaksi bagi keadaan dan beban kognitif pada masa reaksi. Untuk pendedahan GWN dan AWN, ujian t satu-sampel (p<0.05, uncorrected) mencadangkan bahawa pengaktifan girus posterior singulat berkaitan dengan modulasi perhatian dan kawasan tambahan motor berkait rapat dengan

mekanisme WM. ANOVA dua hala pengukuran berulang pada (p<0.05, uncorrected) tugasan WM menyokong modulasi yang disebutkan di atas dengan pengaktifan kawasan *thalamik* dalam keadaan GWN dan kawasan frontoparietal dalam keadaan AWN. **Kesimpulan:** Penemuan awal menunjukkan bahawa BB dilapisi WN boleh dipertimbangkan lebih jauh sebagai kaedah peningkatan WM yang tidak invasif dalam kalangan populasi klinikal dan bukan klinikal.

Kata kunci: bunyi binaural, tugasan n-back, ingatan kerja, fMRI

ALPHA AND LOW GAMMA EMBEDDED WITH WHITE NOISE BINAURAL BEATS MODULATING WORKING MEMORY AMONG MALAYSIAN YOUNG ADULT : AN EXPLORATORY FMRI STUDY

ABSTRACT

Introduction: Exposure to alpha and gamma binaural beats (BB) have provided inconsistent findings in its modulating role of working memory (WM). White noise (WN) has acted as a control condition. **Objective:** The study aims to explore the effect of load on the effectiveness of WN embedded BB on WM performance using functional magnetic resonance imaging. **Method:** The research utilised experimental, block-design n-back task paradigm. **Results:** Six young adults (3 males and 3 females) within the Kota Bharu vicinity were recruited with mean age of 23.5 ± 0.84. The two-way repeated measures ANOVA (p<0.05) on response accuracy shows there is no significant main effect for conditions and load. The interaction effect of conditions and load on response accuracy ($\eta 2$=.171) demonstrates slight improvement in response accuracy The two-way repeated measures ANOVA (p<0.05) of reaction time (RT) shows a significant difference in the main effect of load, in particular during 1-back condition post BB. There is no interaction effect of conditions and load on RT. For GWN and AWN exposure, one sample t-test (p<0.05,uncorrected) suggests that the activation of posterior cingulate gyrus are associated with attentional modulation and supplementary motor area is closely related to WM mechanism respectively. Two-way repeated measures ANOVA (p<0.05,uncorrected) of the WM task further supports the aforementioned modulation in post-BB activations with the activation of thalamic regions in GWN and frontoparietal regions in AWN. **Conclusion:** The preliminary

findings suggest that WN embedded BB should be considered further as a non-invasive WM improvement method amongst clinical and non-clinical population.

Keywords: binaural beats, auditory, n-back, working memory, fMRI

CHAPTER 1

INTRODUCTION

1.1 Rationale and research gap

The literature revolving binaural beats and its modulating role in memory is required in Asia and Malaysia specifically as to date, there are only two studies conducted in Asian population (Jirakittayakorn and Wongsawat, 2017a; Lim et al., 2018) and markedly none in Malaysia. Further, the selected population of young adults who have been recruited are often university students, thus, future studies should be open to public within the age range to allow better generalisation. The studies have also often focused on what works the best in terms of the binaural beats, i.e. beta and gamma binaural beats rather than divulging into the inconsistent findings such as the role of alpha binaural beat and gamma binaural beats in memory-related tasks.

Previously, the neuroimaging modality of choice is electroencephalography (EEG) and magnetoencephalography (MEG) with no functional magnetic resonance imaging (fMRI)-based study. Studies involving EEG have indicated that the frontotemporal region of the brain is involved during exposure to binaural beats based on the attached electrodes (Beauchene et al., 2016, 2017). This shows a need to ascertain the neural underpinnings of binaural beats modulation on attention and memory. The task which are given to the subjects were recommended to be more demanding in the future (Kirk et al., 2019) to generalise the modulatory role of binaural beats on attention and memory. It can be observed that most studies reported that there is a gender imbalance involved during the experiments as female subjects are more involved compared to male. Thus, a comparison between gender and the effect of binaural beats on memory and attention is desired. The implementation of a break between the

exposure of binaural beats should be explored more to provide a further understanding of the entrainment of binaural beats.

Amongst the past studies conducted with binaural beats and working memory (WM), studies have compared binaural beats against other neutral stimuli such as white noise (Beauchene et al., 2016). It is evident that a different range of frequency can either improve or impair WM performance. Generally, it can be inferred that the alpha binaural beat plays a role in improving WM, as shown by past studies (Carter and Russell, 1988; Kraus, 2015; McMurray, 2006). The role of beta and theta has been inconsistent as some has been effective in improving WM performance and others have reduced the result. The role of gamma in WM performance has been underexplored. The study conducted by Engelbregt et al. (2019) was inadequate to conclude the lack of involvement the binaural beat plays in WM performance.

The studies related to binaural beats and memory, in general, has often been conducted with EEG, which is superior in its temporal resolution. However, thus far, the brain regions which are activated upon listening to binaural beats have not been established. Furthermore, studies involving EEG and binaural beats postulated that the binaural beat phenomenon is due to the entrainment of neural networks to the auditory stimulus (Chaieb et al., 2015).

Studies by Lane et al. (1998), Wahbeh et al. (2007) even Engelbregt et al. (2019) have shown that extended exposure to the binaural beats would be detrimental to WM performance and there is a gap in the ideal duration of exposure which would not be suitable in enhancing WM. The older studies discussed have often utilised neuropsychological assessment. Only in recent years, with the example of Beauchene

et al. (2016) and Engelbregt et al. (2019), active tasks were utilised to study the effect of binaural beats on WM performance.

A core objective of the Malaysian Higher Education department is to generate marketable students (Ng et al., 2011). However, newspaper columns (D'Silva, 2020; Welsh and Cheng, 2020) have cited that Malaysian graduates lack multiple skills that are not specific to their study area. One of the many accountable skills is problem-solving skills (Shakur et al., 2020), involving the WM mechanism (Nęcka et al., 2021).

Employers nowadays are looking for potential fresh graduates who are able to think outside the box so that they can produce quality works (D'Silva, 2020). However, they are failing to do so and this situation results in a high unemployment rate among graduates, mainly in Malaysia.

The gnawing issue of unemployment amongst fresh graduates has been on the rise and employers have attributed their lack of ability to think creatively and solve problems critically as one of the indicators of fresh graduates difficulty securing a job (D'Silva, 2020; Shakur et al., 2020; Welsh and Cheng, 2020).

In the Malaysian context, the number of fresh graduates increases from both public and private universities. Based on the Ministry of Education statistics in 2018, the current number of fresh graduates stands at 4.96 million. However, according to a Graduate Tracer Study (Ng et al., 2011) conducted by the aforementioned department, at least 60% remains unemployed a year after graduation. WM influences an individual's performance on the cognitive task, and subsequently, a student's performance in a higher education setting. Further, in the instance of a pandemic-riddled world, the unemployment rate has exponentially increased and a number of 116,161

graduates (Dzulkifly, 2020) remains unemployed and the number is set to increase with the prolonged Movement Control Order (MCO) in Malaysia (Syed Jaafar, 2021). Thus, examining the effect of alpha wave binaural beat on WM performance is beneficial in the long run. The benefits of better WM performance are not reserved for grades. It impacts problem-solving skills reported to be one of the skills that are lacking amongst Malaysian undergraduates (D'Silva, 2020; Shakur et al., 2020; Welsh and Cheng, 2020).

Binaural beat could be a potential medium in enhancing WM, and the benefits of WM improvement can be sowed accordingly. Furthermore, the reduction in the alpha wave during older adulthood implies that ones' WM reduces in time. Thus to be able to supports healthy ageing; utilising a non-invasive method of intervention may be beneficial in the long- run.

1.2 Objectives and hypotheses

1.2.1 General objective

To determine the effect and neural correlates of alpha and gamma binaural auditory beat embedded with white noise on working memory performance

1.2.2 Specific objectives

Specific objective 1

To compare the effect alpha and gamma binaural auditory beat embedded with white noise during a working memory task

Specific objective 2

To identify whether the white noise embedded binaural beats are more effective in improving working memory task performance in comparison to unembedded binaural beats

Specific objective 3

To determine whether white noise embedded alpha binaural beat is more effective in higher working memory load (3-back task)

Specific objective 4

To describe the neural correlates which are involved in the exposure of different white noise embedded binaural beats and their effect on working memory task

1.2.3 Research hypotheses

Hypothesis 1

Alternative hypothesis: The exposure to white noise embedded alpha binaural auditory beats will improve working memory task performance.

Null hypothesis : The exposure to white noise embedded alpha binaural beats will not improve working memory task performance.

Hypothesis 2

Alternative hypothesis: The white noise embedded binaural beats are more effective in improving working memory task performance.

Null hypothesis : The white noise embedded binaural beats is not effective in improving working memory task performance.

Hypothesis 3

Alternative hypothesis: The exposure to white noise embedded alpha binaural beat will improve the working memory performance on a 3-back working memory task.

Null hypothesis : The exposure to white noise embedded alpha binaural beat will not improve the working memory performance on a 3-back working memory task.

CHAPTER 2

LITERATURE REVIEW

2.1 Binaural beats and working memory

The concept of binaural beats has first been established by Oster, (1973) and in the early 2000s, the focus on binaural beats as a non-invasive intervention on modulating cognitive function, an alternative treatment in psychological disorder treatments such as reducing anxiety (Chaieb et al., 2015) and to enhance meditative state (Jirakittayakorn and Wongsawat, 2017b). With the everchanging technology landscape, our cognitive ability has been suggested to decline faster than ever due to the task switching commonly required in the 21st century (Lim et al., 2016; Sousa, 2011; Zavecz et al., 2020). One of our cognitive ability components is working memory, which is further enhanced by attention. As time goes by, our working memory declines over time naturally. Thus, there is a need for non-invasive mediation to ensure healthy ageing.

2.2 Acoustic stimuli and the auditory pathway

The auditory beat stimulation (ABS) elicit a frequency-following brainwave, or better known as entrainment using pulsating auditory stimuli (Engelbregt et al., 2019; Lane et al., 1998). This suggests that the brain is able to emulate the frequency of the auditory beat through synchronizing neural activity and the auditory stimuli (Wahbeh et al., 2007). Namely, there are three different types of ABS which are isochronic tones, monoaural beats (MBs) and binaural beats (BBs). Both monoaural and binaural beats are generated when two sines of pure tones within a similar range are presented to each ear simultaneously (monoaural beats) or binaurally, that is to separate ears (Orozco Perez et al., 2020). For example, the right ear is exposed to 440 Hz tone and the 400 Hz

tone is presented to the left ear resulting in a 40 Hz tone to be perceived. The beat carrier frequencies have to be sufficiently low enough to be temporally encoded by the cortex (Schwarz and Taylor, 2005) and it should be below 1000 Hz (Licklider et al., 1950). Binaural beats have been claimed to produce whole brain entrainment (Atwater, 1997; Rhodes,1993) as well as alteration of the states of consciousness (Atwater, 1997).

In the instance of the listening brain, neural entrainment is considered an essential mechanism that enhances the perception of the attended sounds (Obleser and Kayser, 2019). Brain oscillations can be modulated by entrainment, as it modifies the oscillation in its natural physiological state. It has been suggested that the aforementioned mechanism may play a part in selective attention as it filters any environmental distractors to boost the neural encoding of the attended sounds (Obleser and Kayser, 2019). The process of neural entrainment can be achieved by sensory stimulation among other methods (Hanslmayr et al., 2019). The non-invasive nature, its modulating role without prior training along its cost-effectiveness have been seen to be beneficial to both clinical and healthy population (Perez, 2020). However, this mechanism is not immediate (Thut et al., 2011) and it relies on the intensity of the stimulation presented.

2.2.1 Auditory processing pathway

Sounds are essentially energy waves that travelled by moving molecules. Humans typically can hear within a frequency range of 20 - 20,000 Hz (D. Peterson and Hamel, 2018). Our ear is the organ that undeniable registers and encounters sound. However, it is the brain that extracts and corresponds to the varying sound stimuli from the environment. The auditory system is able to not only process sounds but is also