Age-related changes in alpha and beta oscillations in a sensorimotor task

By
Kirti Saluja

A Dissertation Submitted to the Faculty of
The National Brain Research Centre in Partial
Fulfillment of the Requirements for Master's in Neuroscience

National Brain Research Centre
Manesar, Gurugram, Haryana
May 2019

CERTIFICATE

This is to certify that the Dissertation entitled "*Age-related changes in alpha and beta band oscillations in a sensorimotor task*" was carried out by **Ms. Kirti Saluja** at National Brain Research Centre, (Deemed University), Manesar, Haryana, India as the partial fulfilment for the M.Sc. degree.

The work presented herein is original and has not been submitted previously for the award of any degree or diploma at National Brain Research Centre (Deemed University) or any other University.

Supervisor Director

Place : Manesar, India
Date : 1st June, 2019

DECLARATION BY THE CANDIDATE

I **Kirti Saluja** hereby declare that the work presented in this dissertation is carried out by me, under the guidance of **Dr. Arpan Banerjee** National Brain Research Centre, (Deemed University), Manesar, Haryana.

I also declare that no part of this dissertation has been previously submitted for the award of any degree or diploma at National Brain Research Centre (Deemed University) or any other university.

Place: Manesar

Date: 1st June 2019

Kirti Saluja

M.Sc. Neuroscience

ACKNOWLEDGEMENT

First of all, I would like to thank my thesis surpervisor Dr. Arpan Banerjee for his immense support and encouragement throughout the project. This project wouldn’t be possible without his valuable guidance and motivation. Thanks a lot for showing confidence in me.

I must express my gratitude towards Dr. Dipanjan Roy for his valuable suggestions in the project.

Thanks a lot to all my labmates for such helpful and enlightening discussions. I would like to thank especially Priyanka, Neeraj, Anagh, Vinodh for such stimulating discussions on signal processing. Thanks Moumita for helping me in statistics. I am thankful to vivek who helped me with source localisation.

My heartfelt thanks to Nisha and Vanshika for constant encouragement and interesting conversations. Thanks to my batchmates for all the fun throughout the coursework.

Finally, I would like to thank my family who inspired me and motivated me to achieve my goals. Mumma and papa, you are such an inspiration. I am thankful to my brother Gunjan for his constant advices. I owe this project to all the special ones in my life.

Kirti Saluja

ABSTRACT

Author :	Kirti Saluja
Title :	Age-related changes in neuromagnetic oscillatory properties in a sensorimotor task.
Institution:	National Brain Research Centre
Dissertation Advisor:	Dr. Arpan Banerjee
Degree:	Master's in Neuroscience
Year:	2019

Healthy aging is associated with structural changes in many regions of the brain and functional decline in various cognitive domains. Sensory processing and motor movement are the major cognitive declines reported. As cognition is the result of coordinated neural activity, changes in the intrinsic properties like peak frequency, power of neural oscillation in aging has been reported in many studies. Various new scientific discoveries provides a different take on healthy aging demonstrating brain as more flexible, adaptable and has the ability to preserve its cognitive abilities. The main aim of this study is to a) understand the changes in the properties of neural oscillations in a lifespan data for sensorimotor task b) and to gain insight regarding the neural reorganisation adopted by older adults for preservation of the cognition.

To address this question, a cross-sectional MEG data acquired at Cambridge Centre for Aging and Neuroscience during sensorimotor task for 650 healthy participants between 18 and 88 years was used.

The subjects performed a bimodal (audio and visual) cued button press task while recording MEG.

Behavioural results showed a weak positive linear correlation in the reaction time as the function of age.

Next, we performed power spectral analysis to know the specific neural signatures during the sensorimotor task. A leftward shift in the peak alpha frequency i.e., slowing down of alpha band frequency was observed across the age-groups. Slowing down of the alpha is also observed in various E/MEG studies of Alzheimer’s disease, hence one can speculate that neurodegeneration as an accelerated aging. Increase in beta power was also observed across the age group (from young to old). Literature shows that the increase in beta power is observed mainly because of increase in intra-cortical GABAergic inhibition.

Subsequently, we calculated the angular separation between alpha and beta activation (power) for all the channels for each subject. We observed a significant linear positive correlation for the angular separation between the alpha and beta sensor space and age. Larger angles indicates more separation and less topological overlap between the sensors group.

Source localisation was performed which showed lesser activation in occipital cortex in older adults as compared to younger adults for alpha frequency. Activation was observed in dorso-parietal cortex for beta band frequency. Asymmetric activation for beta band frequency was observed in older adults as compared to the younger adults.

In conclusion, we established the age related changes in the alpha and beta band oscillation in a sensorimotor task.

Contents

1. **Introduction**

2. **Methods : aging through the lens of oscillation**

2.5 Data analysis

3. Results

List of Figures

Chapter 1

Introduction

Aging is often associated with decline in various cognitive abilities. With the increase in life expectancy of the population, the age-related cognitive impairment has become one of the major concern. Various studies shows a correlation between the dynamics of the brain and the underlying cognitive processes **[Lawrence M. Ward]**. Several researchers agree that the synchronous activity of the neurons in the brain give rise to cognition **[Hutt and et al., 2016][Pulvermüller and et al., 2014]**. Specific oscillations can be selective to certain cognitive task.

Several studies have reported the changes in the intrinsic properties such as frequency, power of neural oscillation and other selective changes in the aging brain. There are various theories related to the compensatory mechanism adopted by aging brain for preservation of the selective cognitive abilities **[Joshua O. Goh and Denise C. Park, 2009]**. All these changes can be related to reorganization of the brain networks as a function of age to preserve the performance. These reorganisations can cause the change in the spatiotemporal properties of brain rhythms along the lifespan **[Deco et al., 2016]**.

The aim of this report is to understand the concept of healthy aging in terms of age-related changes in neural oscillations. This study will be helpful from the lens of neurodegenerative diseases as normal brain aging forms a continuum with neurodegeneration **[Tony Wyss-Coray 2016]**.

1.1 Neural oscillations

"Clocks tick, bridges and skyscrapers vibrate, neuronal networks oscillate. Are neuronal oscillations an inevitable by-product, similar to bridge vibrations, or an essential part of the brain's design?" - György Buzsáki

Rhythms in neural activity are observed across various temporal and spatial scales and are oftenreferred to as oscillations **[Voytek et al., 2016]**. Neural oscillations emerge from the dynamic interplay between intrinsic cellular and circuit properties **[Buzsáki and Draguhn, 2004]**. The first electrical brain activity was captured by Hans Berger **[Destexhe and Senjnowski, 2003]**. On the basis of these properties (Figure 1.1), neural oscillations are characterised into Delta (< 4Hz), Theta (4-7 Hz), Alpha (8-12 Hz), Beta (13-30 Hz) and Gamma (31-50 Hz). The frequency and amplitude of these oscillations changes with different behavioural states. These oscillations can be captured by various non-invasive technique called E/MEG (Electro/Magneto-encephalography). Through the data collected from E/MEG, the activity of cortical pyramidal neurons can be estimated. Hence, one can weave a connection between the oscillations recorded from the scalp to the dynamics of various cognitive process. **[P.L. Nunez, 2000]**.

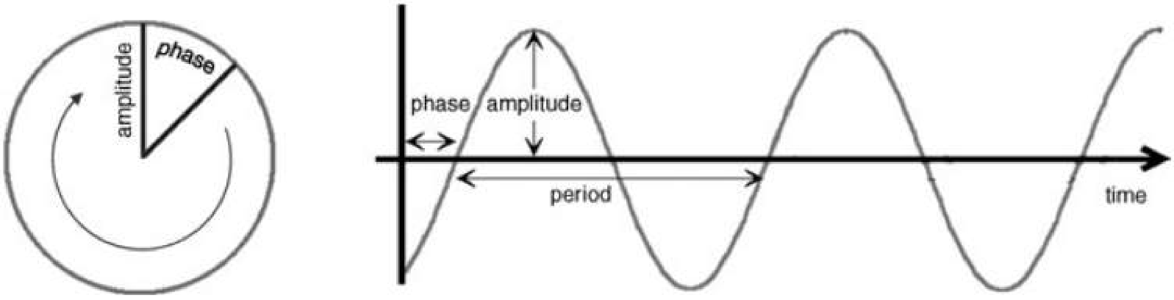


Figure 1.1 : Properties of neural oscillations : Phase, Amplitude and period.

Alpha activity is linked to selective attention. Beta activity is mainly found in motor cortex is associated with muscle movement. Gamma waves are involved in visual awareness.

The strength of the neural oscillation can be assessed by the frequency and power. In order to transform data we must employ a Fourier transform. It has been reported that spectral power also changes with age. **[W. Klimesch , 1999]**.

1.1.1 Magnetoencephalography

MEG is a reference-free non-invasive imaging technique with millisecond temporal resolution that has proved to be a useful tool in measuring brain rhythms. The signals captured by MEG (Figure 1.2a.) is contributed by excitatory and inhibitory dendritic post-synaptic potentials.

This current flows through the apical dendrites, hence detecting dipoles arranged tangential orientation to the scalp. David Cohen at Massachusetts Institute of Technology detected the endogenously generated magnetic field. The sensors in MEG known as SQUID (Superconducting quantum interference device) consist of gradiometers and magnetometers (Figure 1.2b.)

Orthogonal magnetic field is measured by magnetometers and gradients in the magnetic field over space is measured by gradiometers (present in pairs and wound in opposite direction) **[Proudfoot et al., 2014] .**

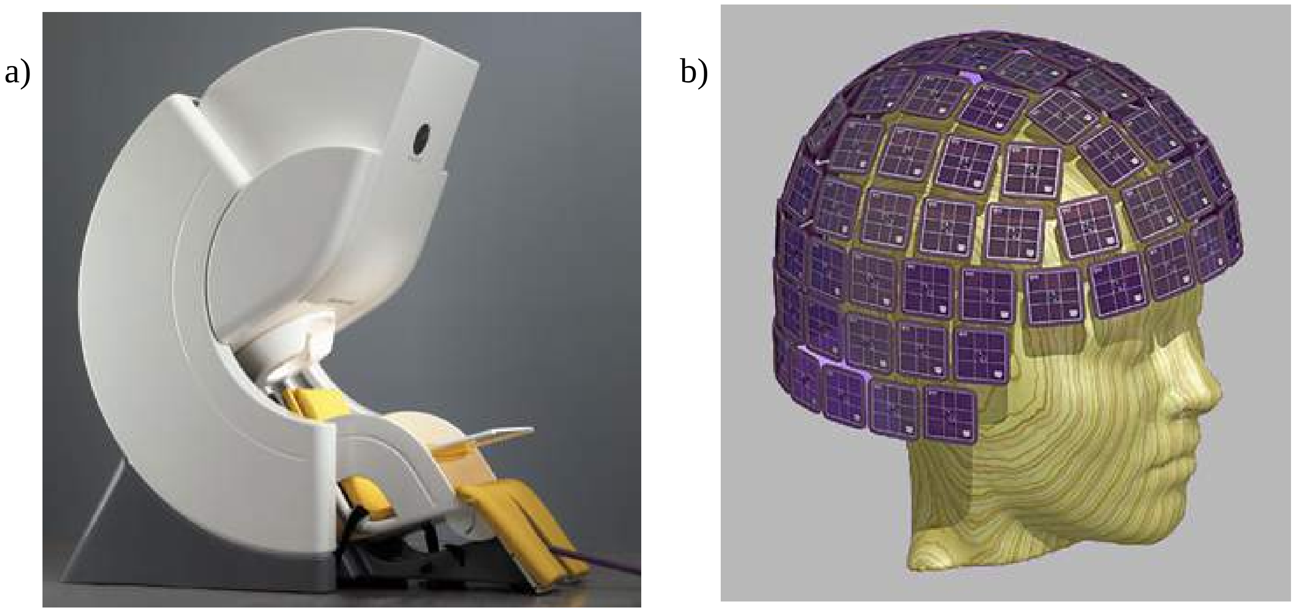


Figure 1.2: a) ELEKTA Magnetoencephalography
b) Sensors used in Magnetoencephalography known as SQUIDS.

MEG mainly measures the magnetic field changes induced by intracellular current flow. Unlike EEG, magnetic field captured passes through dura, skull and scalp relatively unaltered. This provides an advantage to localise the sources precisely.

1.2 Landscape of aging

With the increasing population and life expectancy, aging has become a major concern. Aging is associated with various structural decline such as decrease in white and grey matter, reduction in cortical thickness and many more. Cognitive decline for some executive function such as memory, attention, motor task etc. is the most feared aspect of aging. Dementia and MCI (Mild cognitive impairment) is highly associated to the process of aging but doesn’t lie under the umbrella of healthy aging **[Irwin et al., 2018]**.

1.2.1 Compensatory theories of aging

In the process of aging , the brain changes a lot structurally but atleast most of the cognitive abilities doesn’t suffer the same faith. Various functional neuroimaging studies showed that brain has the capacity to compensate the age related changes to preserve cognitive performance.

Aging also leads to many changes in the intrinsic properties of the neural oscillations. **[Kolassa et al., 2014].**

Through various studies it has been shown that there is recruitment of additional neural resources in old people. The theories related to compensatory mechanism are stated below.

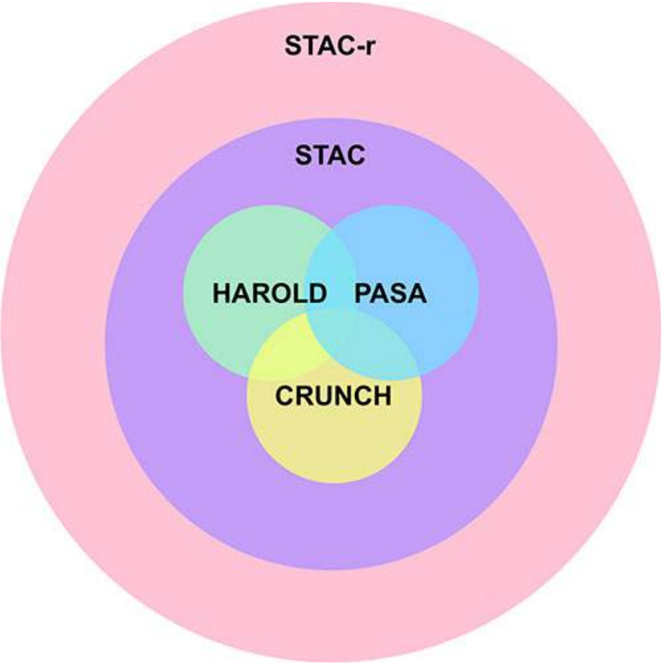


Figure 1.3: Theories related to compensatory mechanism for aging

HAROLD (Hemispheric Asymmetry Reduction in Older Adults) refers to the bilateral activation in older adults as compared to younger adults. These activations somewhat depicts the process of dedifferentiation. Dedifferentiation is referred to the difficulty in recruiting specialized neural networks for a particular task. **[Festini et al., 2018]**

CRUNCH (Compensation- Related Utilization of Neural Circuits Hypothesis)

This theory revolves around the difference between the overactivation or the underactivation of certain brain regions between the younger and older adults in reference to a specific task **[Gordon et al., 2013]**.

PASA (Posterior-Anterior Shift in Aging) describes the increased activity in the frontal/pariet al., cortex and decreased activity in the occipital cortex in older adults as compared to the younger adults. The tradeoff in the activation pattern and location is highly associated with the performance. **[Cabeza et al., 2008]**

STAC (Scaffolding theory of aging and Cognition)

Scaffolding is a protective process in the aging brain that involves use of alternative neural mechanism to achieve a particular cognitive goal. STAC-r provides a dynamic model combining both neurophysiological variable and neural compensatory processes to predict cognitive function over time **[Denise et al., 2014] .**

How does the aging brain compensates the cognitive performance especially in a simple sensorimotor task will be fascinating to understand.

1.3 Sensorimotor cortex

Performance of any motor activity requires proper integration of sensory and motor information. The integration of the information is mediated by sensorimotor cortex which primarily consist of posterior pariet al., association cortex and dorsolateral pre-frontal association cortex. **[Callum F. Ross et al., 2016]**

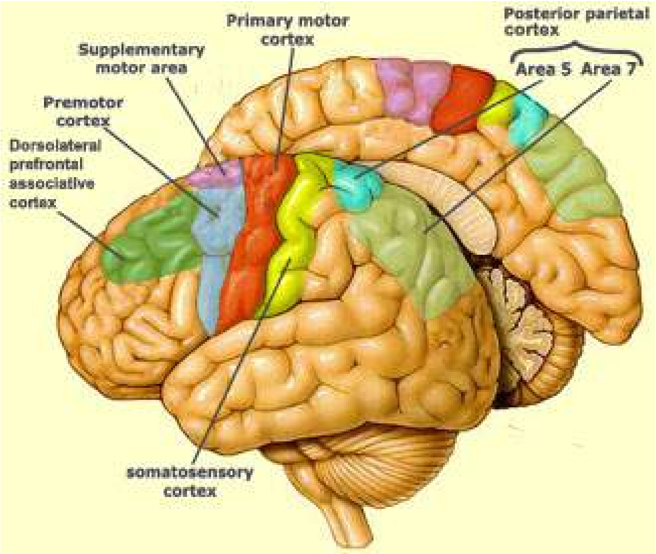


Figure 1.4 : Sensorimotor cortex and other associated regions

Evidence from animal studies showed the decline of the dopaminergic neurotransmitter system and reduction of the inhibitory synapses in the sensorimotor cortex implying age-related changes in the circuity. **[Poe et al., 2001]**

These studies strongly suggest that sensorimotor function face certain alterations as a function of age which eventually affects the performance. Oscillatory signatures like alpha (mu) and beta rhythms are readily observed in the sensorimotor cortex. This thesis focuses on understanding the change in oscillatory patterns produced due to the process of aging in a sensorimotor task.

1.4 Alpha and Beta rhythms in Sensorimotor cortex

Synchronized activity of thalamcortical neurons give rise to mainly alpha and beta oscillations in sensorimotor cortex **[Pfurtscheller et al., 1999]**. These oscillations together helps in movement planning and execution. Various studies shows the phenomena of event related synchronization and desynchronization which depicts the increased and reduced local processing respectively in the underlying cortex. **[Pfurtscheller , 1996]**

The most predominant oscillation is the alpha frequency. Activity of alpha oscillation is affected by aging. AD patients are reported to show a decrease in peak alpha frequency of occipital cortex as compared to healthy old subjects **[Lopez et al., 2013].**

Alpha frequency is highly correlated with the speed of information processing which actually shows up in the reaction time. The relevance of the slowing down of alpha is not properly understood.

Another important frequency which faciliates the action and movement is beta band oscillation. In healthy aging beta power is associated with an increase in movement-related desynchronization in ipsilateral and decrease in frequency in the motor cortex bilaterally **[Yoshimura et al., 2011].** Apart from movement, beta band oscillations are also linked with modulation in visual system. Age related alertness deficits is related to decrease in beta band cortical activation **[Kaminski, 2012].**

Various animal studies have shown age-related changes in the sensorimotor cortex where the integration of sensory and the motor information takes place. Modulation in the alpha and beta rhythms produced mainly by the sensorimotor cortex with age is also reported .

A study by [Sahoo et al.,, 2018] showed the change in peak frequency and beta power across age in a resting state MEG data. Motivated by the fact, this thesis focuses on how the dynamics of neural oscillations changes with age in a sensorimotor task collected by Cambridge Centre for Aging and Neuroscience. This thesis addresses another intriguing aspect of healthy aging i.e., the possible compensatory mechanism adopted by the older adults to preserve their performance in the sensorimotor task.

We employed the concepts of power spectrum, regression analysis and source localisation to answer the above questions (described in chapter-2). Chapter-3 presents the results obtained from the analysis conducted on the MEG (Cam-CAN) data.

Chapter 2

Methods

2.1 Participants

Data used in this study is collected by Cam-CAN (Cambridge Centre for aging and Neuroscience). It is a large-scale, multi-modal, cross-sectional, population-based lifespan (18-88 years) data. The 650 participants relevant to this study were selected from a cohort of 3000 adults drawn from Cambridge City (UK) area. These participants were tested for cognitive measures and neuropsychological test like vision, hearing, verbal intelligence etc. The participants were distributed into four age categories i.e Young (18-35) , Mid-Young (36-51), Mid-Old (52-65) and Old (66-88).

2.2 Stimulus and Trials

The stimulus consist of simple audio/visual sensorimotor task to access basic sensorimotor neural response. In the audio/visual sensorimotor task, participants were presented with the two checkerboards each side of the central fixation and one of the frequency out of these three frequency (300Hz, 600Hz and 1200Hz) were presented as the part of auditory stimulus.

The task included two trial conditions : Bimodal and Unimodal trials. In bimodal trial, the auditory and the visual stimulus were presented stimultaneously for 34ms and 300ms respectively. Either of the auditory or the visual stimulus was presented in case of unimodal stimulus.

The participants were then asked to press a button with the right index finger as soon as they perceive the stimulus. 8 unimodal trials (4 each, audio and visual) were pseudorandomly distributed in between 120 bimodal trials.

The participants were scanned using MEG along with recording reaction time for the sensorimotor task.

Stimulus onset asynchrony : 2-26s

Trial duration : 1750 ms

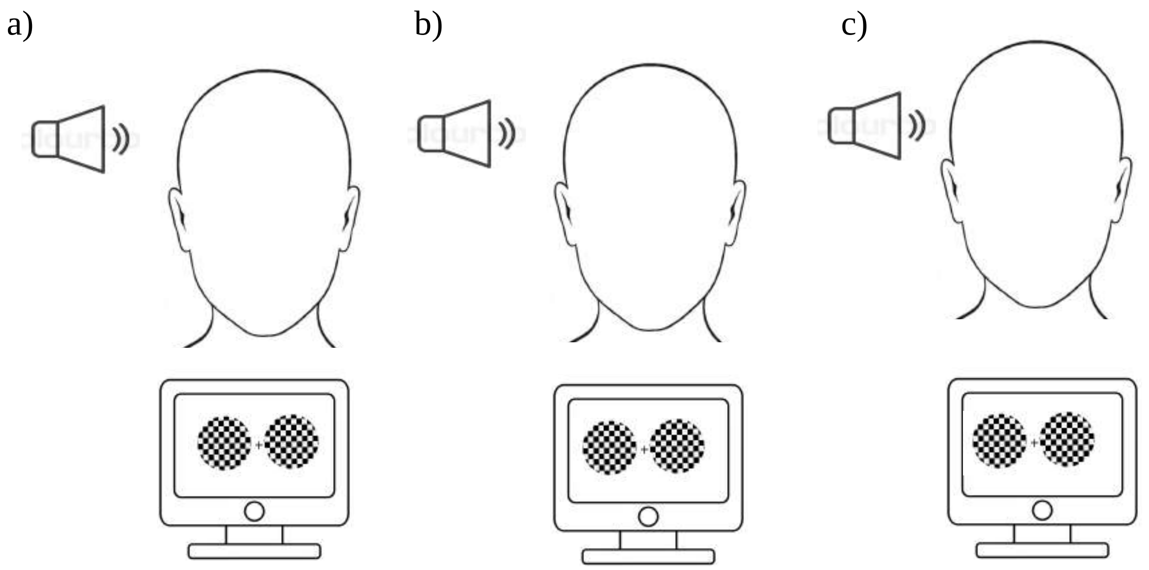


Figure 2.1 : Bimodal stimulus condition in which participants are presented with checkerboard in left and the right visual field separated by a fixation point along with the audio stimulus presented binaurally at frequency a) 300Hz b) 600Hz c) 1200 Hz containing 40 trials each.

2.3 Neuroimaging Technique

The neuroimaging technique used in the study was MEG. The data was acquired using Elekta Neuromag with 306-channel Vectorview system consisting of 102 magnetometers and 204 gradiometers. Sampling frequency used for the data was 1000Hz with the band-pass filter of 0.03-330 Hz. The total duration of the recording was 8m 40s.

Head motion correction was continously measured using HPI (Head-Position Indicator). Electrooculogram (EOG) was also recorded to monitor blinks and eye-movement. Pulse-related artefacts were monitored using electrocardiogram (ECG).

2.4 Preprocessing of the MEG data

The MEG data so used for the analysis was already preprocessed using maxfilter program. The maxfilter program implements Signal-Space Separation (SSS) to segregate signals from the brain to the surrounding. It helps reducing the noise by using "temporal extension".

Maxfilter 2.2 version was used.

Epochs of 1.2 seconds were extracted from the maxfiltered MEG data with 300ms as the prestimulus for each trial condition. Obtained epochs were bandpass filtered between frequency range 0.1-45 Hz. The epochs were then detrended to remove the linear trend present in the signal.

2.5 Data Analysis

The preprocessed data was further used for data analysis.

2.5.1 Reaction time analysis

Reaction time for the sensorimotor task was recorded with the MEG sessions for all the participants and for all the trials. For the quality check, the trials which were above 3SD (standard deviation) or below the mean were removed. The reaction time is averaged for all the trial conditions i.e., AV300 , AV600 and AV1200.

Regression analysis was applied on the reaction time (averaged for each age point) data. Regression analysis helps in establishing a relationship between the dependent and independent variables.

2.5.2 Power spectrum

Power spectrum demonstrates the distribution of power into the frequency components present in that signal. Power spectrum can computed using Fast Fourier transformation (FFT). Fourier analysis converts a signal from its original domain (often time or space) to a representation in the frequency domain and vice versa.

It follows a distribution of 1/freq where smaller frequencies shows a larger power and vice-versa.

Power spectrum was calculated for each trial of all subjects (groupwise) and sensor for every condition (i.e AV300, AV600 and AV1200) separately using multitaper method. All trials were stacked and averaged for each age group. The powers so obtained from fourier transformation were also visualised using the spatial topoplots.

2.5.3 Trends of Beta oscillations with age

Power spectrum analyzed earlier showed changes in alpha peak frequency and beta power as the function of age. Our next aim was to analyse the trajectory followed by the beta band oscillations over the lifespan. The raw beta power so obtained from the power spectrum was used and the data was drawn against the age points. Further curve fitting analysis was done along with the calculation of goodness of fit (R square value).

2.5.4 Angular separation

The visualisation from the spatial topoplots showed different sensors are responsible for the production of alpha and beta band oscillations. Angular separation helps us to quantify the extend of overlap between the sensor topography of alpha and beta band oscillations. The activity of alpha and beta after fourier transformation were normalized separately for each subject.

$$\hat{\alpha}_I(c) = \frac{\alpha_I(c) - <\alpha_I>}{\sigma_{\alpha(I)}}$$

$$\hat{\beta}_I(c) = \frac{\beta_I(c) - <\beta_I>}{\sigma_{\beta(I)}}$$

The separation can be quantified using simple dot product between two mutlidimensional vector space. The formula below depicts the angle (theta) which signifies the angular separation.

$$\theta(\alpha, \beta) = cos^{-1}(\frac{\hat{\alpha}_I . \hat{\beta}_I}{|\hat{\alpha}_I| |\hat{\beta}_I|})$$

2.5.5 Source Localisation

Source level analysis was done using MNE-Python. Ten subjects were selected each from young (18-35) and old (66-88). The method used for source localisation was sLORETA. sLORETA employs the current density estimate given by minimum norm solution and localisation inference is based on standardized values of the current density estimates.

Chapter 3

Results

3.1 Demography

Out of 650 participants, 7 participants were excluded because of insufficient MEG data provided by Cam-CAN. The data consist of 49.46% and 50.54% of female and male respectively. (Figure 3.2)

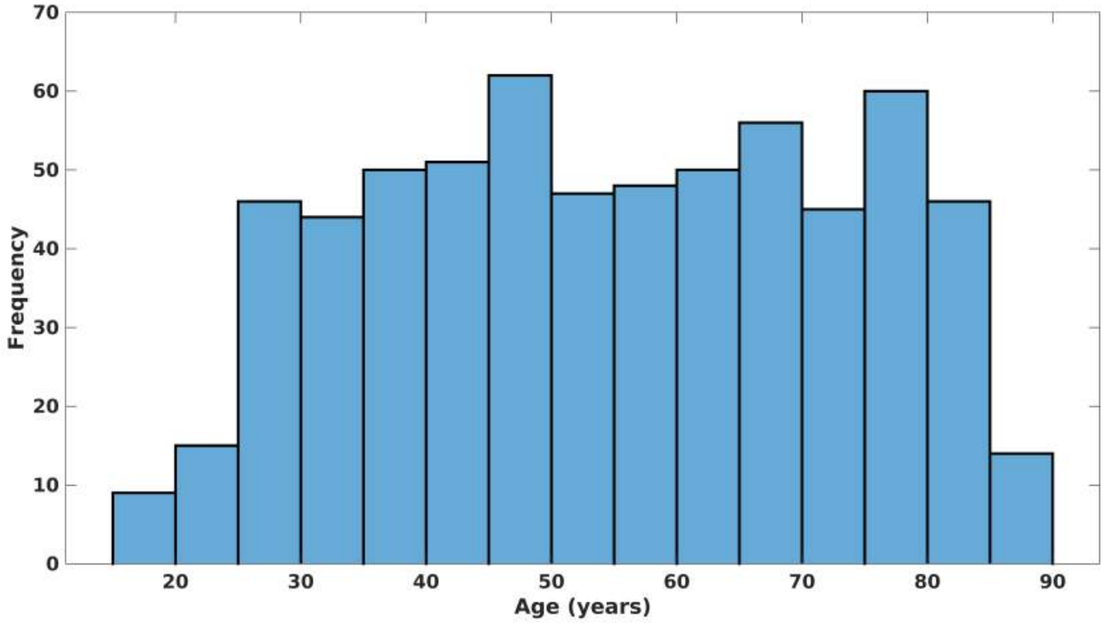


Figure 3.1 : Histogram showing the age distribution of Cam-CAN data

The data was divided into four age categories i.e Young (18-35), Mid-Young (36-51), Mid-Old (52-65) and Old (66-88) for further data analysis.

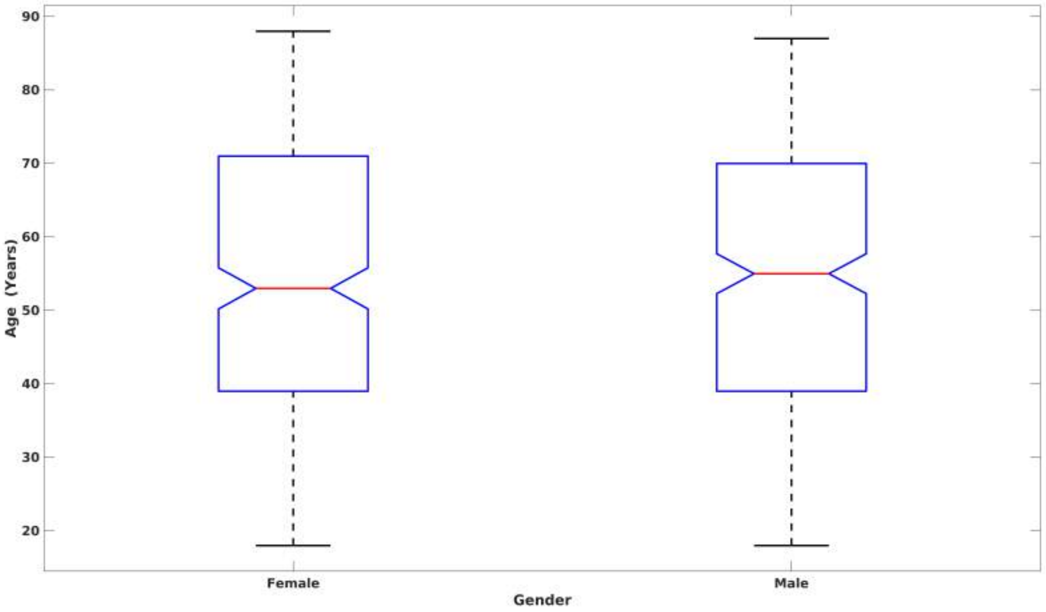


Figure 3.2 : Boxplot showing the age distribution for female and male separately with median age of 53 and 55 respectively.

3.2 Reaction time

In this sensorimotor task, the response time (RT) was captured by Cam-CAN upon the button press as soon as the subject perceived the auditory or/and the visual stimulus. The RT data was averaged across 120 trials for each subject. A simple linear regression was calculated to predict Reaction time based on the age(in years).

The correlation coefficient of **0.2539** indicates a weak positive linear relationship between reaction time and age. The result indicates that there is significant (p = 0.0326) linear relationship between age and reaction time (Figure 3.3).

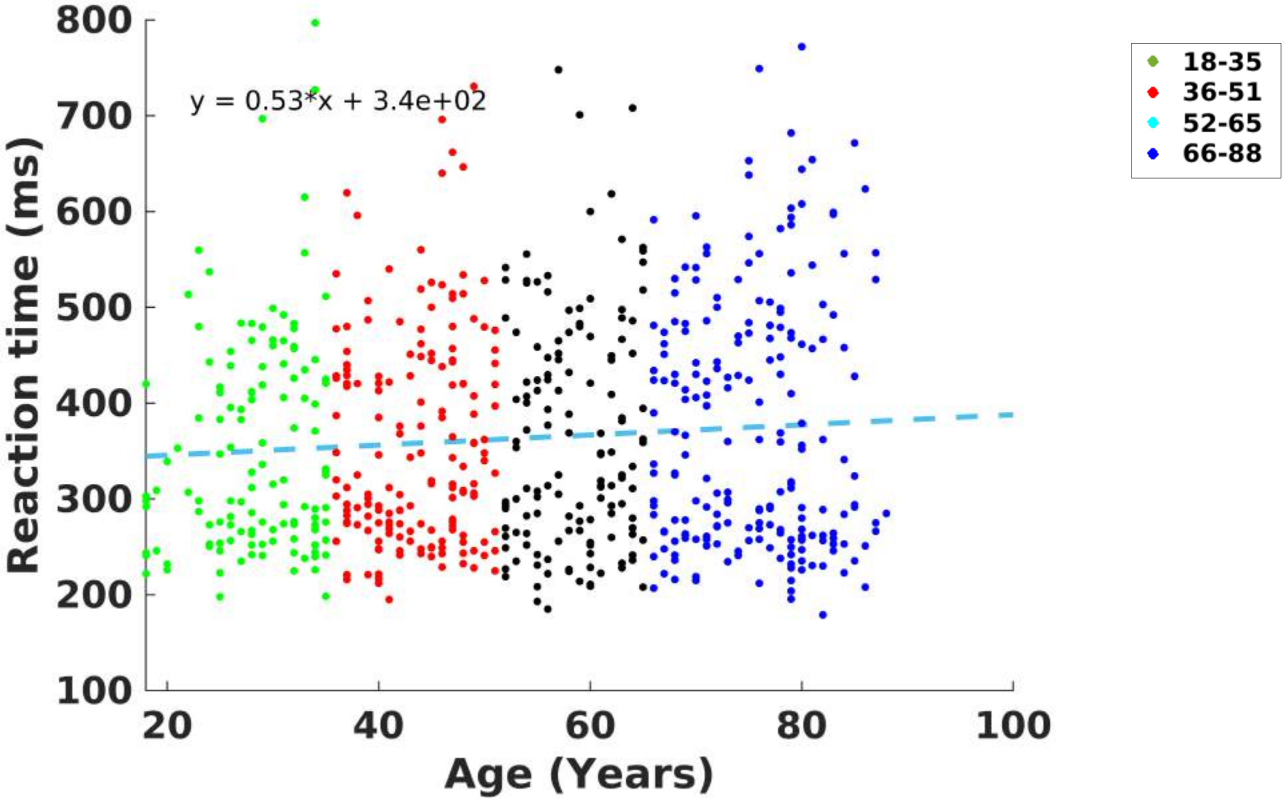


Figure 3.3 : Scatter plot showing mean reaction time for each participant as a function of age. Blue line shows the regression fitting.

The median value of the reaction time increases from young adults (18-35) to old adults (66-88) (Figure 3.4). One-way ANOVA was performed on the reaction time data which shows there is significant difference [P(F>3.9) ; p-Value = 0.0114] between the response times of different age groups.

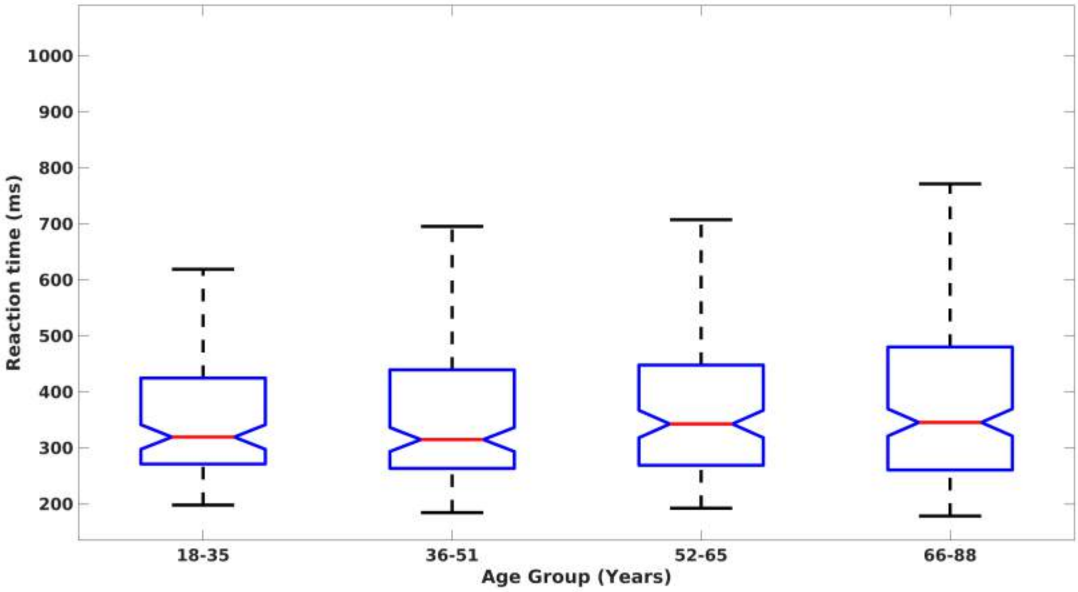


Figure 3.4 : Boxplot depicting the median reaction time of each age group. The red line shows the median RT of Young (18-35), Mid-young (36-51), Mid-Old(52-65) and Old (66-88) as 320ms, 315.5ms, 343.25ms and 346ms respectively. One-way ANOVA shows significant difference between the groups

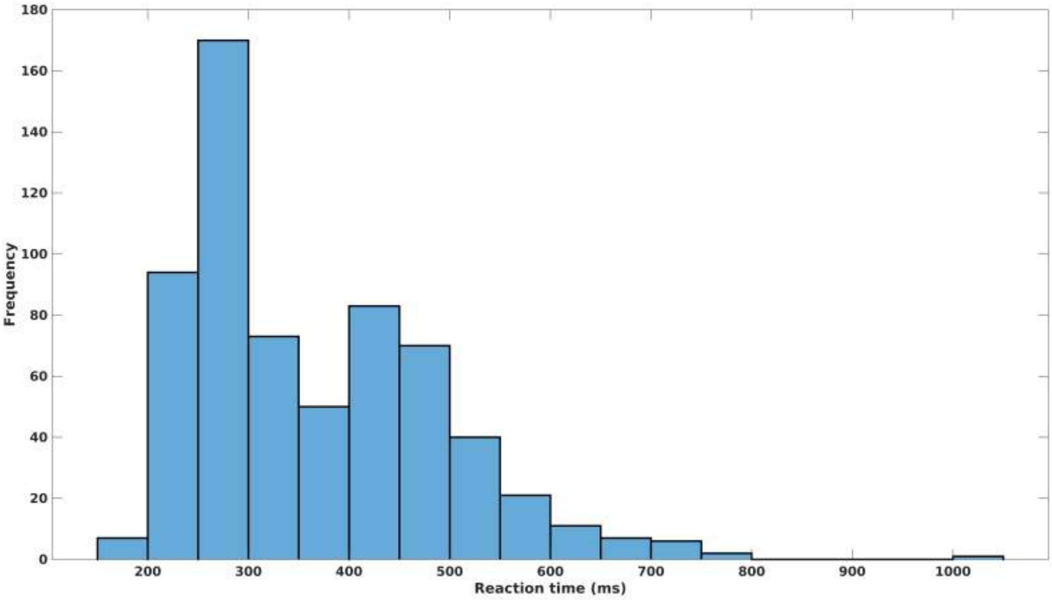


Figure 3.5 : Histogram showing distribution of reaction time for 650 subjects

3.3 Power Spectrum analysis

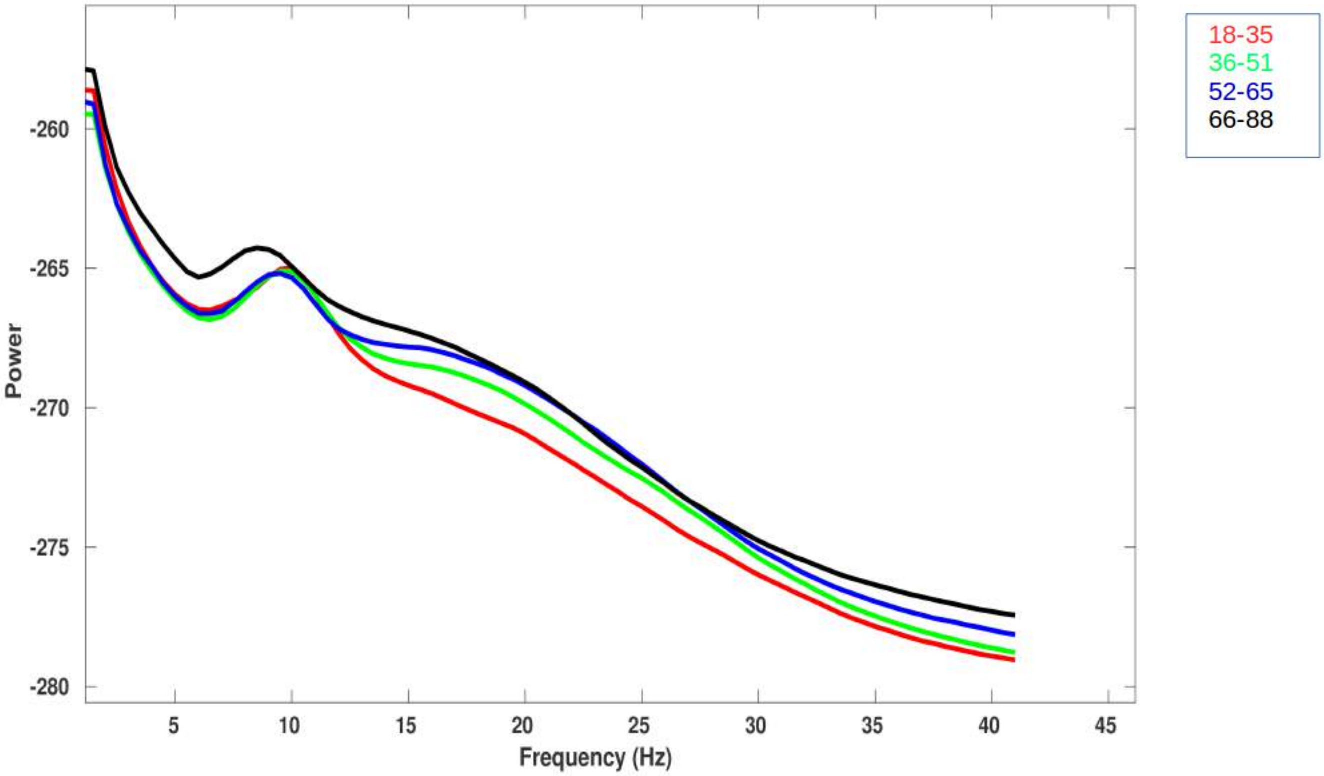


Figure 3.6 : Grand averaged power spectrum across all the sensors and trials measured for the age groups. Red (Young); Green (Mid-Young); Blue (Mid-Old); Black (Old).

Next, we performed power spectrum analysis on the MEG data for sensorimotor task. Power spectrum is plotted in Figure 3.6. We observed a decrease in the alpha peak frequency across the age group (i.e young to old) implying slowing down of the alpha band oscillations. An increase in the power of beta band oscillation across the age group was also observed.

Figure 3.7 shows the average topographical map of alpha activity at the center alpha frequency. Figure 3.8 shows the average topographical map of beta activity averaged for frequency range 13-30 Hz.

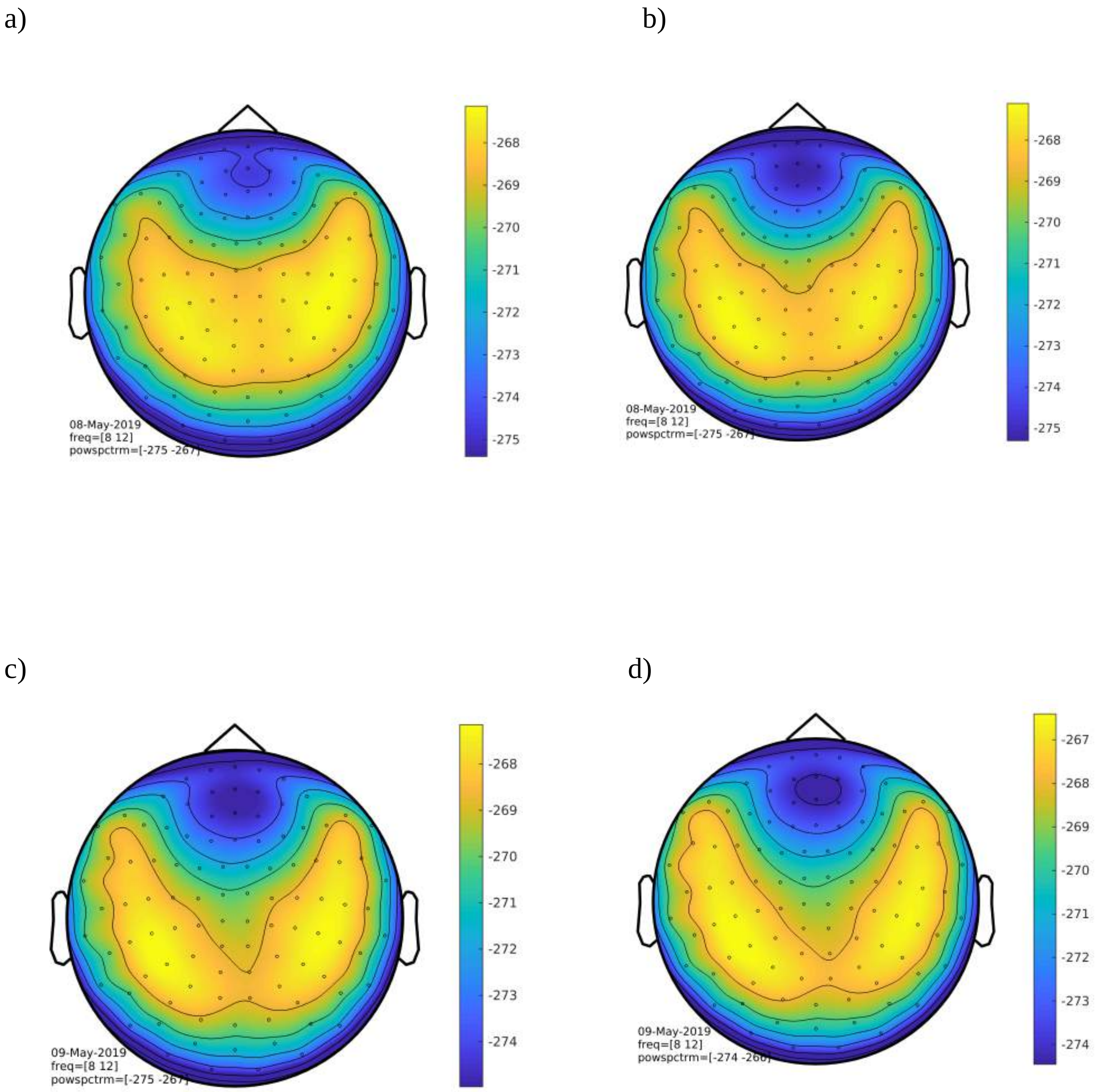


Figure 3.7 : Sensor topographies of alpha power at peak frequencies for all the age groups.

a) Young (18-35) b) Mid-Young(36-51)

c) Mid-Old (52-65) d)Old (66-88)

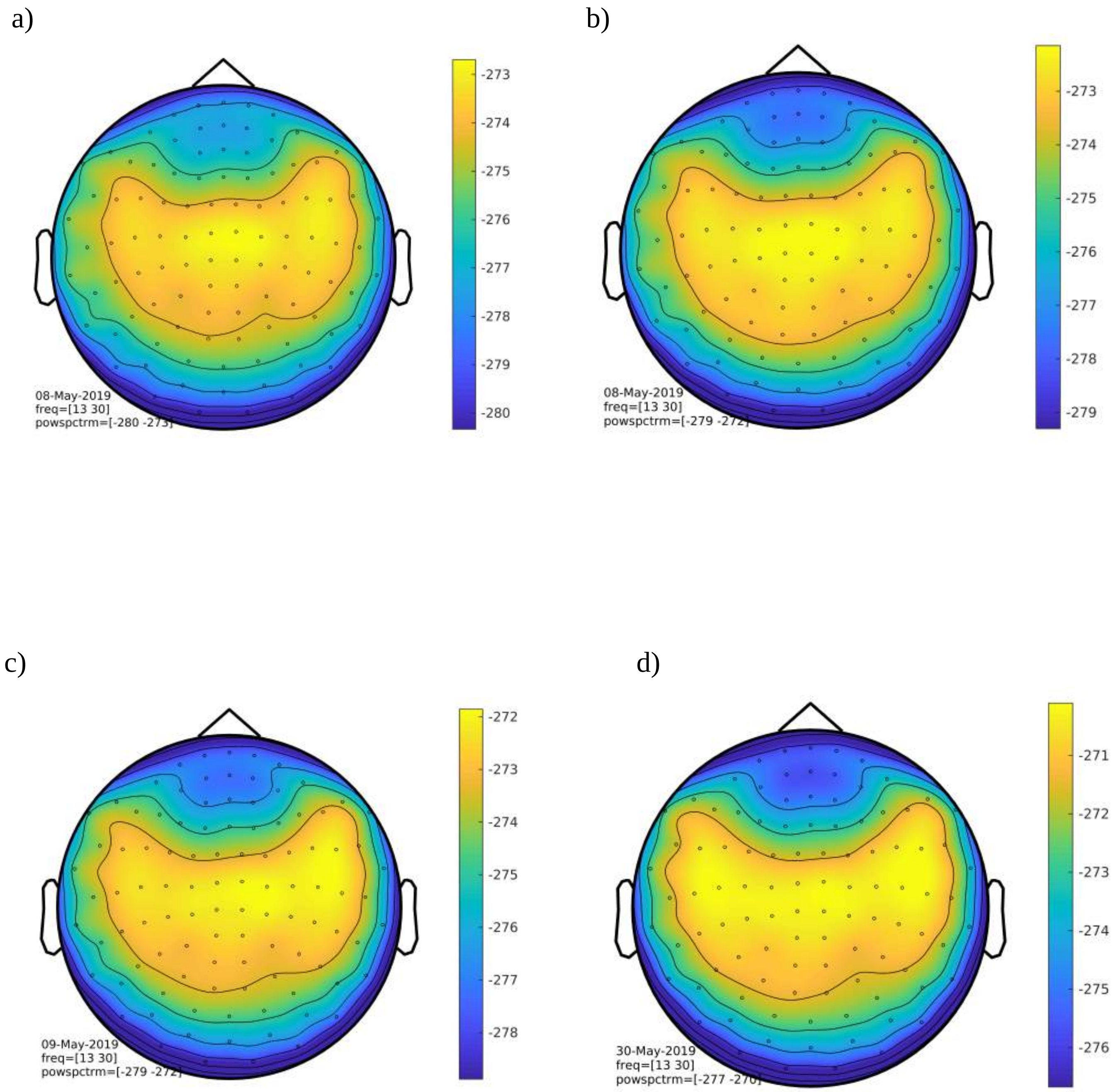


Figure 3.8 : Sensor topographies of average beta power (13-30 Hz) for all the age groups.

a) Young (18-35) b) Mid-Young(36-51)

c)Mid-Old (52-65) d)Old (66-88)

3.4 Angular Separation

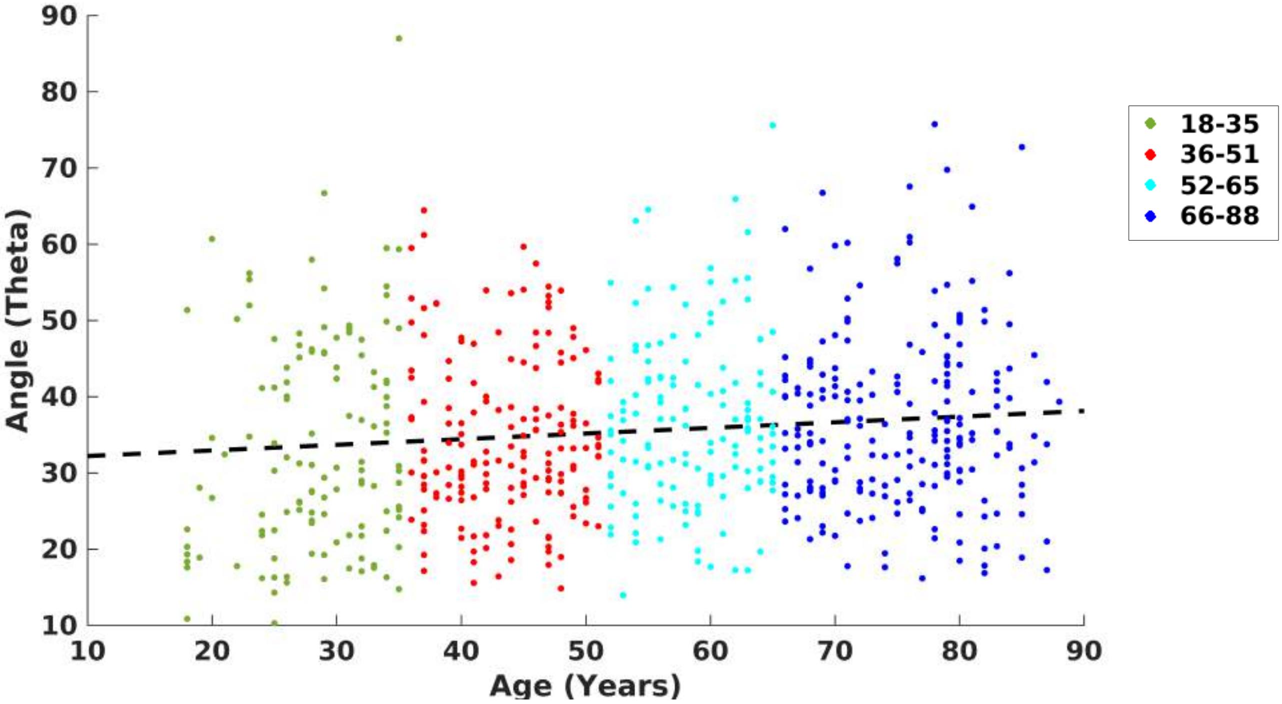


Figure 3.9 : Scatter plot showing the distribution of angles between the sensor topographies of alpha band activation and beta band activation.

The activation of alpha and beta band visualised from spatial topography shows difference in the activation of sensors as a function of age. Angular separation helps to quantify the extend of separation between the alpha and beta activated sensor space pattern. Figure 3.9 shows the scatter plot drawn between the angles obtained and age. A linear positive trend was observed. The correlation coefficient obtained **0.2423** from correlation analysis shows a significant ($p = 0.0417$) weak correlation.

Larger angle indicates more separation and less topological overlap between the sensor groups.

t-Test was performed between four age groups: Young (18-35), Mid-young(36-51), Mid-Old (52-65) and Old (66-88) to reveal association between angular separation and age. Young (18-35) age group was found to be significantly different from all other age groups. Significant difference was also found between Middle young (36-51) and Old (66-88).

3.5 Trends of Beta band oscillations with age

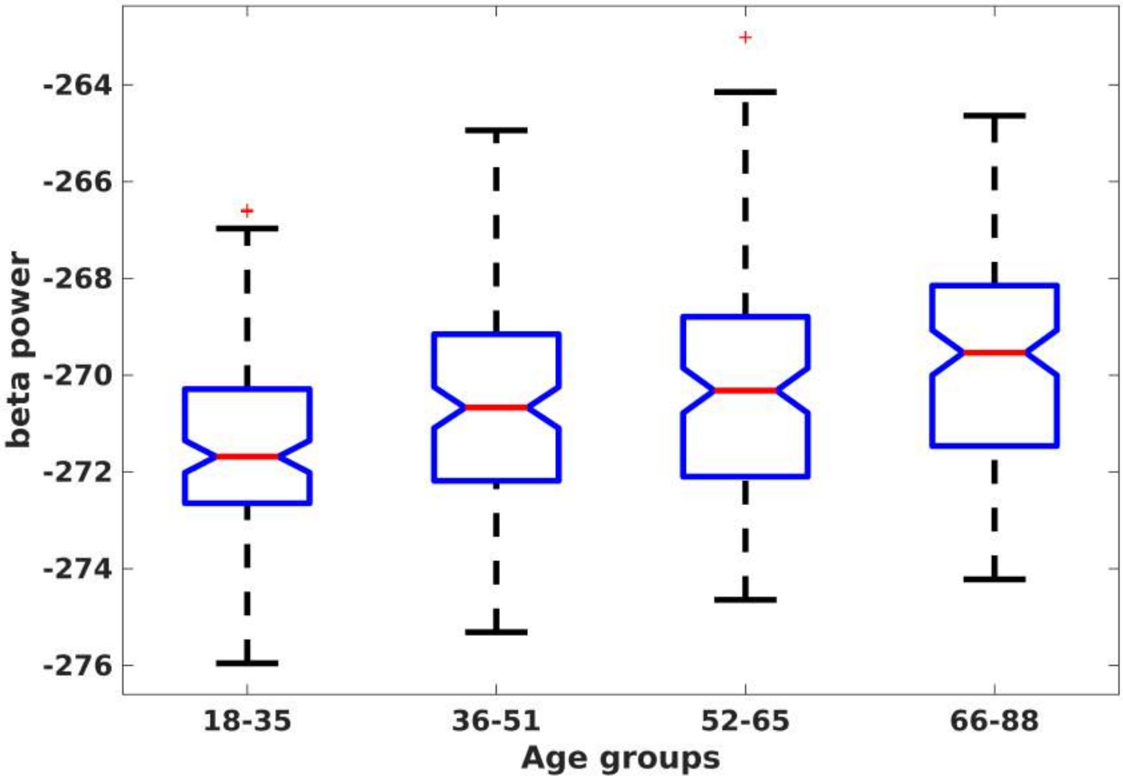


Figure 3.10 : Boxplot showing the median beta power for all the age groups.

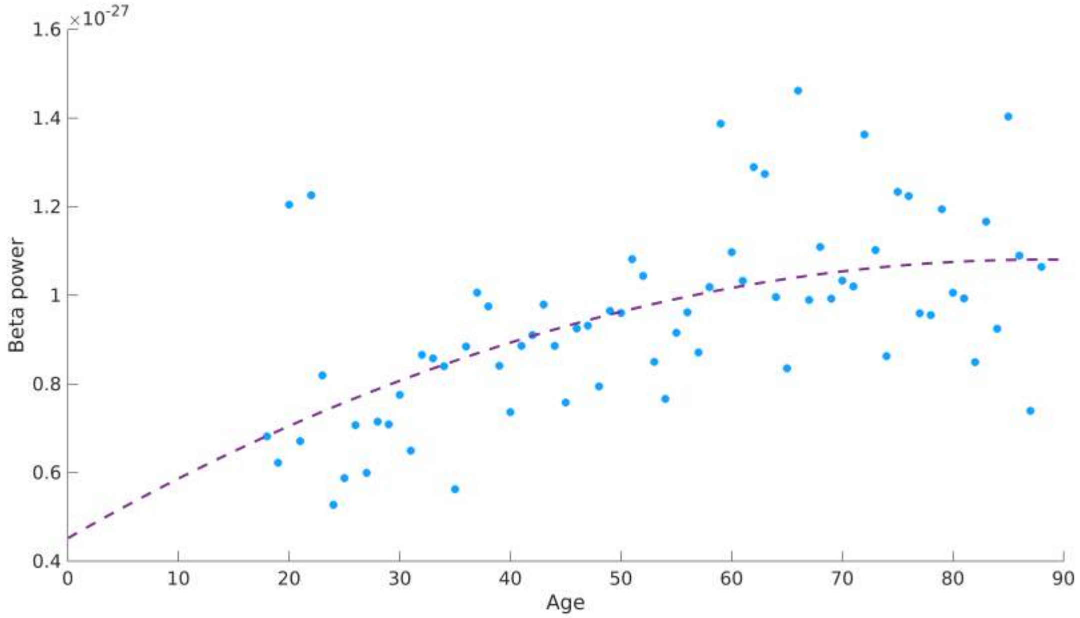
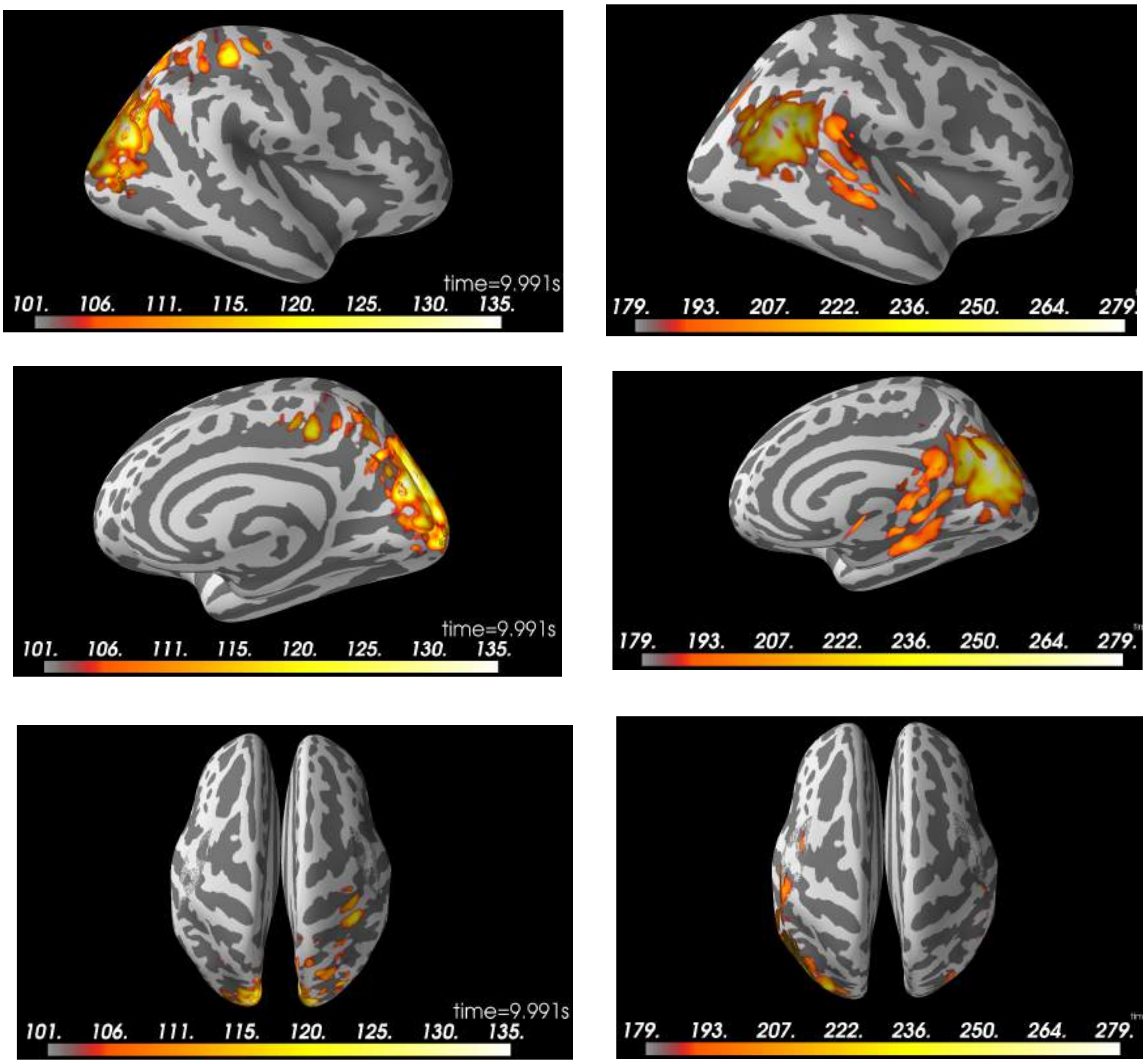


Figure 3.11 : Scatter plot showing the trend followed by the beta power across lifespan. Violet line shows the quadratic curve fitting.

Figure 3.10 shows median beta power in beta power among four age groups. We observe an increase in the median beta power across the age group. We have also observed a quadratic trajectory of the raw beta power as a function of age (Figure 3.11). Goodness of fit analysis shows the R square value of **0.3461.**

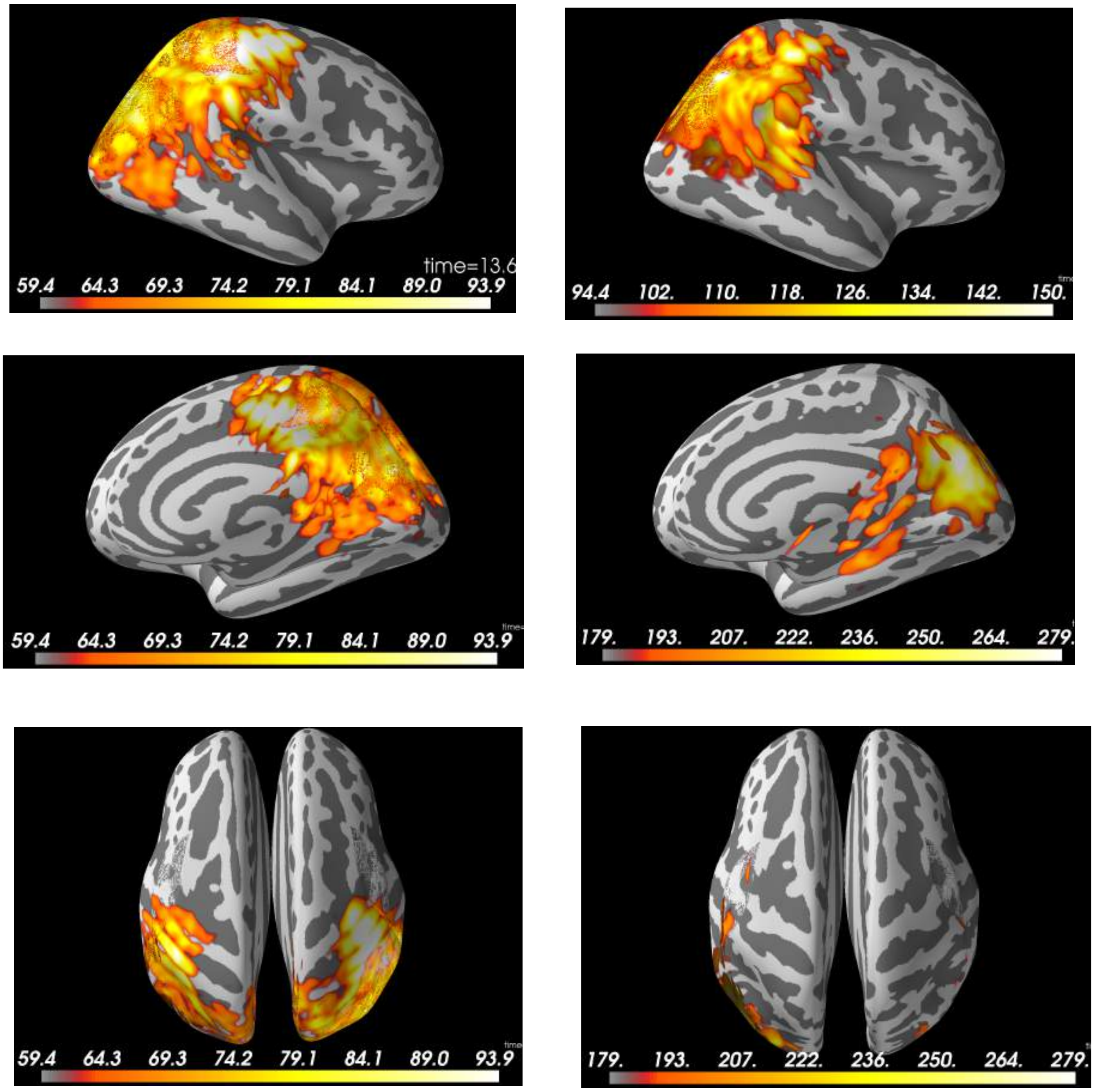
3.6 Source Localisation



a) Young

b) Old

Figure 3.12 : Cortical sources underlying alpha band oscillations using sLORETA from the sensor time series. The regions highlighted in yellow represents maximum power for alpha frequency.



a) Young

b)Old

Figure 3.13 : Cortical sources underlying beta band oscillations using sLORETA from the sensor time series. The regions highlighted in yellow represents maximum power for beta frequency.

Next , we performed source-level analysis for alpha band oscillations. Power ratios were used to compute the patterns of alpha and beta activations.

The results from source level analysis shows the increasing activity for alpha frequency of the occipital cortex in younger adults as compared to older adults. This is accompanied by increased activation in temporal region in alpha frequency regimes (Figure 3.12).

The results from the source level analysis shows increasing activity of occipital cortex and dorsal parietal cortex in younger adults as compared to older adults for beta frequency regimes. Asymmetric activation for beta frequency was observed in older adults as compared to younger adults. (Figure 3.13)

Chapter 4

Conclusion and Summary

Age related cognitive decline in some of the functions is of critical scientific and public health concern because of the growing population. Advancing age impacts our cognitive capacities of perceptual speed, attention, motor task, reasoning, and the most crucial, learning and memory processes dependent on hippocampus and frontal cortex **[Konar etal, 2016]**. Most of the research is dedicated to understand the process of pathological aging such as Alzheimer's Disease and Parkinson’s Disease. Understanding the process of healthy and normal aging will be beneficial in long run as majority of people suffer from subtle age-related cognitive deficits that deteriorate their quality of life. The aim of this study is to identify the age-related changes in the neural oscillatory pattern in a sensorimotor task.

The main findings of the study are :

1. Weak positive linear correlation between reaction time and age.
2. Slowing down of the alpha band oscillations i.e., leftward shift in alpha peak frequency.
3. Increase in beta band power from young (18-35) to old (66-88) age group.
4. Positive linear correlation was observed between the angle of separation between alpha and beta activations in the sensor space and age.
5. Source localisation shows a decrease in activation for alpha band oscillations in the occipital cortex in old as compared to young. For beta frequency regime, increasing activity of occipital cortex and dorsal parietal cortex in younger adults as compared to older adults was observed.

4.1 Increase in Reaction time

A weak positive linear correlation was observed between reaction time and age (in years). Since the task used by Cam-CAN belonged to a simple reaction time (SRT) task where subjects perceive one stimulus and respond to the stimulus with a single button press **[Woods etal, 2015]**. Age-related changes are more prominently observed in the choice reaction time (CRT) task than in simple reaction time (SRT) task **[Dykiert, 2012]**.

The possible explanation behind the increase in reaction time as a function of age are a) older adults taking longer time to perceive the stimulus than younger adults or/and b) older adults taking longer time to respond via the button press as compared to younger adults.

We expected to observe an increase in reaction time though not in great magnitude as the Cam-CAN dataset used consist of healthy individuals from 18-88 years.

4.2 Slowing down of Alpha Oscillations

We observed a leftward shift in the alpha peak frequency across the age group (from young to old) which signifies the slowing down of alpha oscillations. Slowing of oscillatory activity is a prominent functional abnormality that has been reported in several EEG and MEG studies of Alzheimer's disease **[Berendse et al., 2000] [Huang et al., 2000]**. This shows that there exist a great overlap between the changes that occur in aging and neurodegenerative diseases. **[Ciryam et al., 2016]** have speculated that neurodegeneration is an accelerated aging.

A study done by **[W. Surwillo, 1961]** shows a significant correlation between the peak alpha frequency and the reaction time. Hence, one could explain the increasing linear correlation of reaction time with age can be linked to decreasing peak frequency of alpha from young to old.

The results from source level analysis shows the increasing activity of the occipital cortex in younger adults as compared to older adults. This is accompanied by increased activation in temporal region in alpha frequency regimes.

4.2 Increase in Beta band power

Beta oscillations are primarily observed in the sensorimotor cortex and linked with movement execution **[Baker et al., 1997]**. In our study we observed there is an increase in the beta band power across the age group in the sensorimotor task i.e., visual-audio cued button response.

At sensor level, there is activation in parietal cortex for sensorimotor task. The number of sensors activated for beta band in older adults is more than the younger adults. Literature shows that the increase in beta power is observed mainly because of increase in intra-cortical GABAergic inhibition **[Hall et al., 2011]**. **[Heinrichs-Graham et al., 2016]** explains this increase in the strength of beta oscillations within the motor cortex which helps in to perform normal motor performance.

A curve fitting analysis between the age and the raw beta band power shows a quadratic relationship.

A study conducted by **[Sowell et al., , 2003]** showed a significant nonlinear decline in gray matter density with age in frontal and parietal region. Gray matter density increases until age 30 and decline in later decades.

Hence, one can weave a connection between the quadratic trajectory obtained between raw beta power and age in our analysis with the non-linear decline in gray matter density of frontal and parietal cortex as a function of age. Reports have suggested that the decrease in gray matter density is resulted because of the age-related degenerative changes.

The results from the source level analysis shows increasing activity of occipital cortex and dorsal parietal cortex in younger adults as compared to older adults for beta frequency regimes. Asymmetric activation of beta frequency was observed in older adults as compared to younger adults.

4.3 Increase in Angular separation

Angular separation helps us to quantify the extend of overlap between the sensor topography of alpha and beta band oscillations. We observed a significant linear positive correlation for the angular separation between the alpha and beta sensor space and age, though the increase was not large. Hence, this suggests that there is more overlap of alpha and beta activated sensors in younger adults as compared to old adults.

In summary, we found age-related changes in alpha and beta oscillations in the sensorimotor task. The results obtained from source localisation shows the asymmetric activation for beta band frequency along with the increase in beta band power in older adults as compared to the younger adults. Older adults are unable to activate the same number of brain areas as done by younger adults which explains their higher reaction time in this sensorimotor task.

Hence, one can speculate the results with the reduced communication between the hemispheres as various studies have reported the age related structural changes **[Sowell et al., , 2003]** . Alpha frequency in occipital cortex which is associated with the

attention and the sensory perception. The reduced alpha activity of the occipital cortex in older adults as compared to younger adults shows the reduction in sensory processing. The temporal activation of alpha frequency in case of older adults shows the different source generator of alpha oscillations as a shift in alpha peak frequency was observed in our study. Similar results were also observed in resting state MEG data at source and sensor level. This shows that the age related changes are a global phenomena not task specific.

In conclusion, we establish age related changes for alpha and beta oscillations in the sensorimotor task along with certain compensatory mechanism adopted by older adults for the preservation of performance.

5. Bibliography

[Buzsáki and Draguhn, 2004] Neuronal Oscillations in Cortical Networks . *Science*

[Cabeza et al.,, 2008] Qué PASA? The Posterior-Anterior Shift in Aging. *Cerebral Cortex*, Volume 18

[Callum F. Ross et al.,, 2016] Primary motor and sensory cortical areas communicate via spatiotemporally coordinated networks at multiple frequencies. *PNAS*

[Destexhe and Senjnowski, 2003] Interactions Between Membrane Conductances Underlying Thalamocortical Slow-Wave Oscillations. *Physiol Rev*

[Deco and Kringelbach 2016] Metastability and coherence : extending the communication through coherence hypothesis using a whole-brain computational perspective. *Trends in neuroscience*

[Denise et al., ,2014] How Does it STAC Up? Revisiting the Scaffolding Theory of Aging and Cognition. *Neuropsychology Review*

[Dykiert, 2012] Age differences in intra-individual variability in simple and choice reaction time: Systematic review and meta-analysis. *PLoS ONE*

[Festini et al.,, 2018] Theoretical Perspectives on Age Differences in Brain Activation: HAROLD, PASA, CRUNCH—How Do They STAC Up? *Oxford Reserach Encylopedias*

[Gordon et al.,, 2013] Span, CRUNCH, and Beyond: Working Memory Capacity and the Aging Brain. *Journal of cognitive Neuroscience*

[Hall, S.D et al., ,2011] The role of GABAergic modulation in motor function related neuronal network activity.

[Hutt and et al.,, 2016] Dynamic Control of Synchronous Activity in Networks of Spiking Neurons. *Plos One*

[Heinrichs-Graham et al.,,2018]The lifespan trajectory of neural oscillatory activity in the motor system. *Dev Cogn Neurosci.*

[Irwin et al., , 2018] Healthy Aging and Dementia: Two Roads Diverging in Midlife? *Frontiers in aging neuroscience*

[Joshua O. Goh and Denise C. Park 2009] Neuroplasticity and cognitive aging: The scaffolding theory of aging and cognition. *Restorative Neurology and Neuroscience*

[Kolassa et al.,, 2014] Resting-state slow wave power, healthy aging and cognitive performance. *Scientific Reports volume 4, Article number: 510*

[Konar et al.,, 2016] Age-associated Cognitive Decline: Insights into Molecular Switches and Recovery Avenues. *Aging and Disease*

[Lopez et al., ,2013] Brain-wide slowing of spontaneous alpha rhythms in mild cognitive impairment. *Front Aging Neuroscience*

[Pfurtscheller et al., , 1999] Visually guided motor imagery activates sesnorimotor areas in humans. *Neuroscience Lett.*

[Osipova et al.,, 2005] Altered generation of spontaneous oscillations in Alzheimer's disease. *NeuroImage*

[Poe et al., , 2001] Age-related decline of presumptive inhibitory synapses in the sensorimotor cortex as revealed by the physical disector. *J Comp Neurol 2001*

[P.L. Nunez 2000] Toward a quantitative description of large-scale neocortical dynamic function and EEG. *Behavioural Brain Science*

[Proudfoot et al.,, 2014] Magnetoencephalography . *Practical Neurology*

[Pfurtscheller et al.,, 1996] Event-related synchronization (ERS) in the alpha band-an elctrophysiology correlate of cortical idling: a review. *International Journal of Psychophysioloy.*

[Pulvermüller and et al.,, 2014] Thinking in circuits: toward neurobiological explanation in cognitive neuroscience. *Biological Cybernetics*

[Sahoo et al., 2018] Lifespan driven reorganization of the global network dynamics unfold on a multifrequency landscape . *Biorxiv*

[Sowell et al., , 2003] Mapping cortical change across the human life span. *Nature Neuroscience*

[Shafto et al., 2014] The Cambridge Centre for Ageing and Neuroscience (CamCAN) study protocol: a cross-sectional, lifespan, multidisciplinary examination of healthy cognitive ageing. *BMC Neurology*

[Taylor et al., 2017] The Cambridge Centre for Ageing and Neuroscience (Cam-CAN) data repository: Structural and functional MRI, MEG, and cognitive data from a cross-sectional adult lifespan sample. *NeuroImage*

[Timothy et al.,, 2018] The lifespan trjectory of neural oscillatory activity in the motor system. *Developmental Cognitive Neuroscience*

[Tony Wyss-Coray 2016] aging, neurodegeneration and brain rejuvenation. *Nature*

[Voytek et al.,,2016] Brain Oscillations and the importance of waveform shape. *Trends in Cognitive Science*

[W. Klimesch , 1999] EEG alpha and theta oscillations reflect cognitive and memory performance: a review and analysis. *Brain research*

[W. Surwillo, 1961] Frequency of the alpha rhythm, reaction time and age. *Nature*

[Woods et al.,, 2015] Factors influencing the latency of simple reaction time. *Frontiers of Human Neuroscience*

[Yoshimura et al.,,2011] Differences in quantitative EEG between frontotemporal dementia and Alzheimer’s disease. *Clinical Neurophysiology*