EXPLORING THE RELATIONSHIP BETWEEN THE ACOUSTIC FEATURES OF THE QURANIC RECITATIONS AND THE ACTIVITY OF ALPHA AND THETA BRAINWAVES

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by

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LIST OF ABBREVIATIONS

μV	Microvolt
AAL3	Automated Anatomical Labelling Atlas 3
ACC	Anterior Cingulate Cortex
BEM	Boundary Element Method
CSF	Cerebrospinal fluid
DMN	Default Mode Network
dSPM	Dynamical statistical parametric mapping
ECG	Electrocardiography
EEG	Electroencephalography
EMG	Electromyographic
EOG	Electrooculogram
EPSP	Excitatory Post-Synaptic Potential
FEM	Finite Element Method
F0	Fundamental frequency
FFT	Fast Fourier Transform
HD-EEG	High-density Electroencephalography
Hz	Hertz
ICA	Independent Component Analysis
L-VMPFC	Left ventromedial prefrontal cortex
MEG	Magnetoencephalography
PFC	Pre-frontal cortex
PCA	Principal Component Analysis
PSD	Power spectrum density
ROI	Region of interest
R-VMPFC	Right ventromedial prefrontal cortex
sLORETA	Standardized low resolution electrical tomography
SNR	Signal-To-Noise Ratio
SSP	Signal Space Projection
SQUID	Superconducting Quantum Interference Detector
TSSS	Spatiotemporal signal space separation
WMNE	weighted minimum-norm estimation

ABSTRAK

Rangsangan pendengaran sering digunakan sebagai bentuk terapi suara untuk mencetuskan relaksasi serta telah dikaji secara meluas menggunakan teknik electroencephalography (EEG) dan magnetoencephalography (MEG). Bagi umat Islam, bacaan Al-Quran berirama diperakui dapat mendorong kesan relaksasi dan ketenangan yang sebanding. Sehingga kini, kebanyakan kajian EEG menggunapakai analisis pada tahap sensor untuk menyiasat kesan mendengar bacaan Al-Quran terhadap aktiviti gelombang otak manusia. Walau bagaimanapun, penyelidikan seumpamanya tidak mempertimbangkan ciri-ciri prosodik (melodi dan irama) dari kepelbagaian tempo bacaan Al-Quran dan hubungkaitnya dengan punca aktiviti gelombang otak, sebagai contoh alpha (8-13Hz) dan theta (4-7Hz) yang merupakan jenis gelombang yang paling banyak dilaporkan dalam kajian berkaitan bacaan Al-Quran. Oleh itu, kajian ini bertujuan meneroka hubungan antara ciri akustik dalam bacaan Al-Quran dan aktiviti gelombang otak alpha dan theta, dibandingkan dengan rangsangan pendengaran bukan bacaan Al-Quran, dengan menggunakan teknik EEG dan MEG secara serentak, serta mengaplikasikan kaedah pemodelan sumber.

Tiga puluh orang (n = 30) subjek yang sihat berusia 21-35 tahun dipilih setelah mendapat persetujuan, dan dibahagi kepada dua kumpulan kepercayaan yang berbeza (15 orang Muslim dan 15 orang bukan Muslim). Lima jenis rangsangan pendengaran yang setiapnya selama 3 minit disampaikan menggunakan rakaman spontan EEG 61 saluran dan MEG 306 sensor, merangkumi tiga jenis tempo bacaan Al-Quran (bacaan perlahan, bacaan sederhana dan bacaan laju), bacaan berita Arab dan bacaan puisi Arab. Melodi dan irama diekstrak menggunakan perisian Sonic Visualiser. Rakaman data asal diproses menggunakan perisian Brainstorm mengikut aliran analisis yang digunapakai terhadap rakaman EEG dalam keadaan rehat. Rakaman spontan EEG dan

MEG diubah dengan menjadikan frekuensi sebagai domain dan kemudiannya sumber gelombang otak alpha dan theta diekstrak. Analisis kuasa spektra diaplikasi untuk mengenalpasti perubahan aktiviti gelombang otak alpha dan theta semasa mendengar rangsangan pendengaran yang berbeza, serta untuk membandingkan aktiviti EEG dan MEG antara kumpulan Muslim dan bukan Muslim.

Analisis akustik menunjukkan tempo bacaan Al-Quran yang perlahan dan sederhana mempunyai fluks spektrum yang tetap dan kontur bernada tinggi. Sebaliknya, bacaan berita Arab, bacaan puisi Arab, dan bacaan Al-Quran bertempo laju menunjukkan fluks spektrum yang tidak tetap dan berubah-ubah, serta kontur bernada rendah. Penemuan ini menjelaskan bacaan Al-Quran dengan tempo perlahan dan sederhana mempunyai irama biasa dan melodi yang menarik jika dibandingkan dengan rangsangan pendengaran yang lain. Sementara itu, pemodelan sumber EEG dan MEG menunjukkan peningkatan aktiviti gelombang alpha dalam kedua-dua kumpulan ketika mendengarkan ketiga-tiga jenis tempo bacaan Al-Quran, berbeza dengan peningkatan aktiviti gelombang theta yang hanya didapati di kalangan kumpulan bukan Muslim sahaja bagi ketiga-tiga tempo bacaan. Bagi kumpulan bukan Muslim juga, terdapat perbezaan yang signifikan antara rangsangan pendengaran bagi kekuatan relatif gelombang otak theta di bahagian kiri prefrontal ventromedial ($p = .008$) dan kekuatan relatif gelombang otak alpha di bahagian kiri precuneus ($p = .007$), yang keduanya tidak didapati dalam kumpulan Muslim. Penemuan ini menunjukkan bahawa bacaan Al-Quran dapat mencetuskan ketenangan pada individu Muslim dan bukan Muslim.

Penemuan dalam kajian ini menunjukkan bahawa kebiasaan terhadap sesuatu rangsangan dan ciri-ciri prosodik (melodi dan irama) bacaan Al-Quran adalah elemen utama yang mempengaruhi aktiviti gelombang otak alpha dan theta. Pun begitu, kajian

ini adalah yang pertama memberikan bukti empirikal yang menunjukkan bahawa pelbagai tempo bacaan Al-Quran dapat mempengaruhi aktiviti gelombang otak alpha dan theta di kalangan bukan Muslim. Ini juga memberikan bukti kukuh bagi menggambarkan potensi bacaan Al-Quran sebagai bentuk terapi suara untuk mencapai keadaan relaksasi mental, tanpa mengira kepercayaan agama atau latar belakang pendengar.

ABSTRACT

Auditory stimulations are frequently used as a form of sound therapy to induce relaxation and has been studied extensively utilising electroencephalography (EEG) and magnetoencephalography (MEG) techniques. For Muslims, the rhythmic Quranic recitations are widely recognised for similar relaxation and calming effects. To date, most EEG studies have employed sensor-level analysis to investigate the effects of listening to Quranic recitations on human brainwaves' activity. However, such research has not considered the prosodic features (melody and rhythm) from the numerous Quranic recitation tempos and the influence these may have on the underlying brainwaves activity, namely alpha (8-13Hz) and theta (4-7Hz) which represent the common brainwaves studied in relation to Quranic recitations. This present study seeks to explore the link between the acoustic features of Quranic recitations and the activity of alpha and theta brainwaves in comparison with non-Quranic auditory stimuli, using a simultaneous EEG and MEG recording techniques and employing source modelling methods.

Thirty (n=30) healthy subjects aged 21-35 years old were recruited following an informed consent as dual faith groups (15 Muslim and 15 non-Muslim). Five auditory stimuli were presented for 3 minutes each using spontaneous recordings of 61-channels EEG and 306-sensor MEG, which included three tempos Quranic Recitations (slow, moderate, fast), Arabic news and Arabic poem. The melodic and rhythmic patterns (spectral flux and pitch contour) were extracted using Sonic Visualiser software. The raw data were pre-processed using Brainstorm software following analysis pipeline applied to the resting-state EEG recordings. The spontaneous EEG and MEG recordings were transformed to frequency domain and source models of alpha and theta brainwaves were extracted. Power spectra analysis

was used to identify the changes in activity of alpha and theta brainwaves during listening to different auditory stimuli and to compare the EEG and MEG activity between Muslim and non-Muslim subjects.

The acoustic analysis revealed that the slow and moderate tempos of Quranic recitations have a steady fluctuating spectral flux and high-pitched contour. In contrast, the Arabic news, Arabic poem, and fast tempo had quickly fluctuating spectral flux and low-pitch contour. These findings indicates that the slow and moderate tempos have regular rhythm and attractive melody compared to the other auditory stimuli. Meanwhile, source modelling of EEG and MEG showed that alpha brainwaves' activity was increased in both groups when listening to all three Quranic recitations, whereas the activity of theta brainwaves was increased only in non-Muslims while listening to all three Quranic recitations. For the non-Muslim group but not in Muslims, there was significant difference between the experimental conditions in the relative power of theta brainwaves over left ventromedial prefrontal cortex ($p=.008$) and the relative power of alpha brainwaves over the left precuneus ($p=.007$). These observations demonstrate that Quranic recitations elicit a relaxing response in both Muslim and non-Muslim individuals.

The findings provided in this study signify that the familiarity and the prosodic features (melody and rhythm) of Quranic recitations are major elements that influence the activity of alpha and theta brainwaves. However, this study is the first to give empirical proof indicating varying tempos of Quranic recitations can produce alpha and theta brainwave activity in non-Muslims. This finding also provides the evidence-based basis to uplift the potential of Quranic recitations as a form of sound therapy to promote a state of mental relaxation, irrespective of the listener's religious belief or background.

CHAPTER 1

INTRODUCTION

This thesis is divided into six chapters: The first study describes the study's research background, hypothesis, aims, and significance. The second chapter reviews the literature pertaining to the study's different grounds. In Chapter 3, the methods and procedures employed in the project are described. The results are presented in text, and figures in Chapter 4. The study findings are thoroughly discussed in Chapter 5, and the study is concluded in Chapter 6 with recommendations for future work.

1.1 Background

Stress and anxiety are common illnesses that have a substantial influence on both mental and physical health and are frequently managed with conventional medications, among other approaches (Ravindran and Stein, 2010, Bandelow et al., 2017). Additional alternative and complementary techniques, such as the novel use of sound stimulations and music, have received much interest in recent years (Lavretsky, 2009, Pan et al., 2012, Fusar-Poli et al., 2018). There has been a rise in interest in the application of these techniques since it has been shown to be cost-effective and the relative ease to the intervention required (Hole et al., 2015, Särkämö, 2018, Raglio and Attardo, 2020). The importance and relevance of sound and/or music as an alternative method of treatment of physical and mental problems is well recognized (Solanki et al., 2013, Stegemann et al., 2019, Tang et al., 2021). Sound therapy was utilized as a non-pharmacological alternative treatment for a wide range of clinical disorders, including pain management (Boyd-Brewer and McCaffrey, 2004), psychological and emotional problems (Kim et al., 2009), depression (Erkkilä et al., 2011), post-stroke rehabilitation (Knight and Wiese, 2011), post-traumatic brain injury recovery (Thaut

et al., 2009) and seizure control in epilepsy (Maguire, 2012). It was previously suggested that actively listening to sound, such as music or spoken words, affects thoughts and feelings, which in turn influence brain electrochemistry and body physiology (Schneck and Berger, 2005). The reported advantages of such therapy include stress reduction, improved sleep, lower blood pressure, and promote relaxation (Raglio et al., 2015, Mofredj et al., 2016).

Usage of music for promoting relaxation and anxiety reductions has been comprehensively investigated (Yehuda, 2011, Elliott et al., 2011, van Willenswaard et al., 2017). Previous research had revealed that music enhances brain functions that include attention (Loui and Guetta, 2019), learning (Henley, 2018), memory (Sihvonen et al., 2020), and work performance (Meyer, 2019). The scientific investigation of the cognitive processes underlying music is a major area of interest within the field of cognitive neuroscience, particularly research utilizing non-invasive neuroimaging methods. Music has been studied by many researchers employing novel methods such as Positron Emission Tomography (PET) (Lee et al., 2017), Functional Magnetic Resonance Imaging (fMRI) (Okuya et al., 2017), EEG (Daly et al., 2014), and MEG (Boasen et al., 2018).

The EEG and MEG are standard methods for recording the electrical and the magnetic fields of the neural activity (NiederMeyer, 2011). MEG and EEG recordings are commonly utilized for studying of biological or pathological processes with a millisecond time resolution (Puce and Hamalainen, 2017). EEG- MEG signals reveal wave activity in particular frequency bands (brainwaves, oscillations, brain rhythm): delta , theta, alpha, beta, and gamma; which can be identified from specific brain regions and linked to certain functional/cognitive state such as level of alertness, sleeping or waking (Thatcher, 2009, Groppe et al., 2013b). Theta and alpha brainwaves

activity are known to be involved in the relaxation response as an outcome of music and sound therapy (Prätzlich et al., 2016, Herholz and Pantev, 2019).

Similar to music and sound therapy, the impact of the Quranic recitations on the human brain has been a subject of investigation in the neuroimaging and cognitive neuroscience fields. The holy Quran is the principal source to which Muslims refer while adhering to Islamic values. The pleasing recitation of the Quran, the principal holy book of Islam, is often believed to have a calming and relaxing impact on the listeners whether Muslims or not, and even if they may not comprehend its language (Nayef and Wahab, 2018, Zaidah and Imaduddin, 2018). Distinct from any other book or scripture, the recitation of the Quran is governed by standard guidelines called *tajweed* rules that regulate the precise articulation and intonation of reciting the Quran (Qadhi, 1999). By careful adherence to the recitation rules, the sound of the recitation is clearly and precisely articulated and produced in a melodious and rhythmical way (Czerepinski and Swayd, 2006). The Quranic recitations are generally performed in three tempos: *Tahqiq*, *Hadr*, and *Tadwir*, which differ in recitation speed, i.e. slow, moderate, and fast tempos (Nelson, 2001). Beyond the spiritual and religious practices, even passive listening to Quran is believed to enhance tranquillity, serenity, and a sense of well-being (Mustapha et al., 2016). Furthermore, it is frequently anticipated that Quranic recitations will provide a method of treatment for psychological issues (Tumiran et al., 2013). However, the specific underlying neurophysiological processes supporting the beneficial impact of the Quranic recitations remain poorly understood. At best, previous research examined the influence of listening to Quran on brainwaves which mainly used low-density EEG recordings and employed sensor-level analysis (Vaghefi et al., 2015, Samhani et al., 2018). Determining the precise underlying neural mechanisms for the impacts of Quranic recitation on brain functions is crucial because

evidence-based leads may be utilised to inform the use of Quranic recitation as a complementary therapy, as demonstrated for the conventional sound and music practices.

1.2 Problem statement and study rationale

In contrast to research on Quranic recitation, research on music and its neural involvement had been well substantiated in the neuroscience literature. Nevertheless, the neuronal processes underlying the reported pleasing and psychological effects of the Holy Quran remains largely unexplored. The neural correlations from few studies on Quranic recitation had been conducted mainly using a low-density EEG recording and employ a simple sensor-level analysis procedure which limits a more in-depth interpretation. Most of the investigations had focused on the alpha brainwaves, and with an emerging interest in the theta brainwaves. Nevertheless, earlier research has not examined the impact of these brainwaves on non-Muslim subjects upon listening to Quranic recitations. As there are several tempos in reciting the Quran, no study had previously investigated brainwaves activity when listening to different tempos of Quranic recitation. Similarly, the impact of acoustic features from such recitation with diverse rhythm and melody patterns had not been previously explored. Hence, further delineating these aspects would provide empirical evidence and could contribute towards the effort in raising wider awareness of the therapeutic potential of Quranic recitation as a form of sound therapy.

Consequently, the current EEG-MEG study seeks to explore how different tempos of the Quranic recitations with their respective acoustic features could influence the activity of alpha and theta brainwaves. In this study, we had used a high-density (61 electrodes) EEG combined with MEG (306 sensors) to attain a high

temporal and spatial resolution, allowing source modelling of the primary brain signals (alpha and theta) following passive listening to the different Quranic tempos.

1.3 Research Questions

The current study explored the activity of alpha and theta brainwaves while listening to the Quranic recitation and non-Quranic Arabic stimuli, among Muslims and non-Muslims. The questions addressed for the present study were as follows:

1. Are there any differences in the rhythmic and melodic patterns between the Quranic recitations and non-Quranic Arabic stimuli?
2. Do the different Quranic recitations and non-Quranic Arabic stimuli affect the activity of the alpha and theta brainwaves?
3. Which brain region of interest (ROI) shows significant theta and alpha changes during passive listening to the auditory stimuli?
4. Is there a difference in alpha and theta brainwaves' responses while listening to Quranic recitation and non-Quranic Arabic stimuli between Muslims and non-Muslims?
5. Is there any relationship between the acoustic features and the spectral power changes of alpha and theta brainwaves?

1.4 Research hypotheses

1.4.1 General hypothesis

The different auditory stimuli, characterized by diverse rhythmic and melodic patterns, may exhibit considerable changes in the activity of alpha and theta brainwaves.

1.4.2 Alternative hypotheses

1. There are significant differences in melodic and rhythmic patterns between the various auditory stimuli.
2. There are considerable changes in EEG spectral power when listening to the Quranic and non-Quranic Arabic stimuli, among Muslims and non-Muslims groups.
3. There are considerable changes in MEG spectral power when listening to the Quranic recitations and non-Quranic Arabic stimuli, among Muslims and non-Muslims groups.
4. There are substantial differences in the theta and alpha power of regions of interest (ROI) while listening to the Quranic recitations and non-Quranic Arabic stimuli.
5. There are significant differences in alpha and theta brainwaves' responses between the Muslims and non-Muslims during passive listening to the Quranic recitation and non-Quranic Arabic stimuli.
6. There is a relationship between the acoustic features and the spectral power changes in alpha and theta brainwaves.

1.4.3 Null hypotheses

1. There are no significant differences in melodic and rhythmic patterns between the various auditory stimuli.
2. There are no considerable changes in EEG spectral power when listening to the Quranic and non-Quranic Arabic stimuli, among Muslims and non-Muslims groups.
3. There are no considerable changes in MEG spectral power when listening to the Quranic and non-Quranic Arabic stimuli, among Muslims and non-Muslims groups.
4. There are no substantial differences in the theta and alpha power of regions of interest (ROI) while listening to the Quranic recitations and non-Quranic Arabic stimuli.
5. There are no significant differences in alpha and theta brainwaves' responses between the Muslim and non-Muslim groups during passive listening to the Quranic recitation and non-Quranic Arabic stimuli.
6. There is no relationship between the acoustic features and the spectral power changes in alpha and theta brainwaves.

1.5 Research objectives

1.5.1 General objective

The study's purpose is to find the relation between the acoustic features of different tempo Quranic recitations and the changes of the activity of alpha and theta brainwaves in comparison to non-Quranic Arabic stimuli using EEG-MEG recordings, among Muslims and non-Muslims.

1.5.2 Specific Objectives

1. To identify and compare the rhythmic and melodic patterns of the Quranic recitations, Arabic news, and poem.
2. To determine the spectral power changes in alpha and theta brainwaves during passive listening of the Quranic recitation, Arabic news, and poem using 64-channel EEG recordings and its corresponding spectral power changes using 306-channel MEG recordings.
3. To compare alpha and theta responses between Muslim and non-Muslim groups during passive listening to Quran and non-Quranic Arabic stimuli.
4. To compare the responses of theta and alpha brainwaves over the identified brain regions of interest (ROI) between the different auditory stimuli.
5. To identify the link between the prosodic features of the Quranic recitations and the changes in the activity alpha and theta brainwaves.

1.6 Significance of the study

There are several important areas where the current study makes a novel contribution to the growing research area that examines the effects of listening to the Quranic recitations on alpha and theta brainwaves activity. The current project is considered a unique approach to exploring the impact of listening to the Quranic recitations on the activity of alpha and theta brainwaves using the simultaneous MEG and EEG recording techniques, employing source modelling measures. However, this is the first research that looks at the influence of Quranic recitation on non-Muslims. The present research explores, for the first time, the prosodic features toward an improved understanding of the relaxing response when listening to the Quranic recitations.

Hence, the current study attempts to profile the melodic and rhythmic patterns, as well as source modelling of alpha and theta brainwaves in order to establish the link between the acoustic features and neural correlates as the underlying neurobiological basis for relaxation associated with Quranic recitation. Moreover, it may help to make recommendations to its practice as a complementary therapy in a clinical setting for related future studies.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter summarizes research work that lies within the scope of this study and clarifies pieces of evidence and propositions in the existing literature that form the foundations for the present study. These include areas of auditory stimulations as sound therapy, resting-state brainwaves activity, and neural substrate representations in Quran-related research to highlight the gaps in knowledge that are being addressed in this study.

2.2 Sound therapy and relaxation

Sound therapy has been shown in neuroscience studies over the last few decades to have a variety of health benefits, including stress reduction (Goldsby et al., 2017), anxiety and depression reduction (Quach and Lee, 2017), improved memory (Simmons-Stern et al., 2012), lower blood pressure (Loewy et al., 2013), and pain relief (Homel et al., 2017). During a session, individuals may sit or lie down while listening to particular auditory stimuli. Music, instruments, speech rhythms, and chants are examples of auditory stimulations that are widely employed as sound therapy (Thompson and Schlaug, 2015, Hurt-Thaut and Johnson, 2015). Moreover, music is utilized as a complementary therapy to relieve symptoms in a variety of conditions, including dementia (Keough et al., 2016), autism spectrum disorder and learning difficulties (Janzen and Thaut, 2018), behavioural and psychiatric disorders (Solanki et al., 2013), and cancer (Stanczyk, 2011, Jia et al., 2020).

2.2.1 Music and the brainwaves

Comprehensive studies had been conducted on the use of music to induce relaxation (Mandel et al., 2013, Nelson et al., 2017, Johnson and Elkins, 2020). Much of this research makes use of EEG and MEG as conventional tools for evaluating the effects of music on brainwave activity (Banerjee et al., 2016, Tandle et al., 2018, Herholz and Pantev, 2019). Numerous studies have shown that music can induce relaxation by increasing the activity of theta and alpha brainwaves (Sammler et al., 2007, Geethanjali et al., 2012). Alpha and theta brainwaves are often investigated as neural correlates of the state of relaxation when listening to music and meditation (Kučikienė and Praninskienė, 2018, Ara and Marco-Pallarés, 2020). To estimate changes in brainwaves activity, the relaxation response while listening to music is frequently assessed using the spectral power analysis method (Goshvarpour and Goshvarpour, 2019, Sasaki et al., 2019, Almudena et al., 2020).

North and Hargreaves (2008) the influence of music is affected by extrinsic aspects that link people with the music individually, such as experiences, music preference, and familiarity, as well as core features in the music, for instance rhythm, melody, tempo, and harmony.

2.2.2 Music familiarity

Previously, researchers looked at the brain areas that are active when people listen to familiar music (Groussard et al., 2009, Pereira et al., 2011). Furthermore, it was shown that familiarity and prior experience with music is an important factor influencing brainwave activity (Pereira et al., 2011). It has been revealed that unfamiliar music evoked a greater response in the cerebral cortex than familiar music (Meltzer et al., 2015). It had been shown that familiarity modulates attention, with unfamiliar

sounds eliciting a greater increase in attention than familiar auditory stimuli (Barenholtz et al., 2016).

2.2.3 Musical features

Previous research has shown that many features of music, such as tempo, rhythm, and melody, play a role to induce relaxation (Clark and Tamplin, 2016, Fernández-Sotos et al., 2016, Liu et al., 2018). It had been hypothesized that the neurophysiological responses to music are affected by compound interrelation incorporating all the acoustic qualities, which have a strong impact on emotions (Schneck and Berger, 2005).

It had been proposed that rhythm in music is particularly influential that serves as a powerful element in eliciting positive emotions (Zatorre et al., 2007, Zentner and Eerola, 2010, Trost and Vuilleumier, 2013). It has been demonstrated that tempo is an essential element in musical rhythm's perception (Burger et al., 2013). Moreover , the musical tempo has been shown to be a critical element in inducing relaxation response through influencing changes in brainwave activity (Yuan et al., 2009, Liu et al., 2018). Additionally, it has been shown that melody is an essential characteristic of music that modulates the activity of alpha and theta brainwaves (Clark and Tamplin, 2016, Radchenko et al., 2018). In this context, the section that follows focuses on EEG-MEG techniques and brainwaves that relate to the neural correlates of melodic, rhythmic Quranic recitations.

2.3 Fundamentals of EEG-MEG activity and brainwaves

The EEG and MEG are basic methods that are employed to record electrical and magnetic potentials originating from the brain (Siems et al., 2016, Gross, 2019). The EEG-MEG are recorded from the head's surface, and they represent the current flow in the active brain regions (Darvas et al., 2004). The EEG-MEG potentials are obtained at scalp electrodes from the post-synaptic potentials generated by cortical pyramidal nerve cells (Nunez and Srinivasan, 2006). EEG and MEG are complimentary attributable to their varied sensitivity in recording potential signals, despite the fact that the main currents making the signals remain the same (Puce and Hamalainen, 2017). Previous EEG and MEG reports found a dynamical background (rather than stimulus- or task-evoked) continuous neural activity in restful awake state, from which temporary alterations are triggered by particular sensory or cognitive activity (Kucyi et al., 2018).

The EEG-MEG signal is composed of numerous brainwaves that depict electrical activity in the brain based on electrode placement and function in nearby brain regions (Ramos-Arguelles et al., 2009). The study of brainwaves has gained in importance in neuroscience as fundamental key components of perceptual and cognitive activities (Başar, 2012, Başar et al., 2013). These brain oscillations are the most clinically employed forms of intrinsic neural activity in EEG and MEG (Shibasaki, 2008, Babiloni et al., 2009, Baillet, 2017). Alpha and theta brainwaves are widely studied as a neurological correlate of a relaxed state when listening to music (Kucikiene and Praninskiene, 2018, Ara and Marco-Pallarés, 2020).

2.3.1 Alpha brainwaves

Alpha brainwaves, which are often recorded with the eyes closed in states of mental inactivity, are the traditional EEG correlates for relaxed awake states (NiederMeyer, 2011). A degree of increased alertness, especially cognitive effort, reduces the activity of alpha brainwaves (Niedermeyer, 2005). Additionally, alpha is frequently observed when cortical regions are disengaged and is negatively linked to brain activity (Oakes et al., 2004, Groppe et al., 2013a). Moreover, it is widely assumed that alpha is involved in attention and sensory processing, as well as to facilitate communication across different cortical regions (Foxe and Snyder, 2011). Furthermore, alpha brainwaves are associated with suppression and selection of attention (Mathewson et al., 2011, Klimesch, 2012). The enhancement of alpha brainwaves has been correlated to a relaxed state and a pleasant mood (Phneah and Nisar, 2017).

2.3.2 Theta brainwaves

Theta brainwave activity has been linked to mental processes that require focused attention (Travis and Shear, 2010, Ishii et al., 2014). Theta brainwave activity has been detected over frontal regions, that are involved in cognitive control, executive function, and behavioural adjustment (Ishii et al., 1999, Cavanagh and Shackman, 2015). It is also known to be responsible in the pathophysiology of anxiety and mood disorders (Cavanagh and Shackman, 2015, Fernández-Palleiro et al., 2020). Additionally, it had been recognised that when participants listened to pleasant music, their frontal theta power increased (Geethanjali et al., 2012). Furthermore, it has been shown that theta brainwaves is stimulated during deep meditation and when participants are alleviated of anxiety (Sammler et al., 2007, Kaur and Singh, 2015).

2.3.3 Default mode network (DMN)

The DMN is made up of brain regions that are activated even though the brain is resting, and have been observed that alpha brainwaves is stimulated in these areas (Chen et al., 2008, Knyazev et al., 2011). DMN is composed of the medial frontal areas, the praecuneus/posterior cingulate cortex, the inferior frontal, inferior parietal, and middle temporal cortices, as well as the cerebellum (Rusiniak et al., 2018). This DMN deactivates during attention-demanding cognitive processes, implying that an activity that improves attention processing is accompanied by induction of theta activity (Mason et al., 2007, Min and Park, 2010).

2.3.4 Sources of alpha and theta brainwaves

Previous research has verified theta brainwave location across the frontal midline areas, particularly the ventromedial prefrontal cortex. (Cohen et al., 2008, Gilboa and Moscovitch, 2017). The ventromedial prefrontal cortex is recognised to be implicated in decision making, reward, and positive emotions (Otero and Barker, 2014).

Alpha brainwave activity has been observed over the parieto-occipital region, including the precuneus cortex (Gómez-Herrero et al., 2008, Mazaheri et al., 2014). The precuneus cortex has been anticipated to be activated during resting consciousness and is involved in DMN (Buckner et al., 2008)

Figure 2.3.1 illustrates the regional activity of alpha and theta brainwaves over parieto-occipital and frontal regions, respectively.

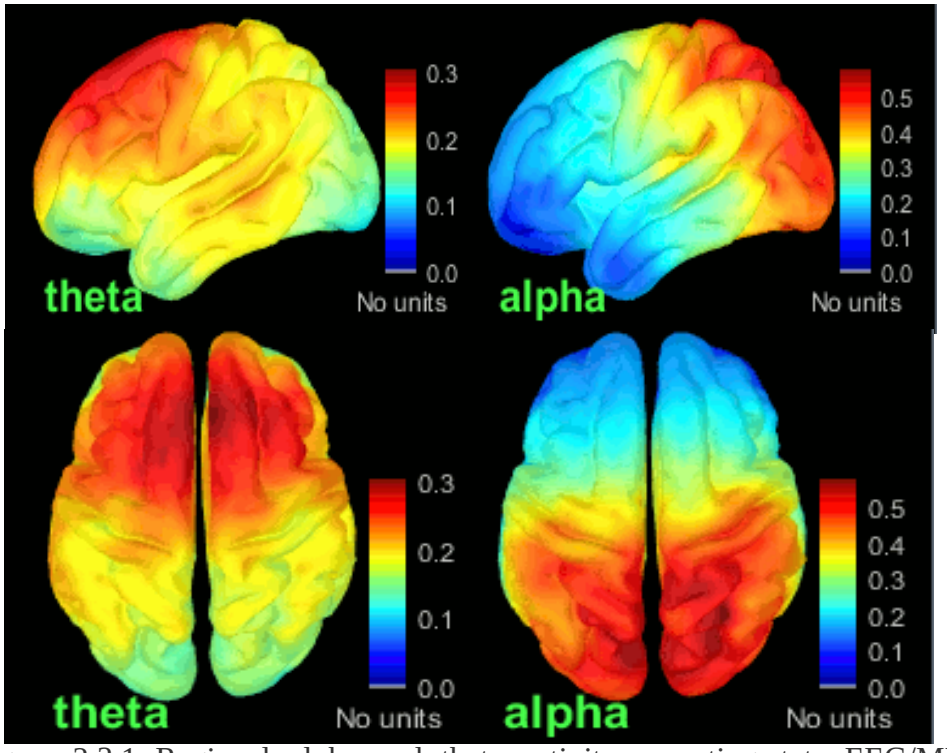

Figure 2.3.1 Regional alpha and theta activity – resting-state EEG/MEG (adapted from brainstorm)

2.3.5 Spectral power (frequency) analysis

The purpose of the frequency analysis is to deconstruct fundamental bandwidths that constitute acquired EEG data and link these to various cognitive processes (Babiloni et al., 2020). The fast Fourier transform (FFT) method has traditionally been used to create spectral power of specific pre-selected frequency bands contained in EEG and MEG time series (Sałabun, 2014). Several basic spectral properties, such as absolute power and relative power, can be estimated within the specified frequency bands (Cerna and Harvey, 2000). It has been suggested that a relative measure of spectral intensity is preferred to an absolute measure since the latter is influenced by a number of misleading factors (e.g., skull thickness) (Schomer and Da Silva, 2012). The spectral analysis of the time series is often plotted on a topographic map or shown as a power graph in a specific frequency versus time (Dehghani et al., 2010).

Spectral power analysis of resting-state EEG-MEG signals is presently the most standard method and the most effectively employed method investigating the power modulation (changes) in certain brainwaves (Mantini et al., 2007, Vecchio et al., 2013, Wang et al., 2015). It has been established that changes in the spectral power of alpha and theta would serve as a quantitative indication of relaxing state. (Hinterberger et al., 2014, Jirakittayakorn and Wongsawat, 2017, Tang et al., 2019).

However, in comparison to the comprehensive EEG-MEG research on music, the following part of this chapter emphasize earlier investigations on the impacts of Quranic recitation on brainwaves, as well as aspects pertaining to Quranic recitation as a potential form of sound therapy.

2.4 The foundation for the relaxing response of listening to the Quran.

2.4.1 *Tajweed* rules and recitation tempos

The recitation of the Quran, unlike any other book or scripture, is governed by a set of articulation guidelines known as *tajweed* rules, which regulate the precise articulation and intonation of reciting the Quran (Qadhi, 1999). By strictly adhering to the recitation guidelines, the sound of the recitation is clearly and accurately articulated and produced in a harmonic and rhythmical pattern (Czerepinski and Swayd, 2006). These guidelines for reciting the Quran set it apart from other Arabic literature (Nakhavali and Seyyedi, 2013). In fact, some scholars even position Quran as the text that represent and conserve the Arabic language (Rahman et al., 2017). *Tajweed*'s objective is to organize and preserve the integrity of a revelation, as well as to verbalize Quranic recitation. Because the verses of the Holy Quran are precisely arranged, its recitation retains its distinct intonation and pleasing tone (Nayef and Wahab, 2018).

Tahqiq, *Hadr*, and *Tadwir* are the three main tempos for Quranic recitations, which differ in the articulation rate, which vary between slow, moderate, and fast tempos (Nelson, 2001). *Tahqiq* has a slow speed, *Tadwir* has a moderate speed, and *Hadr* has a fast pace. For Muslims, moderate tempo recitation is the most employed in prayer or when reciting the Quran. Regardless of recitation tempo, *tajweed* rules must be maintained not only to enhance the recitation but also to keep the verses meaning. Although different recitation tempos may produce variations in some recitation rules, such as elongations, reciters must also recite the Quran with *tarteel* (correct articulation). Because the Quranic recitations are performed at various tempos, the reciter must apply distinct changes in prolongation, word stress, and pauses, resulting in distinct intonation and rhythmic patterns.

2.4.2 The use of the Quran as a therapy

A growing number of research have been conducted on the effect of listening to the Quran on human mental and physical well-being. Listening to the Quran is thought to be complimentary coping strategy in Muslim behaviour and mental health challenges. Some Quranic verses are believed to have healing impacts and are used in alternative therapy (or syifa') (Ramly et al., 2018, Elcokany and Abd El Wareth, 2019). Moreover, listening to Quran has been demonstrated to be effective to reduce stress and anxiety during pregnancy (Jabbari et al., 2020), in managing depression (Rafique et al., 2019) and in managing of pain (Wirakhmi et al., 2018). Furthermore, it is commonly assumed that daily Quran recitation may increase positive emotions in patients or healthy individuals, as well as general well-being among Muslims (Nayef and Wahab, 2018).

2.4.3 The Quran and the brainwaves

A few imaging investigations had looked at the impact of listening to the Quran on human brainwaves. A series of EEG examinations have been conducted to investigate the efficiency and distinctiveness of Quranic recitation on human brainwaves (Shekha et al., 2013, Vaghefi et al., 2015, Puri, 2017, Samhani et al., 2018). Earlier studies have shown the value of listening to and reciting the Quran to relieve anxiety, stress, and depression in the participants, hence emphasizing the Quran's relaxing effect (Mahmood et al., 2007, Mahjoob et al., 2016).

However, most researchers have primarily utilized EEG recording to study the impacts of the Quran on brainwaves, with just one preliminary report to date, which was part of our research group, that used a combined EEG-MEG approach (Ab Rani et al., 2015). Additionally, previous investigations on the influence of listening to Quran on brainwaves have employed low-density EEG (20 electrodes) recordings, which

imply poor spatial resolution, limiting signal source localisation. High-density EEG (> 32 electrodes) is typically advised to improve spatial resolution and, as a result, the precision and sensitivity of the brainwave source localization (Michel and Brunet, 2019).

While three studies explored the impact of Quranic recitations on the theta brainwaves (Vaghefi et al., 2015, Ab Rani et al., 2015, Puri, 2017), alpha brainwave was the most often investigated. It had been discovered that when listening to Quranic recitation, the alpha brainwave is significantly increased compared to listening to hard rock music (Abdullah and Omar, 2011). This finding is consistent with the earlier work that reported an improve in alpha activity during listening to Quran compared to classical music (Abdurrochman et al., 2007). In addition, it has been shown that reciting the Quran has a calming effect compared to reading a book (Kamal et al., 2013). According to these studies, listening to and reciting the Quran has a relaxing and pleasant effect.

The primary comparisons to the Quranic recitation were based on limited experimental conditions, such as reading books (Kamal et al., 2013), conventional music (Zulkurnaini et al., 2012), hard rock music (Alshaikhli et al., 2014) and mantra chanting (Ab Rani et al., 2015). Nevertheless, no study has been conducted to compare listening to Quran with ordinary/usual or rhymed Arabic speech.

Nonetheless, it is unclear whether the different tempos of reciting the Quran have an impact on the activity of alpha and theta brainwaves. It is often theoretical that the pleasing recitation of the Quran could impacts the non-Arabic, non-Muslims listeners who are unaccustomed to the sound of the Quran (Nakhavali and Seyyedi, 2013). Nevertheless, the effects of Quran on the non-Muslims individuals have not been thoroughly studied.

2.5 Prosodic features of speech sounds

The Quranic recitations, like any other speech sound signal, are produced and reached the ear in the form of sound waves. Speech is made by the vocal tract, which contains complex and constantly changing acoustic patterns such as melody and rhythm (Lindblom and Sundberg, 2014). Across several languages, the usual speech frequency of syllable formation is 3–8 Hz (Chandrasekaran et al., 2009). This frequency ranges pertains to the actual moving patterns of articulators such as the tongue, throat, mouth, mandible, and lip during vocalization (Peelle and Davis, 2012). It has been found sounds could be perceived in a range between 20 Hz and 20,000 Hz (Raphael et al., 2007). It had been suggested that the temporal patterns are fundamental to speech perception (Bent et al., 2008). It has been demonstrated that speech perception depends on lexical and syntactical information in addition to prosodic features (Friederici, 2002).

Prosodic features are essential elements to observe which is concerned with the elements of speech that are not individual phonetic (vowel and consonant), but properties of syllable and larger unit of speech-sound (Meyer et al., 2018). These elements are known as suprasegmental that contribute to the creation and perception of stress, rhythm, and intonation of an utterance (Fletcher, 2010). The prosody intitles the changes of syllable duration and pitch (Patel et al., 2011, Gibbon, 2017). Prosodic features determines the acoustic quality of voice sound in stress-time languages such as Arabic and English (Ibrahim et al., 2019), and previous work has shown the relevance of prosody for speech perception (Mattys et al., 2005). Additionally, it had been suggested that the prosodic features of the speech play an important role to elicit the feeling of pleasure (Rodero, 2011). It has been shown that rhythm and melody are the most important features in arranging acoustic events in a speech and defining its prosody (Milicevic and Marymount, 2013).

2.5.1 Speech rhythm

The term "speech rhythm" refers to how languages are arranged in time, which is assumed to be universal across languages (Arvaniti, 2009, Gordon et al., 2011). It is also defined as the temporal patterning of speech that is determined by the rate of speech production (Goswami and Leong, 2013). The duration of syllable length influences the rhythm of speech (Lunden, 2017). It has been shown that the speech rate influenced the perception of speech rhythm (Dellwo, 2008). A rhythmic sound is one that is generated in a regular recurring pattern.

The spectral Flux feature had been utilized to describe rhythm patterns in the speech (Srinivasamurthy et al., 2015, Srinivasamurthy et al., 2017). Moreover, spectral flux, which represent the fluctuations in the frequency power (spectral) arrangement of audio signals, has been employed for speech discrimination (Khan et al., 2004, Alías et al., 2016). The spectral flux estimates the energy fluctuations in the spectral domain, and it is used to assess how rhythmic a sound is in the time domain (Khan and Al-Khatib, 2006).

2.5.2 Speech melody

Speech melody represents the pattern of fundamental frequency (F0) levels that correspond to the experienced pitch over time (Goto, 2004) or the pitch variations in the course of an utterance (Poliner et al., 2007). Varying the F0 of vocal fold vibration produces different speech intonation patterns (Chow and Brown, 2018). The pitch contour is often used to describe the melody and outline the intonation of the speech over time. Pitch contour represents the pitch sequence over time that can be traced on the F0 contour graph, generated using speech analysis software (Salamon and Gomez, 2012).

It is necessary to investigate its prosodic features of the Quranic recitations to understand how it would influence the brainwaves. The spectral flux and pitch contour of the sound signal are the two prosodic features under investigation.

Conceptual frameworkFigure 2.6.1 illustrates the theoretical structure of this study.

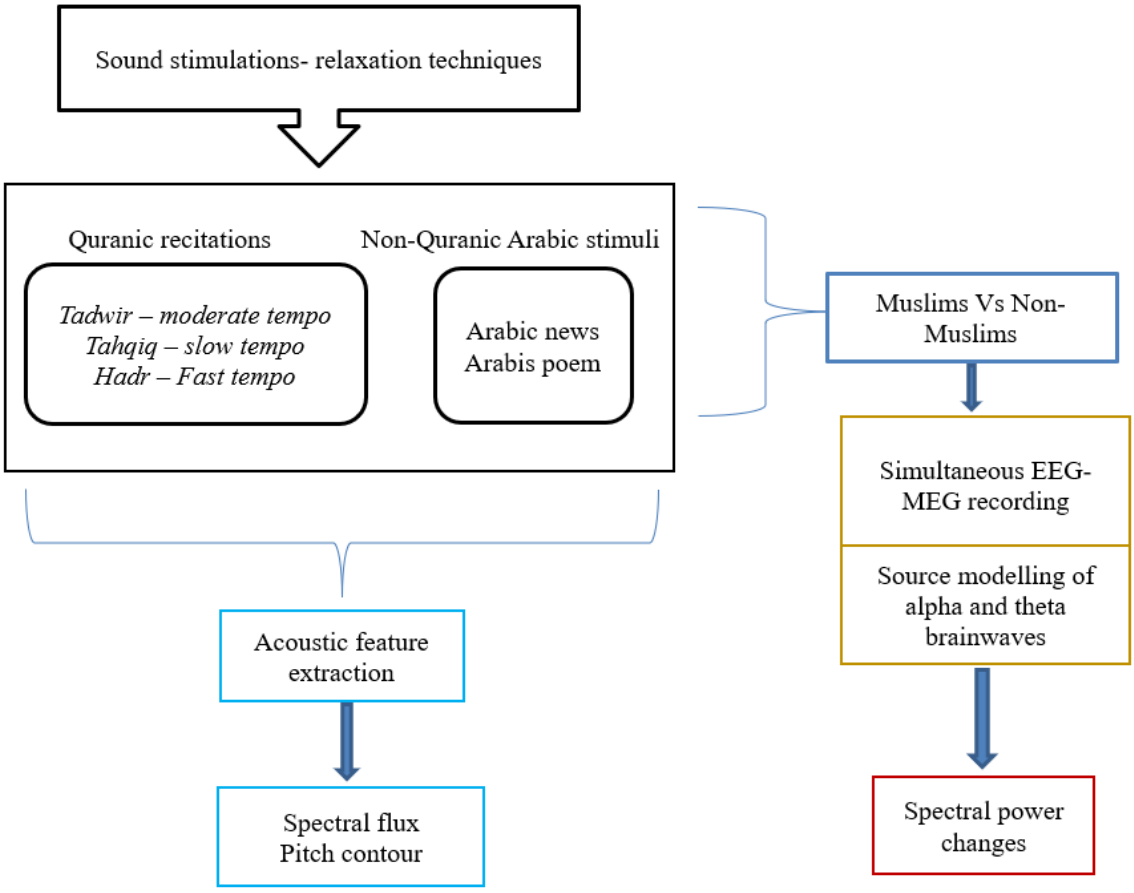

Figure 2.6.1 The conceptual framework of the study

CHAPTER 3

METHODOLOGY

3.1 Ethical considerations

The current study received an ethical endorsement from USM Ethics Board (FWA Reg No: 00007718; IRB Reg No: 00004494). (Appendices A & B).

3.2 Study design

The current study followed an experimental, repeated measures, comparative and cross-sectional study design including two groups of subjects, Muslims and non-Muslims.

3.3 Location of the study

Data acquisitions (recording of alpha and theta brainwaves activity) were done in a magnetically isolated room at the EEG-MEG laboratory of Hospital USM.