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Effect of aging in cortical activity during sensory integration to balance posture

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Zusammenfassung

Einleitung

In der Europäischen Union (EU) ist ein stetiger Zuwachs der älteren Generation zu verzeichnen, wobei im Jahr 2017 19,5 % der Bevölkerung der EU mindestens 65 Jahre alt war. Prognosen zufolge wird dieser Anteil bis zum Jahr 2080 voraussichtlich auf 29,1 % ansteigen. Da mit dem Alterungsprozess nachweislich funktionale Beeinträchtigungen, die zu psychischen und physischen Behinderungen führen können, einhergehen, stellt dieser eine Herausforderung für die Gesellschaft dar. So verursacht der Alterungsprozess u.a. Einschränkungen der Gleichgewichtsfähigkeit, die eine wesentliche Ursache für Stürze darstellen. 30 bis 60 % dieser Altersgruppe stürzen einmal pro Jahr und etwa die Hälfte von ihnen sogar häufiger. Für 5 bis 10 % der Senioren resultieren aus diesen Stürzen ernsthafte körperliche Verletzungen und die Gefahr, dass die Stürze zum Tod führen können. Dementsprechend wird der Sturzprävention im öffentlichen Gesundheitswesen zunehmend Bedeutung beigemessen.

In bisherigen wissenschaftlichen Studien wurde die Problematik von Gleichgewichtsstörungen intensiv untersucht und eine Vielzahl von Maßnahmen angeregt, diese zu bewältigen. Dabei konnten die wissenschaftlichen Untersuchungen insbesondere zu dem Erkenntnisgewinn beitragen, dass körperliche und sportliche Aktivitäten die Gleichgewichtsfähigkeit in allen Altersklassen verbessern kann. Dennoch sind noch immer Forschungsdefizite vorhanden, die es zu beheben gilt.

Die vorgelegte Studie will im Sinne der Reduzierung dieser Defizite einen Beitrag leisten. Folgende Schwerpunkte wurden analysiert:

- der Einfluss des Alterns auf die Gleichgewichtsfähigkeit bei aktiven älteren Menschen,
- der Einfluss des Alterns auf die Leistungsfähigkeit der Sensorik mit Bezug auf die Aufrechterhaltung des Gleichgewichts,
- der Einfluss der kortikalen Umstrukturierung auf die Aufrechterhaltung des Gleichgewichts,
- die Wirkung der kortikalen Modulation auf die Leistungsfähigkeit der Sensorik zwecks Aufrechterhaltung des Gleichgewichts unter dem Einfluss des Alters.

Forschungsgrundlagen

Die Gleichgewichtsfähigkeit verschlechtert sich mit fortschreitendem Alter. Dieser Entwicklung kann mit körperlichen Aktivitäten, insbesondere dem sportlichen Üben, entgegengewirkt werden.

Um eine aufrechte Körperhaltung auch im Alter beizubehalten, nutzt der Körper Strategien, bei der die Fußgelenke und die Hüfte koordinativ zusammenwirken. Kann die Muskulatur der Fußgelenke die Gleichgewichtsschwankungen nicht ausgleichen, muss zusätzlich die Muskulatur der Hüftgelenke aktiviert werden, um das Gleichgewicht zu sichern. Gesunde jüngere Menschen nutzen zu 90 % eine Fußgelenk-Strategie. Sobald die Gleichgewichtsfähigkeit mit zunehmendem Alter nachlässt, wird vermehrt die Hüftgelenk-Strategie benutzt. Ältere Menschen sind daher verstärkt auf die Unterstützung der Hüftmuskeln zur Aufrechterhaltung des Gleichgewichts angewiesen. Im Vergleich mit der Fußgelenk-Strategie benötigen die dafür verantwortlichen Reflexbögen jedoch mehr Zeit, so dass oft ein Verlust des Gleichgewichts die Folge ist. Spezifisches Training kann jedoch auch im Alter dazu beitragen, die anspruchsvolle Fußgelenks-Strategie zu verbessern.

Bisher wurden keine Studien veröffentlicht, die die Gleichgewichtsfähigkeit sowie die Gleichgewichts-Strategien gesunder, körperlich aktiver Menschen unter Berücksichtigung des Alterungsprozesses untersucht haben.

Die Aufrechterhaltung des Gleichgewichts ist eine komplexe Fähigkeit, die die Aufnahme von Informationen aus den somatosensorischen, visuellen und den vestibulären Systemen voraussetzt. Diese Informationen werden vom Kortex und den unterhalb des Kortex liegenden nervalen Strukturen weiterverarbeitet, um eine erfolgreiche motorische Reaktion zur Aufrechterhaltung der Körperhaltung zu gewährleisten. Dabei ist der Einfluss der Reaktionsfähigkeit abhängig von der individuellen Lebensweise, beruflichen Anforderungen und der körperlichen Beanspruchung im Alltag. Zudem wird die bevorzugte Gleichgewichts-Strategie vom sensorischen Input während des Ausbalancierens der Körpergleichgewichts beeinflusst. In diesem Zusammenhang können junge Menschen ihr Gleichgewicht unter visuellen und somatosensorischen Einwirkungen besser als ältere Menschen ausbalancieren. Die Gleichgewichtsfähigkeit wird ab einem Alter von 50 Jahren verstärkt auf die visuellen und somatosensorischen Informationen reduziert. Der Anteil von sensorischen Informationen geht mit steigendem Alter insbesondere zurück.

Ein Faktor für die Abnahme der sensorischen (kinästhetischen) Leistungen bei Senioren sind strukturelle Veränderungen der Muskelspindeln. Dabei verringert sich zum einen die Dichte der innerhalb einer jeden Spindel gelegenen Fasern und zum anderen reduziert sich die Anzahl der außerhalb gelegenen Axone. Darüber hinaus verringert die Alterung auch die Sensitivität der Muskelspindeln sowie der Rezeptoren in den Gelenken zwecks Erfassung der Faserlänge sowie Gelenkposition. Zudem werden Mechanorezeptoren im Fuß während des Alterungsprozesses reduziert, wodurch sich die Druckempfindlichkeit verringert und die Schwingungswahrnehmung abnimmt. Diese Reduktion wirkt sich des Weiteren auf das somatosensorische System aus, wodurch die posturale Kontrolle für die älteren Menschen nachhaltig erschwert wird.

Weiterhin kommt es im Rahmen des Alterungsprozesses zum Nachlassen der Leistungen des vestibulären Systems. Das ist mit der Verringerung der Anzahl der Nervenfasern im Vestibulum begründet. Ab dem 40. Lebensjahr sinkt die Leistung alle 10 Jahre um etwa 3 %. In diesem Zusammenhang betrifft das auch die Funktion des Vestibulo-Okkularen-Reflexsystems (VOR). Es kommt verstärkt zum Verlust von Sinneszellen im Sacculus und Utriculus, die mit fortschreitendem Alter ebenfalls die Funktion der Gleichgewichtsfähigkeit einschränken.

Senioren erfahren des Weiteren infolge des Nachlassens der Sehschärfe einen Abbau der Kontrastempfindlichkeit, eine verschlechterte Wahrnehmung der räumlichen Tiefe bei der Beurteilung der Entfernung von Objekten sowie eine geringere Adaptation an den Wechsel der Lichtverhältnisse in der Umgebung. Diese Defizite tragen ebenfalls zum Abbau der Gleichgewichtsfähigkeit bei.

Die posturale Kontrolle des Gleichgewichts wird auf verschiedenen Ebenen des Zentralen Nervensystems (ZNS) organisiert. Das betrifft sowohl die bereits im Stammhirn integrierten Reflexsysteme als auch die auf höherer Ebene angelegten Leistungen des Kleinhirns und der Basalganglien sowie die auf höchster Ebene involvierten Strukturen des Kortex. In der vorliegenden Studie liegt der Schwerpunkt in der Analyse der am Gleichgewicht beteiligten kortikalen Strukturen, wie dem supplementär-motorischen Areal (SMA), den primärmotorischen und sensomotorischen Arealen sowie den präfrontalen Arealen, die an den kognitiven Prozessen beteiligt sind. Mit zunehmendem Alter baut das ZNS weiße Substanz ab. Daraus resultiert eine Verringerung der Rückmeldungskapazität sensorischer Informationen, woraufhin das Cerebellum die Integration der sensorischen Informationen reduziert. Diese Reduktion widerspiegelt sich auch im Rückgang der grauen Substanz. Um die

Rückbildung der Struktur aufzuhalten und die funktionalen Fähigkeiten zu erhalten, greift das neuromotorische System unterstützend ein. Der Rückbildungsprozess nimmt Einfluss auf die funktionalen Veränderungen und wird durch das neuromotorische System wieder ausgeglichen. Derselbe Prozess tritt auch mit Bezug auf den Gleichgewichtserhalt auf. Aus diesem Grund benötigen ältere Menschen mehr kortikale Ressourcen zur Aufrechterhaltung der Körperhaltung im Sinne eines Ausgleichs der Rückbildungstendenzen.

Aktuell ist dem Autor nur eine Studie bekannt, die den Einfluss der Alterung anhand der kortikalen Anforderungen an den Gleichgewichtserhalt untersuchte. In dieser Studie konnte nachgewiesen werden, dass sich die Gamma-Aktivität in dem sensomotorischen Areal des Kortex erhöht.

Der Einfluss des Alters auf die Gleichgewichtsfähigkeit und die damit im Zusammenhang stehenden Veränderungen der sensorische Organisation ist ein Schwerpunkt der vorliegenden Studie. Des Weiteren soll die Wirkung des Alterns auf die kortikale Aktivität anhand des sensorischen Inputs während der Aufrechterhaltung des Gleichgewichts älterer Personen untersucht werden.

Methoden

20 junge sportlich aktive Studierende mit einem Durchschnittsalter von 24,64 ± 2,47 Jahren sowie 20 sportlich aktive Senioren im Alter von durchschnittlich 68,45 ± 5,37 Jahren führten in der vorliegenden Studie den Sensorischen-Organisations-Test (SOT) durch. Dieser ist Bestandteil des sogenannten Balance Masters (NeuroCom® International, Inc. USA). Der Test generiert Daten zur statischen Gleichgewichtsfähigkeit, zum Effekt von sensorischen Integrationsleistungen auf das Gleichgewicht sowie zum Einfluss der somatosensorischen, visuellen und vestibulären Systeme auf die posturale Kontrolle. Während des Tests wurde ein 32 Kanäle umfassendes mobiles EEG mit einem 10/20-System genutzt, um die elektroenzephalographische (EEG) Aktivität der Probanden zu messen. Die Kopplung und Kompatibilität der beiden Messsysteme wurden im „Strukturbereich Sport und Technik-Bewegungswissenschaften“ des Bereichs „Sportwissenschaft“ der Otto-von-Guericke-Universität Magdeburg (Magdeburg, Deutschland) entwickelt.

Die Analyse der EEG-Daten erfolgte offline mit dem Gehirnstrom Analyzer, Version 2.1.2.327. Ein IIR-Filter, bei dem die untere Frequenzgrenze bei 0,5 Hz und die obere Frequenzgrenze bei 120 Hz liegt, wurde für die Auswertung der EEG-Daten angewandt. Die Independent-Component-Ocular-Correction (ICA) diente der Entfernung von Artefakten. Aus den Artefakt freien Daten konnte die spektrale Leistungsdichte berechnet werden; die Low-Resolution-

Brain-Electromagnetic-Tomography-Daten (LORETA) wurden exportiert, aus denen durch die Anwendung der LORETA Software die funktionale Lokalisation sowie die lineare Konnektivität im Delta-, Theta-, Alpha-, Beta- und Gamma-Frequenzband berechnet werden konnten.

Für die aus den Messdaten abgeleiteten statistischen Variablen erfolgte anschließend eine Überprüfung auf Normalverteilung. Zur Anwendung kam die Analysesoftware SPSS. Lagen normalverteilte Daten vor, kamen der unabhängige t-Test, die One-way ANOVA und die einseitige Maßkorrelation nach Pearson zum Einsatz. Wiesen die Variablen keine Normalverteilung auf, wurde der Mann-Whitney-U-Test, der Kruskal-Wallis-Test oder Spearman's einseitige Rangkorrelation als parameterfreie Verfahren angewendet. In Bezug auf die funktionale Lokalisation sowie die lineare verzögerte Konnektivität eignete sich die statistische Software Non-Parametric-Mapping (SnPM). Des Weiteren kamen auch hier die einseitige Maßkorrelation nach Pearson für normalverteilte Daten sowie die einseitige Rangkorrelation nach Spearman für nicht normalverteilte Daten zum Einsatz.

Ergebnisse

In der Zusammenfassung der Ergebnisse werden die statistisch signifikanten Parameter dargestellt.

Die älteren Probanden wiesen eine geringere posturale Kontrolle sowie einen geringeren Strategiewert im Vergleich zu den jüngeren Probanden auf. Zudem trat bei den älteren Probanden im Vergleich zu den jüngeren während der statischen Gleichgewichtsanforderung eine geringere Theta-Aktivität im Frontallappen in Erscheinung. Allerdings waren die Gamma-Aktivitäten im Temporallappen bei den älteren Probanden höher. Im Zentrallappen waren die Theta-Aktivitäten bei den älteren Probanden geringer und die Beta-Aktivitäten höher als bei den jüngeren Probanden. Im Parietallappen konnten bei den älteren Probanden geringere Delta- und Theta-Aktivitäten, dafür aber höhere Beta-Aktivitäten als bei den jüngeren Probanden nachgewiesen werden. Im Okzipitallappen waren geringere Delta- und Theta-Aktivitäten sowie höhere Beta- und Gamma-Aktivitäten bei den älteren im Vergleich zu den jüngeren Probanden zu verzeichnen.

Bei der Lokalisierung der kortikalen Aktivitäten ließ sich im präfrontalen Cortex eine geringere Theta- und Alpha-Aktivität bei den älteren Probanden feststellen. Die Gamma-Aktivität war hingegen höher im Vergleich zu den jüngeren Probanden. Zudem zeigte sich bei den älteren Probanden im Vergleich zu den jüngeren Probanden eine geringere Theta- und Alpha-Aktivität in dem primär somatosensorischen Kortex, eine geringere Theta- und

Alpha-Aktivität im prämotorischen Kortex sowie eine geringere Theta-Aktivität im posterioparietalen Kortex. Darüber hinaus konnte bei den älteren Probanden eine geringere Theta-Aktivität im primär visuellen Kortex als bei den jüngeren Probanden nachgewiesen werden.

Die Gruppe der Senioren erzielte zudem einen signifikant geringeren SOT-Wert im Vergleich zur Gruppe der Junioren. Weiterhin zeigte sich bei den Senioren eine weniger ausgeprägte Gleichgewichtsfähigkeit unter den visuellen und vestibulären Einflüssen im Vergleich mit der jüngeren Vergleichsgruppe. Während sich der Einfluss des somatosensorischen Anteils in der Delta-Aktivität prozentual verringerte, stieg demgegenüber der prozentuale Anteil der Gamma-Aktivität im Frontallappen. Bei der funktionalen Lokalisation verringerten sich die Delta-, Theta-, Beta- sowie Gamma-Aktivitäten. Dahingegen erhöhte sich die Alpha-Aktivität im Vergleich zur Baseline. Es gab bei den Senioren im Verhältnis zur Grundaktivität eine Zunahme der Alpha-Aktivität und generell keinen Rückgang in Bezug auf die anderen Aktivitäten. Zudem konnte gezeigt werden, dass bei den Senioren im Vergleich mit den jüngeren Probanden der prozentuale Anteil der Delta- und Theta-Aktivität im Frontallappen unter visuellem Einfluss rückläufig ist, wohingegen dort die Beta- und Gamma-Aktivitäten zunahmen. Ferner konnte in diesem Bereich kein signifikanter Unterschied hinsichtlich der funktionalen Lokalisation gefunden werden.

Darüber hinaus konnte aufgezeigt werden, dass bei den älteren Probanden im Vergleich zu den jüngeren Probanden im Frontal- sowie im Temporallappen eine geringere prozentuale Alpha-Aktivität und eine höhere Beta- und Gamma-Aktivität auftritt; außerdem im Zentral-, Parietal- und Okzipitallappen eine geringere Alpha- und eine höhere Gamma-Aktivität vorliegt. In der funktionalen Lokalisation reduzierten sich die Delta-, Beta- und Gamma-Aktivitäten, während sich im Vergleich zur Baseline die Alpha-Aktivität bei den jüngeren Probanden erhöhte. Die Senioren zeigten zudem eine Erhöhung der Alpha-Aktivität und eine Reduzierung der Beta-Aktivitäten in Relation zur Baseline. Des Weiteren gab es Zusammenhänge zwischen den einzelnen EEG-Frequenzen und dem Gleichgewicht.

Diskussion und Fazit

Diese Studie ist die erste wissenschaftliche Untersuchung, in der der Einfluss des Alterns auf die Gleichgewichtsfähigkeit detailliert untersucht wurde. Dabei zeigten die Senioren eine verringerte Gleichgewichtsleistung im Vergleich zu den jungen Probanden und waren abhängiger von der Hüft-Strategie. Die Senioren wiesen eine hohe kortikale Modulation auf. Dies äußerte sich darin, dass die Fähigkeiten zur Erkennung von Fehlern verringert waren, einhergehend mit weniger interner Weiterverarbeitung im Kortex. Daher nutzten die Senioren höhere Ebene des ZNS, um die Defizite zu kompensieren und die sensomotorischen Aufgaben von Temporal-, Zentral- und Occipitallappen im Zusammenwirken mit höheren kognitiven Funktionen zu bewältigen. Die vorliegende Studie basiert auf einer Elektroenzephalografie häufigkeitsbasierten Analyse, in der eine Vielzahl kontroverser Interpretationen berichtet werden. Zudem werden Korrelationen dargestellt. Auf diese Weise konnten positive und negative Häufigkeitskorrelationen im Hinblick auf die Gleichgewichtsfähigkeit gefunden werden, die bei der Interpretation der Ergebnisse halfen.

Zusammenfassend betrachtet zeigten die älteren Probanden in der funktionalen Lokalisation der kortikalen Aktivität verringerte Fähigkeiten zu Fehlererkennung im Vergleich zu den jungen Probanden mit Bezug auf den primären visuellen Kortex und dem posterior parietalen Kortex auf. Eine verminderte Fähigkeit zur Fehlererkennung konnte auch im primären sensorischen Kortex gezeigt werden, wobei die Senioren mehr Ressourcen als die Junioren im Sinne des Gleichgewichterhalts nutzten. Die supplementär-motorische Rinde und der primäre motorische Kortex - die auch mit den Basalganglien und dem Hippocampus verbunden sind - sind die höchsten nervalen Instanzen, um die Körperhaltung zu stabilisieren. Darüber hinaus konnten im präfrontalen Kortex der älteren Probanden geringere Aufmerksamkeits- und Fehlererkennungsfähigkeiten als bei den jungen Probanden festgestellt werden. Des Weiteren nutzen die Senioren mehr Ressourcen hinsichtlich des Arbeits- und Raumgedächtnisses sowie der Koordination und Aktionen der sensorischen Systeme.

Die jungen Probanden wiesen eine bessere sensorische Integration zum Erhalt des Gleichgewichts auf als die Senioren, wobei das somatosensorische System bei den jungen Probanden dominierte, während die älteren Probanden vom visuellen System abhängig waren. Darüber hinaus zeigten die älteren Probanden im Vergleich mit den jungen Probanden eine geringere Gleichgewichtsfähigkeit unter dem Einfluss des visuellen und vestibulären Systems auf.

Die Senioren nutzten weniger interne Weiterverarbeitung- und Aufmerksamkeitsstrategien im Frontallappen hinsichtlich der sensorischen Kompetenz zum Erhalt des Gleichgewichts als die Junioren. Bei der funktionalen Lokalisation der kortikalen Aktivität zeigten die jungen Probanden eine Verminderung hinsichtlich der Nutzung kortikaler Ressourcen. Allerdings nahm die Aufmerksamkeitsleistung zu, was durch die Steigerung in der Alpha-

Aktivität interpretiert werden kann. In der vorliegenden Studie wurde die Loreta-Technik (low resolution brain electromagnetic tomography) benutzt, die zuvor noch nie bei Untersuchungen der Gleichgewichtsfähigkeit zur Anwendung kam. Es konnten Aktivitäten in tiefer liegenden kortikalen Bereichen gefunden werden, die zuvor noch nicht mit Hilfe eines EEG´s erschlossen werden konnten.

Die älteren Probanden nutzten hohe Aufmerksamkeitsleistungen mit höherer kortikaler Modulation und sensomotorischer Integration im Frontallappen und Temporallappen unter vestibulärem Einfluss, um das Gleichgewicht zu halten und benutzten weniger Ressourcen im Zentrallappen und Parietallappen im Vergleich zu den jungen Probanden.

Die Ergebnisse der Studie verdeutlichen, dass der Alterungsprozess die Gleichgewichtsfähigkeit reduziert und einhergeht mit dem Rückgang der sensorischen Integrationsfähigkeiten. Ältere Probanden nutzen mehr kortikale Instanzen für die Gleichgewichtsregulation. Mit Bezug auf die jüngeren Probanden waren die höheren kortikalen Aktivitäten im Vergleich zur Baseline reduziert, weil sie weniger Informationen zu verarbeiten hatten. Sie regulierten das Gleichgewicht verstärkt mit Hilfe des unbedingten Reflexsystems.

Summa summarum reicht ein einseitiges körperliches Training ohne kognitive Beanspruchung nicht aus, um die Gleichgewichtsfähigkeit älterer Menschen zu verbessern. Daher wird empfohlen, dass das Training sowohl physische Herausforderungen, Komponenten der Bewegungskoordination sowie der Kognition beinhaltet. Die beste Intervention ist daher ein koordinativ anspruchsvolles Training, z.B. ein Tanztraining mit Musik, das hilfreich sein kann, um die Gleichgewichtsfähigkeit zu verbessern.

Abstract

Postural balance maintenance is a fundamental ability of human movements, achieved and maintained by a complex set of the sensory-motor control system. The sensory inputs from the somatosensory, visual and vestibular systems are integrated by the CNS to generate the motoric response required to balance the posture. Postural balance becomes very crucial in seniors. This study aims at identifying the impact of aging on postural balance, and the sensory integration involved in the postural balance, as well as the cortical response during static balance and sensory integration.

In this study, 20 young active students 24.64 ± 2.47 years of age and 20 active seniors 68.45 ± 5.37 years of age underwent a sensory organisation test (SOT) with Balance Master. Along with coupled 32-channel wireless MOVE EEG 10/20 system. An IIR filter with a low cut-off of 0.5 Hz and a high cut-off of 120 Hz, were applied to the EEG data. The independent component ocular correction was used to remove the artifacts. The power spectrum and functional localisation were analysed in the delta, theta, alpha, beta and gamma frequency bands.

The senior participants exhibited a decline in their ability to maintain postural balance $p < 0.001$ and balance strategies $p < 0.05$, together with decreased sensory integration abilities to balance the posture $p < 0.001$ when compared with the young participants. The senior participants also showed high-level cortical modulation, during postural balance. Delta and theta activities decreased, while alpha, beta and gamma activities increased under somatosensory visual and vestibular influence. Further, in functional localisation beta and gamma activities get reduced in young participants, and alpha activity was noted increased in senior participants.

The significant finding from this study was that the cortical response was higher during the static postural balance in the seniors when compared with the young participants. As the sensory information to balance the posture was isolated, the cortical activity was observed to further decrease in young participates about baseline. To improve the postural balance of seniors training comprises physical challenges, coordination and cognition is proposed, e.g. dance training with music, which can be helpful to improve the balance ability.

Keywords: Postural balance, Central nervous system, Aging, Sensory inputs, cortical modulation

Table of contents

List of abbreviations

Abbreviation	Description
± / SD	Standard deviation
ABF	Auditory biofeedback
ACC	Anterior cingulate gyrus
AP	Anterior-posterior
APAs	Anticipatory postural adjustments
AR	Augmented reality
BOS	Base of support
CBF	Cerebral blood flow
CCD	Charge coupled device
CDP	Computer Dynamic Posturograph
CL	Central Lobe
Cm	Centimetre
cm/s	Centimeter per second
CNS	Central nervous system
COG	Center of gravity
COM	Center of mass
COP	Center of pressure
CPG	Central pattern generators
DLPFC	Dorsolateral prefrontal cortices
DMN	Default mode network
DMN	Default mode network
DOF	Degree of freedom
DTI	Diffusion tensor imaging
DWI	Diffusion-weighted magnetic resonance imaging
EEG	Electroencephalography / Elektroenzephalographische
EMG	Electromyography
ERD	Event-related desynchronization
EROI	Region of interests of eLORETA
ES	Equilibrium score
EU	European Union / Europäischen Union
FEF	Frontal eye field
FFT	Fast Fourier Transform
FL	Frontal Lobe
FSR	Force-sensitive resistor
GTO	Golgi tendon organ
HARDI	High angular resolution diffusion imaging
Hz	Hertz
iAPF	Individual alpha peak frequency
ICA	Independent component analysis
IIR	Infinite impulse response
JPS	Joint position sense

LORETA	low-resolution brain electromagnetic tomography
m/s	Meter per second
MEG	Magnetoencephalography
ML	Medio-lateral
mm	Millimetre
MRCP	Movement-related cortical potentials
MRI	Magnetic resonance imaging
ms	Millisecond
mV	Millivolt
NI	National Instruments
NIRS	Functional near-infrared spectroscopy
OL	Occipital Lobe
oxyHb	Oxygenated haemoglobin
PC	Postural balance
PET	Position emission tomography
PL	Parietal Lobe
PSD	Power spectrum density
Q-Q plot	Quantile-Quantile plot
SMA	Supplementary motor area / supplementär-motorischen Areal
SMC	Sensorimotor cortices
SnPM	Statistical NonParametric Mapping
SOT	Sensory Organization Test / Sensorischen-Organisations-Test
SPL	Superior parietal lobule
SPSS	Statistical package for the social sciences
TL	Temporal Lobe
TMS	Transcranial magnetic stimulation
TSRS	Tactile stochastic resonance stimulus
VOR	Vestibulo-ocular reflex / Vestibulo-Okkularen-Reflexsystems
VR	virtual reality
VTC	Virtual time to contact
VTC	Virtual time to contact
ZNS	Zentralen Nervensystems
µV	Microvolt

List of tables

List of figures

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1 Introduction

The senior population is continuously growing day by day in the European Union (EU). In 2017, it was noted that 19.5 % of the population of the EU was above 65 years, and by 2080 it is predicted to rise to 29.1 % of the population (Eurostat Staff, 2017). In 2020, an estimated 20 % of the population in the western counties will be older than 70 years (Mills, Sadler, Peterson, & Pang, 2018). Aging poses a challenge to society because senior individuals experience functional decline and functional limitations which can lead to disability (Trombetti *et al.*, 2016). As the aging process causes a decline in the postural balance abilities, it is one of the significant cause for falls (Barbieri & Vitório, 2017; Horak, 2006; Sturnieks, George, & Lord, 2008; Morris, 2014; Rubenstein, 2002, 2006).

Fall prevention is one of the challenges facing the senior population, which leads to injuries (Lamb, Jørstad-Stein, Hauer, & Becker, 2005; Stewart Williams *et al.*, 2015). In fact, 30 to 60 % of seniors fall once a year, and nearly half of them experience it more than one time. Due to this 5 to 10 % of the seniors face serious injury problems (Rubenstein, 2002). Besides injuries, it has also been reported as the cause of death (Paul, 2018; Rubenstein, 2002). To support the short-term and long-term health care costs related to falls, approximately 30 billion dollars per year is spent only in the USA (Stevens, Corso, Finkelstein, & Miller, 2006), while it is 1.8 billion euro in the European Union for fall-related injuries related to benzodiazepine in the year 2000 (Panneman, Goettsch, Kramarz, & Herings, 2003).

Fall prevention has thus become a public health crisis (Mills *et al.*, 2018) which is the reason for investigating the effect of aging on postural balance from a different angle. The aging process affects the postural balance system, and the sensorimotor, cognitive and psychological aspects together contribute to increasing the risk of fall in the senior population. The relationship of these factors affects postural balance as aging progresses (Laurence & Michel, 2017). Postural balance is a complex skill achieved by receiving sensory information from the somatosensory, visual and vestibular systems and is processed by the cortex, to generate the motoric response to stabilise the posture (Horak, 2006; Pollock, Durward, Rowe, & Paul, 2000). The sensory inputs from the sensory systems too must be integrated to interpret the complex sensory environment. As individuals keep changing their sensory surroundings, they need to reassess their corresponding reliance on each sense accordingly. In a normal environment under stable conditions with a firm Base of support (BOS), the reliance of healthy persons on the somatosensory inputs is up to 70%, while dependence on vestibular is 20% and on visual it is 10% (Horak, 2006; Peterka, 2002). On the contrary, when some unstable base of support is encountered, their reliance increases on the vestibular (60%) and visual information (30%) and decreases on the somatosensory (10%) inputs (Horak, 2006). However, the three sensory systems together help in the maintenance of the balance of an individual. According to some theories by a few researchers, it is the visual system that is primarily used by the young adults in their 20s and 30s to control the balance. However, they also use some of the control strategies which could work effectively, even in the absence of vision in the maintenance of balance. Particularly, in cases when either the visual or vestibular system is not fully working, then the somatosensory system frequently takes over the control of maintaining the balance (Grace Gaerlan, Alpert, Cross, Louis, & Kowalski, 2012).

The somatosensory system including the muscle spindles, Golgi tendon organs, and joint and skin receptors supply the information regarding the movement and position of the body in relation to its segments (Proske & Gandevia, 2012; Spooner, Wiesman, Proskovec, Heinrichs-Graham, & Wilson, 2018). The visual system provides information about the surrounding environment, as well as the position and motion of the head to stabilise. (Horak, 2006; Woollacott, Shumway-Cook, & Nashner, 1986). The vestibular system provides the information in relation to gravity regarding the position of the head and the forces of inertia concerning the postural balance (Angelaki & Cullen, 2008; Pozzo, Levik, & Berthoz, 1995).

Nerve fibres transmit the sensory information to the brain through the central nervous system (CNS) to induce the modified motoric response (Martini, Timmons, & Tallitsch, 2014). The subcortical areas generate the response modified by the cortex (Jacobs, Lou, Kraakevik, & Horak, 2009). The cortex, especially the pre-motor cortex and primary motor cortex, plays a vital role in postural balance (Jacobs & Horak, 2007; Weerdesteyn, Nienhuis, Hampsink, & Duysens, 2004). The modified motoric response generated by the muscles balances the posture and transmits the new information together with the sensory system to the CNS (Kingma, 2016).

The decline in postural balance in the elderly is not caused by a single component (Horak, 2006). The aging process decreases the muscle spindles along with the sensitivity, including a sense of consciousness from the knee, ankle, and toe, which affect the somatosensory information (Shaffer & Harrison, 2007). Visual information gets reduced because of the decrease in the acuity, contrast sensitivity, depth perception and adaptation to the new environment (Lord & Dayhew, 2001; Lord & Menz, 2000) and induces a drop in the amplitude of the vestibular reflexes and the loss of the sensors induces a decrease in the vestibular information for postural balance (Zalewski, 2015).

The CNS declines with the aging process because the nerve fibres and white matter (Sturnieks *et al.*, 2008a; Sullivan, Deshmukh, Desmond, Lim, & Pfefferbaum, 2000) are reduced, and therefore the feedback response from the sensory input gets reduced (Cabeza, Nyberg, & Park, 2016; Shaffer & Harrison, 2007). The cerebellum alters the integration of the sensory information and the cortical response also gets changed due to a decline in the grey matter (Sturnieks et al., 2008; Sullivan *et al.*, 2000).

The motor system also deteriorates due to aging, including the motor units, precision (Enoka *et al.*, 2003), muscle fibers, strength stiffness and force transmission (Roy, Steyer, Gargesha, Stone, & Wilson, 2012). The postural balance showed a decline under each batch of sensory information, viz., somatosensory, visual, vestibular condition in the elderly compared to that in the young people (Cohen, Heaten, & Congdon, 1996; Peterka & Black, 1990).

As highlighted above, the postural balance and the influence of the sensory system, the CNS and motor system, as well as the effects of aging on it were intensely investigated. To cope with the postural balance problem, a number of intervention plans were proposed and adopted. It was determined by the fact that physical activity and sports improve the postural balance abilities in all age groups. However, several questions still require answers to understand the mechanism of postural balance and the way aging affects it.

While considering the research gap and attempting to understand the effect of aging on the active elderly, the current study aims at identifying the following.

- The effect of aging on the postural balance in active seniors.
- The effect of sensory integration on the postural balance with aging.
- The effect of cortical modulation during postural balance.
- The cortical modulation during sensory integration in postural balance and the effect of aging on it.

2 Theoretical background

Human beings are bipeds who move on the ground. The basic activities of humans include walking, during which one foot is always in contact with the ground, running when no feet are in contact with the ground and standing when both feet are planted on the ground. The standing state poses a challenge for our balance control or postural balance system (Winter, 1995). It is the fundamental need for human beings, as it is necessary to meet the activities of daily life under various environmental conditions. Daily tasks like standing, walking, running, cycling, etc., seem to be quite simple and require a normal capacity for balance. Therefore, we can maintain our posture quite upright without requiring much attention (Pollock *et al.*, 2000).

Postural balance involves the ability to maintain appropriate alignment between the body segments. It preserves an appropriate relationship between the body and environment and establishes a vertical orientation in order to counteract gravity and is a reference frame for perception and action concerning the external world (McCollum & Leen, 1989).

Postural control involves three functions: the first is maintaining the alignment of the body segments in different positions like supine, prone, sitting, quadruped, and standing. The second is that posture can work to anticipate the changes of the body to perform voluntary, targeted movements while reaching or stepping, which the body can make before, during and after specific movements. The third function is to react against unexpected perturbations or disturbances in balance, which need quick adaptation; therefore, postural balance not only includes maintaining the body in the standing or active condition but can be defined as the ability to maintain the existing postural position or move from one position to another. The primary objective of postural balance is to keep the posture of the head and trunk stable against gravity (Cech & Martin, 2011, Forssberg, 1999). The phenomena of ‘balance,’ ‘equilibrium’ and ‘postural control (PC)’ are synonyms for the same concept (Thakkar & E, 2015).

> *The term balance is commonly used for the stability and postural balance* (Pollock, Durward, Rowe, & Paul, 2000)*. It is also defined as “the ability to control the body’s position in space for stability and orientation”* (Sulivan & Schmitz, 2008, P. 242)*. The ability to maintain equilibrium in a gravitational field by keeping or returning the centre of body mass over its base of support; thus preventing the human body from falling or losing balance by controlling the dual purposes*

of stability and orientation (Horak, 1987) is also one definition of balance.

Mechanically, balance is defined as the condition of the object when the resultant load on the object is zero (Newton’s First Law) (Bell, 1998) and in the static state it is associated with the position of the centre of mass or centre of gravity (COG), (Kreighbaum & Barthels, 1996). In consideration of Newton’s First Law, we use the term “**Postural balance**” to indicate the balance of the posture.

Postural balance abilities can be measured with postural sway in a standstill position by quantifying the changes in the centre of pressure (COP) in the anteroposterior or mediolateral directions. Hence, the anteroposterior balance is under the control of ankle strategy and the mediolateral balance stance is under the control of hip strategy (Winter, Prince, Frank, Powell, & Zabjek, 1996). Furthermore, if there are significant changes in the COP in the case of perturbations like vibrations or muscle fatigue at the hip and ankle levels, it ultimately results in postural instability (Vuillerme, Danion, Forestier, & Nougier, 2002).

McColluma (1985) developed a scheme, in which he showed posture could be kept in balance in the sagittal plane by using either the hip or ankle strategy separately or combined, depending on the response of the nervous system to maintain a stable posture. If the body reacts like a single rigid rod, the ankle repositions the body using torque like an inverse pendulum. The combined strategy of the hip and ankle will be involved in the motion to make the body stable if the body acts in two segments of an inverted pendulum. In another case, the hip strategy also gets involved when the ankle is unable to handle the motion of the whole body.

It has been proposed that human bodies act like an inverted pendulum during a reasonable stance, with their ankle responses being adequate to counteract the small perturbations (Vuillerme *et al.*, 2002). Therefore, in the case of small perturbations and also a still stance, the ankle strategy is applied to control this inverted pendulum using the action of the ankle muscles. However, when the perturbations are quick and sufficiently large that the ankle muscles are unable to control the balance, then the hip strategy is applied by the action of the muscles around the hip joint, thus moving the COG accordingly, in the forward or backward direction (Winter, 1995).

Postural balance is, in fact, a complex motor skill attained by the interaction of multiple sensorimotor processes working together with the essential skill to accomplish the activities of daily life (Sturnieks *et al.*, 2008; Pollock *et al.*, 2000). There are three major stages which stabilise postural balance.

1. **Sensation**, which gives the information regarding the position and displacement from the visual, somatosensory and vestibular systems.
2. **Processing**, which processes the information and selects the action after sensory information.
3. **The motor process**, which responds to the stable postural balance to re-stabilise the posture (Redfern, Jennings, Martin, & Furman, 2001; Schmidt, 1975).

Postural stability has been categorised into four types according to the function to stabilise the posture (Cech & Martin, 2011).

I. Static postural balance

Static postural balance is considered the basic standing condition which maintains any specific condition within the limits of stability about the base of support (BOS). In this condition, all the forces act equally to keep the centre of the mass (COM) within the limits of BOS. In some cases, a movement occurs, especially in humans, because they cannot be rigid like an element or robots; thus, this condition is called the steady state of static postural balance, in which even if the movement were to occur, the body remains within the range of the limit of stability. This is also termed as static postural balance.

II. Reactive balance

Reactive postural balance is the condition when the subject faces some unexpected situation, which causes him to control the COM within or outside of the BOS. This response could result from the speed of displacement, which produces weight shifting in the limit of the BOS if the centre of mass moves out of the BOS which required the postural adjustment.

III. Anticipatory postural balance

Anticipatory postural balance occurs just prior to the movement occurring to adjust the postural balance, like lifting and stepping. In this condition, the nervous system already conveys the information to the muscles regarding the future activities, and the muscles respond accordingly to make the body stable.

IV. Adaptive postural balance

Adaptive postural balance is used to describe when the body needs to adjust the postural balance system according to the environment and demands of the task, like walking in the snow. In this case, the body changes its motor response, such as a change in the stride length and walking speed. This type of postural balance requires more cognitive abilities like attention.

The abilities to balance posture develop with the passage of time from childhood to old age. The ontogenetic model for balance development has been defined based on two functional principles (Assaiante & Amblard, 1995).

1. The stable reference to maintain balance in light of the support which it considers the static condition when the subjects are not moving and remain on the base of support and gravity (Gurfinkel, Lipshits, Mori, & Popov, 1981).
2. The mastery of the degree of freedom based on body composition as children commences to control their movements in various degrees together with dynamic balance situations (Bernstein, 1967).

Assaiante and Amblard (1995) proposed four stages of the postural balance model during lifespan from earlier research. The development of postural balance from birth to gain the ability of upright standing starts from the head to the toe with the ability to control the remaining body segments, which are involved in unperturbed postural balance and related to the development of head and trunk control. In the second stage when children acquire the ability to stand upright up to the age of 6 years, the postural balance abilities develop in the ascending direction, in the body. In the third stage from age seven years onwards, again the postural balance abilities improve from the head to the feet. In the last or adulthood stage, the ability of selectivity develops, so that adults can maintain good postures according to the tasks they are faced with.

Postural balance is one of the basic skills which starts to develop from early childhood, and it is organised at two different levels. The first level explains the anatomical relationships, the concept of the support and body scheme including the head and trunk and sensory receptors, which represent posture as a reference to gravity. It also signifies the body structure which includes body geometry and kinetics. The second level contributes towards executing different postural tasks in relation to getting information from the different body segments, which make a representation level by sensory information. The postural networks make an effort to adjust the anticipatory and voluntary movements by one or several segments of the body, to stabilise the posture (Fig. 1) (Massion, 1994).

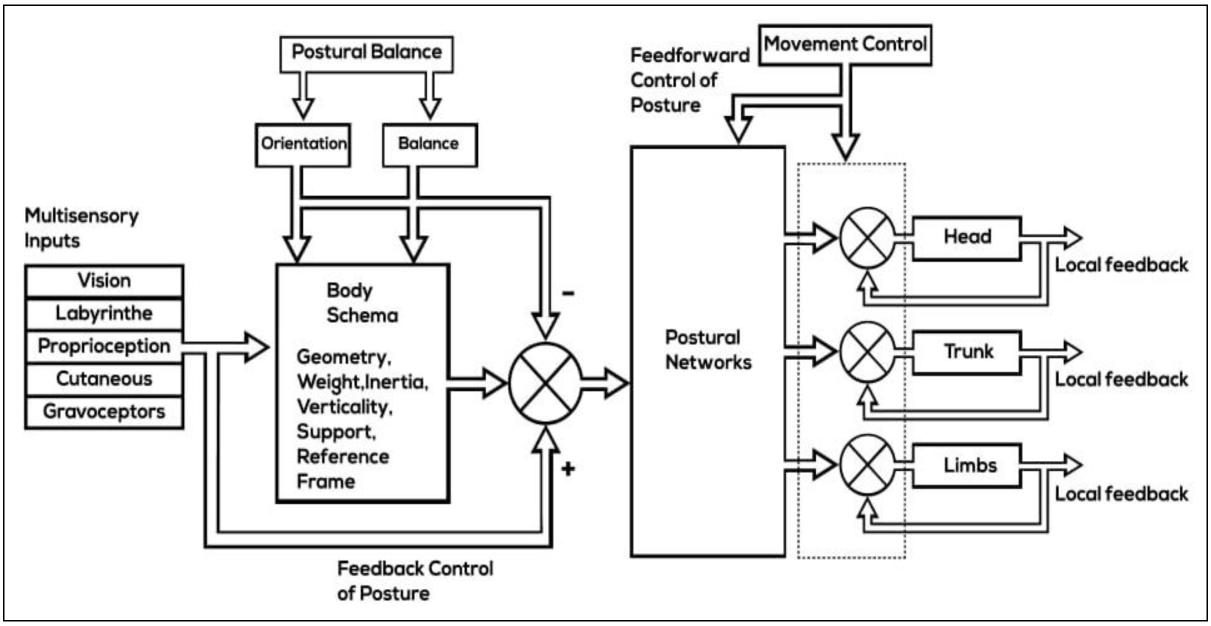


Fig. 1. Representation of the two levels of the postural organisation, the body scheme and the postural networks (Massion, 1994, p. 878)

Postural balance is not a stand-alone system. It is dependent on the task, ability of the individual and environment in which person is balancing the posture. It is a complex skill which needs different components to accomplish its function, like the musculoskeletal system, internal representations, adaptive mechanisms, anticipatory mechanisms, sensory strategies, individual sensory systems and neuromuscular synergies. The basic component of postural balance is the sensory input from the different sensory systems, which when processed in the CNS, leads to inducing reactions in the components mentioned above to balance the posture (Shumway-Cook & Woollacott, 2017).

Three basic sensory systems are specifically responsible for good postural balance. They help to determine how well a person can perceive the information from the surroundings and how to respond accordingly. Balance is achieved and maintained by a complex set of sensorimotor control systems involving sensory inputs from the proprioceptive, visual and vestibular systems. From these sensory sources, the information required is sent to the brain via the sensory receptors as nerve impulses (Riemann & Lephart, 2002b). Within the CNS, all these data are sorted out and passed through a process of integration through the cerebellum and cerebral cortex. The cerebellum is responsible for coordinating certain movements and regulates those movements that have been learned through repetitive exposure to certain specific kinds of motions. This sensory integration in the CNS helps in transmitting the motor impulses to the muscles that will finally control the movements of the body parts involved in maintaining the balance (Peterka, 2002). Coelho *et al.* (2017) elaborated on the postural balance set of systems and showed that the somatosensory (proprioception), visual and vestibular systems give information about the postural balance to the CNS, and the cortex processes the information flow and generates the motoric response to stabilise the posture. The complete postural balance loop is shown in Fig. 2 except for the thalamus, due to its location in the cortex.

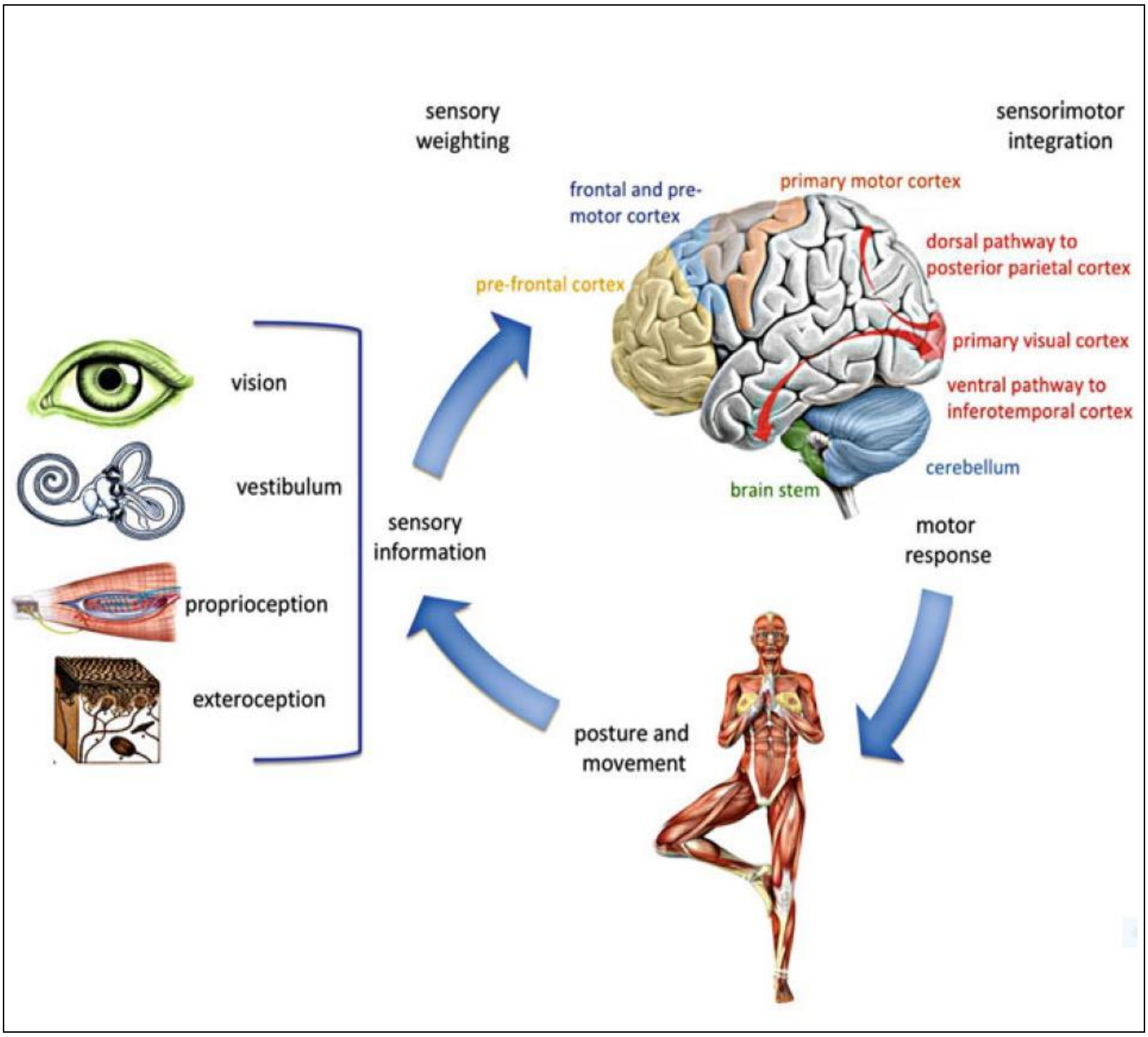


Fig. 2. Postural balance loop (Coelho *et al.*, 2017, p. 241)

2.1 *Sensory system*

The postural balance based on the somatosensory (proprioception and exteroception) visual and vestibular sensory information (Riemann & Lephart, 2002; Peterka, 2002; Coelho *et al.*, 2017).

2.1.1 Somatosensory

Somatosensation is a globalised term which encompasses the thermo-receptors, mechanoreceptors and pain receptors emerging from the peripheries of the body (Hall & Guyton, 2006). Consequently, the perception of the sensations of temperature, touch, tactile and proprioception are achieved by this conscious awareness of the somatosensory system (Riemann & Lephart, 2002). In this system, proprioception is responsible for conveying all the afferent information drawn from the proprioceptors which contain specially adapted receptors for detecting changes that occur within the body (Levine, 2007).

Proprioception has been generally defined as an afferent input of joint sense position or movement (Emery, 2003). However, according to some sources, this definition has been widely and incorrectly used as a synonym for somatosensation, joint position sense, balance and stability (Riemann & Lephart, 2002a). However, if the definition of proprioception is considered in a broad sense, then it can be simply termed as a neuromuscular to postural balance. (Emery, 2003). In order to safely achieve most of the activities of daily living and maintain a normal stable body stance, an individual is predominantly dependent on the proprioceptive inputs. In the case of the lack of vision, the somatosensory system then acts as the primary source of sensory information to maintain upright balance or move about in dark places (Swank, 1996). This system is not situated on the specific location but its spread all over the body, which includes the muscle spindles, Golgi tendon organs, and joint and skin receptors (Proske & Gandevia, 2012).

2.1.1.1 Muscle spindle

The muscle spindles are crucial in proprioception. First, the mechanoreceptors present in the muscles, ligaments, capsules, and tendons, detect changes in the muscle lengths and then send this information to the CNS, which later helps in distinguishing the joint position sense (JPS) and joint movements (kinesthesia) (Shaffer & Harrison, 2007). The afferent fibres from the muscle spindles enter into the CNS where its branches could take many different paths. For instance, one of these paths leads to the direct stimulation of the motor neurons that go back to the muscle which was stretched, thus making a reflex arc termed a ‘stretch reflex’. This stretch reflex in return triggers an immediate contraction of the muscle that had previously been stretched (Guskiewicz & Perrin, 1996). The muscle spindles also assist in the transformation of the stimuli from afferent inputs into suitable voluntary or reflexive movements (Grace Gaerlan *et al.*, 2012).

The sensory information from the muscle spindles comes from two primary sources. The first, ‘primary endings’, are located within the non-contractile central portion of the muscle spindles and are connected to CNS by ‘type Ia afferent neurons’. ‘Secondary endings’, or the second source, are located on the contractile end portions of the spindles and connected to the CNS by the ‘type II afferent neurons’. Primary endings respond to stretch; the type Ia afferent neurons send impulses back to the CNS, when the whole muscle is stretched or when a contraction of the ends of the intrafusal fibres (controlled by the gamma motor system) are not matched by an equal shortening of the extrafusal fibres (under the control of the alpha motor system) (Proske & Gandevia, 2012), as shown in Fig. 3.

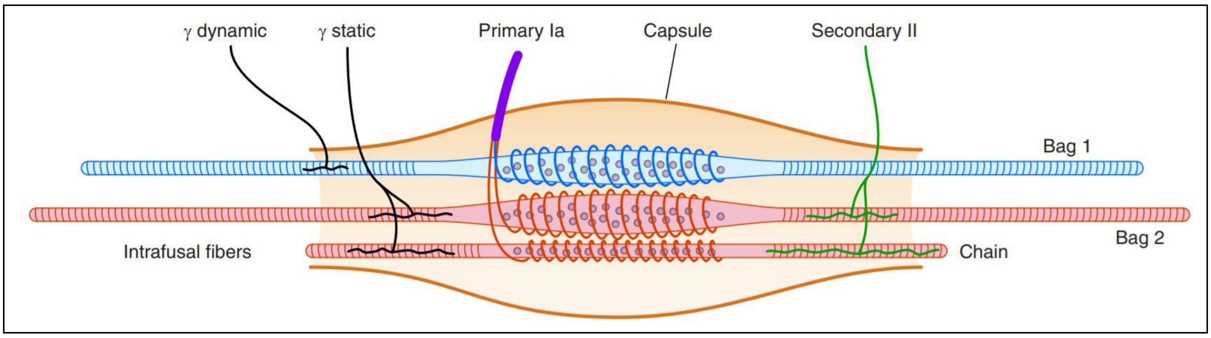


Fig. 3. Three bags of muscle spindles with a chain of nuclear fibres with primary and secondary endings (Proske & Gandevia, 2012, p. 1654)

2.1.1.2 Golgi tendon organ

The Golgi tendon organ (GTO), another component of the somatosensory system, assists in the proprioception of information. Present in the musculotendinous junction it detects the tensile forces in the muscles. Being highly sensitive even to the slight changes it, therefore, sends the CNS quick and instantaneous information regarding the tension levels in each segment of the muscles (Shaffer & Harrison, 2007). As the muscle gets into tension, the GTO is activated, and the afferent neurons synapsing with the interneurons in the spinal cord stimulate the interneurons, which in turn inhibit the alpha motor neurons, reducing the tension in the muscles and tendons (Grace Gaerlan *et al.*, 2012).

This scattered location of the GTOs within the locomotory muscles like the gastrocnemius, soleus, quadriceps etc., helps in coordinating the stability during movement. Thus, if one muscle group is inhibited, the other muscle group is simultaneously stimulated. Therefore, while walking, in the swing phase of one leg, the flexor muscles are stimulated, and on the contrary, the flexors of the other leg are inhibited in order to support the weight of the body on the ground. These combined afferent inputs ultimately produce a rhythmic locomotion pattern and enable postural stability (Grey, Nielsen, Mazzaro, & Sinkjaer, 2007).

One of the most probable stimuli of the myotatic stretch reflex is the ankle rotation and after any movement change or perturbation in the erect posture of an individual, this ankle rotation is considered the first important phase of activity in the leg muscles, in order to compensate for the postural sway (Dietz, Horstmann, & Berger, 1989). Muscle spindles sense a stretching of the agonist, and thus send the information along with its afferent fibres to the spinal cord. There the information is transferred to the alpha and gamma motor neurons which convey that information back to the muscle fibres and muscle spindle, respectively, and contract the muscle to prevent or control any additional postural sway (Dietz *et al.*, 1989). The GTO structure with the information transmitted to the spinal cord is shown in Fig. 4.

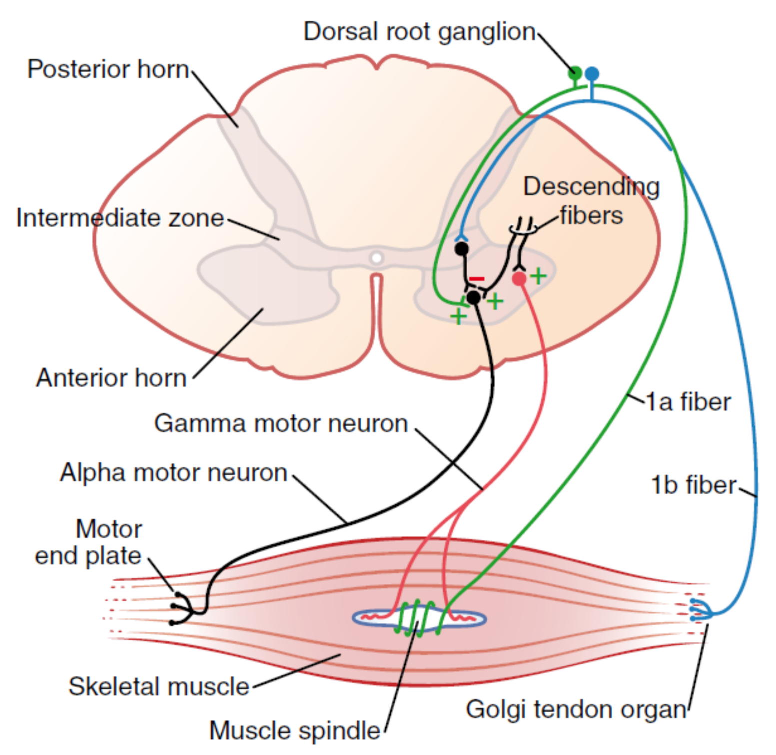


Fig. 4. The circuit of the sensory neurons from the GTO to respond to the motor activity joint receptors (Hall, 2012, p. 656)

2.1.1.3 Joint receptors

Another group of proprioceptors, usually present in the joints, are called articular receptors. Similar to the GTO, they too are sensitive to changes in the tension forces but in the joint capsules. Thus, as the intensity of the muscle force is increased, a corresponding rise is evident in the joint capsule tension, resulting in the activation of the articular receptor, and consequently, the afferent information about the joint position is sent. These receptors are considered more suitable for the detection of those joints which are potentially damaged, inflamed or possess a higher tension in their capsules and ligaments (Latash, 2008).

Three types of joint receptors are found in the tissues surrounding a joint. The first, the ‘modified Ruffini corpuscles’ are situated in the joint capsule, while the second, the ‘modified Pacinian corpuscles’ are located in the joint capsule and the third, the ‘Golgi organs’ are present in the ligaments. However, debate continues over their exact function as sensory receptors, although they appear to signal extreme range of movements at the joints (Abernethy, 2013).

2.1.1.4 Skin receptors

Sensory information from light touch is received from multiple sources, viz., Meissner’s corpuscles, Merkel’s discs, free nerve endings, Ruffini corpuscles, and nerve endings around the hair follicles. Sensory information from deep compression and high-frequency vibration is received from the Pacinian corpuscles present deeper in the skin within the subcutaneous tissue. The different skin sensory receptors are not uniformly distributed around the body. Regions specialising in fine movements like the fingertips are more densely populated with receptors compared with gross movements. Cutaneous sensitivity varies in relation to the number of receptors per unit area. Overall, the skin receptors play an essential role in movement control (Abernethy, 2013). The anatomical structures of the skin receptors are shown in Fig. 5.

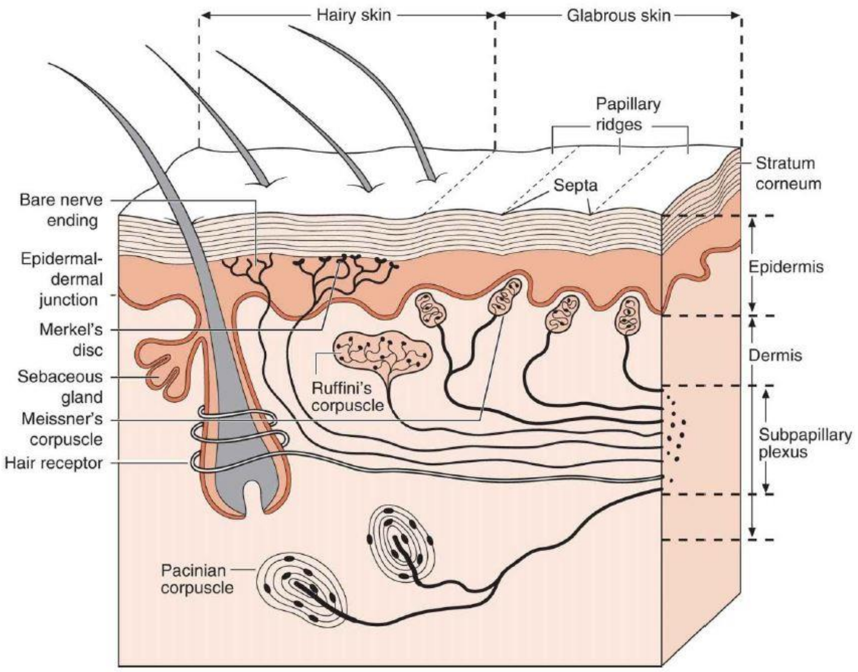


Fig. 5. The anatomical structures of the skin receptors (A. Shumway-Cook & H. Woollacott, 2017, p. 167)

Cutaneous receptors are the mechanoreceptors present in the skin which play a significant role in controlling human movements (Latash, 2008). According to some researchers, these receptors are not considered typical proprioceptors. However, the information these receptors convey is very helpful in the enhancement of the JPS and movement (Lundy-Ekman, 2013). For instance, the receptors on the plantar surface of the foot transmit the afferent information about the position and pressure forces during the weight-bearing activities (Shaffer & Harrison, 2007).

2.1.1.5 Somatosensory information track

There are three tracts through which information from the body is transmitted to the CNS (Martini *et al.*, 2014). 1) **Posterior columns tract** provides information regarding fine touch, vibration, pressure, and proprioception to the alternative side of the cortex by passing the information across from the medulla. 2) **Spinothalamic tract** conveys information on crude touch, pressure, and proprioception to the alternative side of the cortex via the spinal cord, but the information while being transmitted crosses towards the cortex at the entry point in the spinal cord.

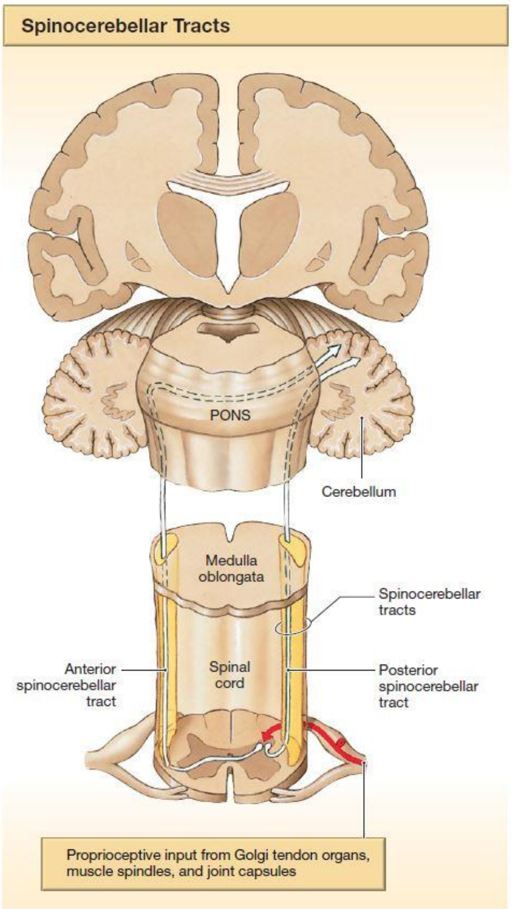


Fig. 6. Spinocerebellar Sensory Tract (Martini *et al.*, 2014, p. 397)

3) **Spinocerebellar Sensory** tract transfers the information of the proprioceptive input from the Golgi tendon organs, muscle spindles, and joint capsules to the cerebellum. It starts with the spinal cord and ends in the cerebellum. The spinocerebellar sensory tract is seen in Fig. 6 (Martini *et al.*, 2014).

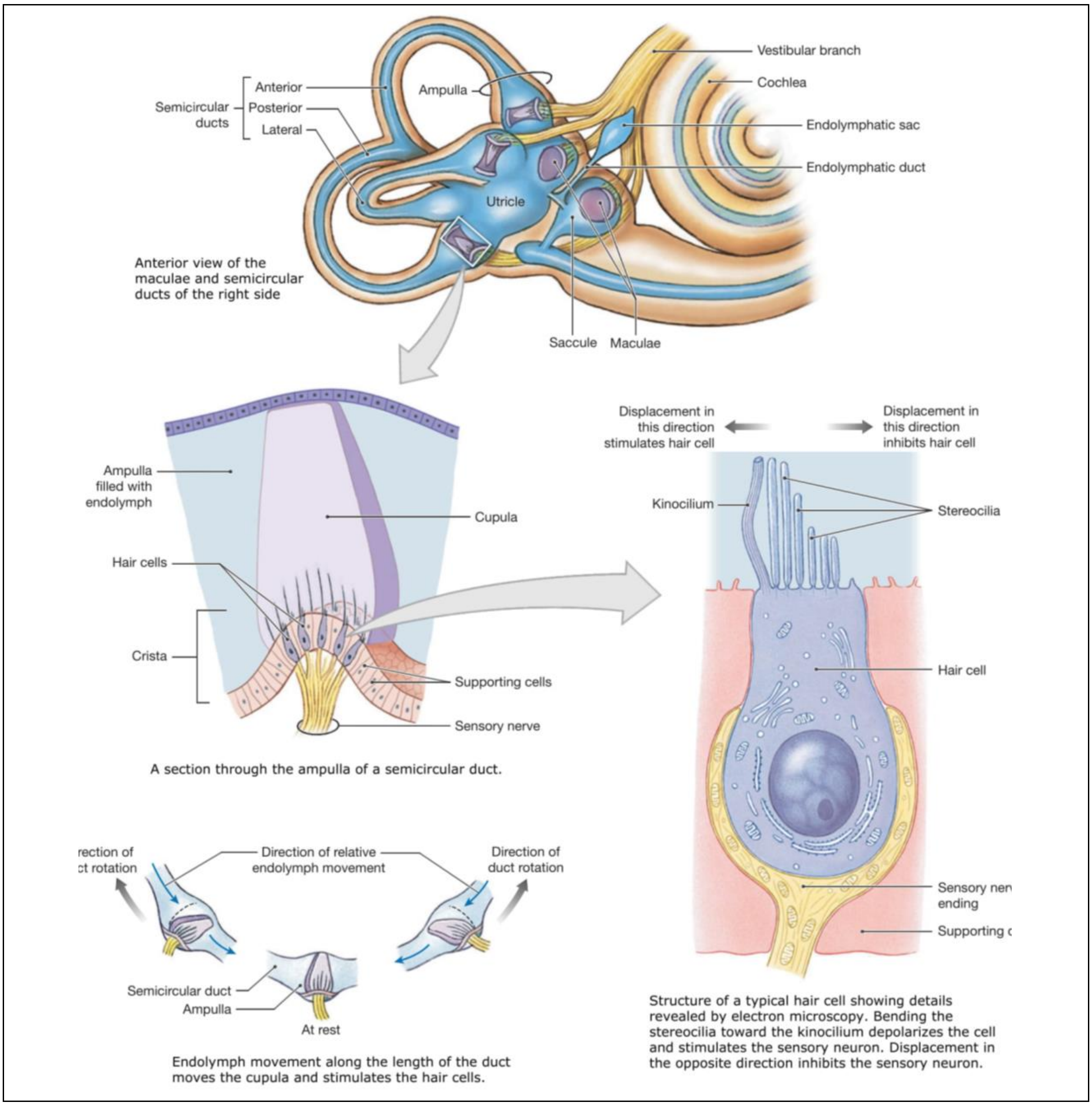
2.1.2 Vestibular system

The vestibular system is a natural motion sensing system located in the inner ear of humans (Hall & Guyton, 2006). It has been established as one of the prime motion sensors responsible for postural balance. Therefore, for the balance control and gaze stabilisation, this system detects the head rotation and body acceleration and subsequently sends the afferent inputs to the CNS and peripheral nervous system (Zeng & Zhao, 2011).

The human ear is distinguishable into three parts: the external ear, middle ear, and inner ear. The inner ear contains a spiral-shaped cochlea, which contains the receptor to give the feedback about the body balance; within the central egg-shaped cavity is the vestibule, which contains the membranous saccule and utricle, in which are present the utricle hair cells, otherwise termed sensory receptors. It is covered by the macula, covered with otoliths. When the head moves the macula also moves and transmits the information of the position with respect to gravity. Behind the vestibule, semicircular canals are present. Their function is to detect motion in three dimensions. Each canal contains a semicircular duct, where angular momentum is set, and at the base of each duct is an enlargement, called the ampulla. Within the ampulla, long stereocilia of hair cells are present in the cupula, which stick in the endolymph. When the head moves, the endolymph moves the cupula, which stimulates the stereocilia, and thus information about the position is conveyed. Fig. 7. (Martini *et al.*, 2014).

An extensive investigation of the physiological features of the sensors showed that the semicircular canals are responsible for sensing rotational or angular movements, while the utricle and saccule normally sense the linear or translational movements (Nashner, 1971).

In the case of sensing three-dimensional movements, each ear contains three semicircular canals, aligned perpendicular to each other and are termed the anterior, horizontal and posterior semicircular canals. These canals are arranged in such a specific pattern that the canals located in one ear have parallel counterparts situated in the other one. Therefore, if one of them in one ear is stimulated, then the corresponding counterpart of that canal in the other ear is simultaneously inhibited. This trend of information relay enables the individual to differentiate the direction of the angular movements. This push-pull fashion allows human beings to differentiate between the direction of the rotational movements. These semicircular canals also play a vital role in controlling the vestibulo-ocular reflex (VOR), which is responsible for stabilising the images on the retina of the eye during head movements. As the VOR receives afferent information in response to the head rotation, it causes the eye movement in the opposite direction, so as to sustain the image in the centre of the visual field. In the case of any impairment of the VOR system, blurred vision will occur, and even very slight head vibrations may result in dizziness and vertigo. Furthermore, suitable motor impulses cannot be attained for steady postural balance, which subsequently causes postural instability (Zeng & Zhao, 2011).



Anterior view of the maculae and semicircular ducts of the right side

A section through the ampulla of a semicircular duct.

Endolymph movement along the length of the duct moves the cupula and stimulates the hair cells.

Structure of a typical hair cell showing details revealed by electron microscopy. Bending the stereocilia toward the kinocilium depolarizes the cell and stimulates the sensory neuron. Displacement in the opposite direction inhibits the sensory neuron.

Fig. 7. Schematic representation of the human vestibular system showing the three perpendicular semi-circular canals and otolith (utricle and saccule) and inner ear (Martini *et al.*, 2014, p. 483)

The vestibular system uses information in three different ways. First, when the head changes position, the information helps to control the eye muscles by keeping the eyes fixed on one point. Second, the information from the vestibular system is used to maintain the upright posture, as the vestibular organs are better known as the ‘sense organs of balance.’ Third, this information helps to establish a conscious awareness of body position and acceleration after the information is transmitted to the cortex (Guskiewicz & Perrin, 1996).

The vestibular system appears to be multisensory and multimodal, and is, therefore, distinctive from the other systems. For instance, the vestibular system interacts with the proprioceptive system combined with a consequent discharge of motor output enabling the brain to distinguish activity from passive head movement (Angelaki & Cullen, 2008). The interaction of the vestibular system with both the proprioceptive and visual systems through the central vestibular pathways is essential for posture and gaze control (Grace Gaerlan *et al.*, 2012). A direct linkage is seen among the vestibular apparatus, cerebellum and cerebral cortex, which eventually facilitates the maintenance of equilibrium and posture (Haas, 2010). These are also known as the neural pathways for balance sensation, in which the nerves (N III, N IV, N VI, and N XI give the motor commands to the motor nuclei regarding the positions of the head, eye, and neck received from the vestibular nucleus (Martini *et al.*, 2014). The Neural Pathways for balance sensation is shown in Fig. 8.

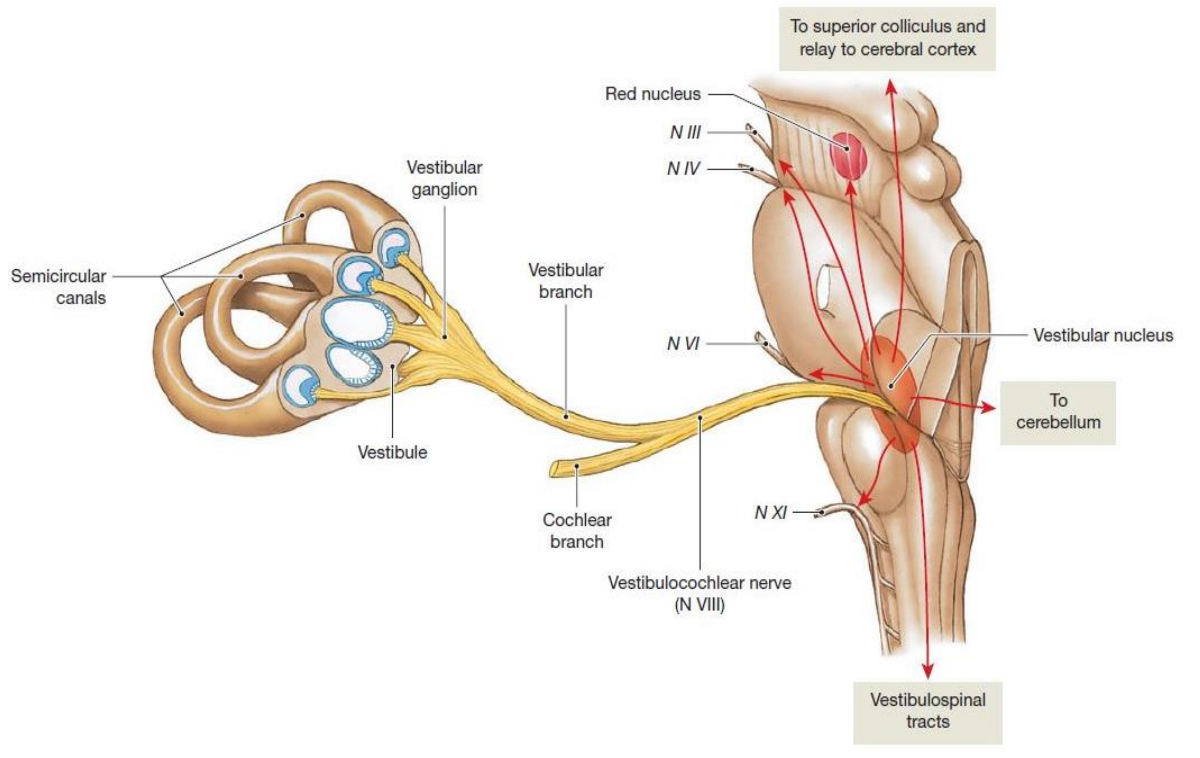


Fig. 8. Neural Pathways for postural sensations (Martini *et al.*, 2014, p. 486)

2.1.3 Visual system

The visual system clearly has considerable significance in the maintenance of balance control, particularly in the case of postural perturbations. Besides, if the eyes would not have been able to remain fixed on an object long enough to obtain a clear image, then they would be least useful in image sensing. That is why, when the head abruptly tilts in one direction, the impulses from the semicircular canals of the vestibular system induce the eyes to rotate in an equal and opposite direction to the head rotation (Hall, 2010). This is mainly the function of the vestibulo-ocular reflex (VOR). Therefore, when there is any kind of inclination in the support surface and visual surroundings, the vestibular system automatically assumes prime control (Nashner, 1982). Briefly, the vestibular apparatus chiefly controls the posture by maintaining the reflexes related to the positions of the head and neck in vertical alignment and by allowing the VOR to control the eye movements.

In terms of motion perception, visual motion can be either afferent or efferent. Here, the afferent motions are referred to as the moving objects in the external environment, whereas the efferent ones are related to the movement of the eyes, head or body (Kapoula & Lê, 2006).

In order to maintain a stable posture, the peripheral vision plays a more significant role than the central vision. Some studies reported any stimulation of the peripheral visual system causes a decrease in the postural sway in the anteroposterior direction of the visual stimulus, then in a mediolateral direction (Berencsi, Ishihara, & Imanaka, 2005). Some researchers have also concluded that the peripheral vision system functions in a viewer-centred frame of reference, explaining that in order to control posture, humans mostly utilise peripheral vision which may consequently enable visual stabilisation of the spontaneous or visually induced body sway. These authors concluded that peripheral vision operates in a viewer-centred frame of reference. They elaborate that individuals use peripheral vision for visual stabilisation of spontaneous or visually induced body sway to control posture (Guerraz & Bronstein, 2008). A few studies observed that in the young individuals, the visual system has greater dominance when compared to the middle-aged and older populations (Cohen, Heaton, Congdon, & Jenkins, 1996). Nonetheless, while it is true that vision is the basic sensory system used for balance control, it should also be remembered that an individual can also stand in the dark and remain upright (Grace Gaerlan *et al.*, 2012).

The visual system is composed of three basic parts viz., the central, ambient and retinal slips. The central visual system focuses on the perception of motion and recognition of the respective moving object. The ambient system, otherwise termed peripheral vision, is responsible for detecting the movement of the scene and can control and perceive both self-motion and postural stability. The retinal slip, however, which is actually a component of the afferent motion perception, is mainly concerned with the displacement of an individual and is subsequently used to provide the feedback for the compensatory postural sway (Guerraz & Bronstein, 2008).

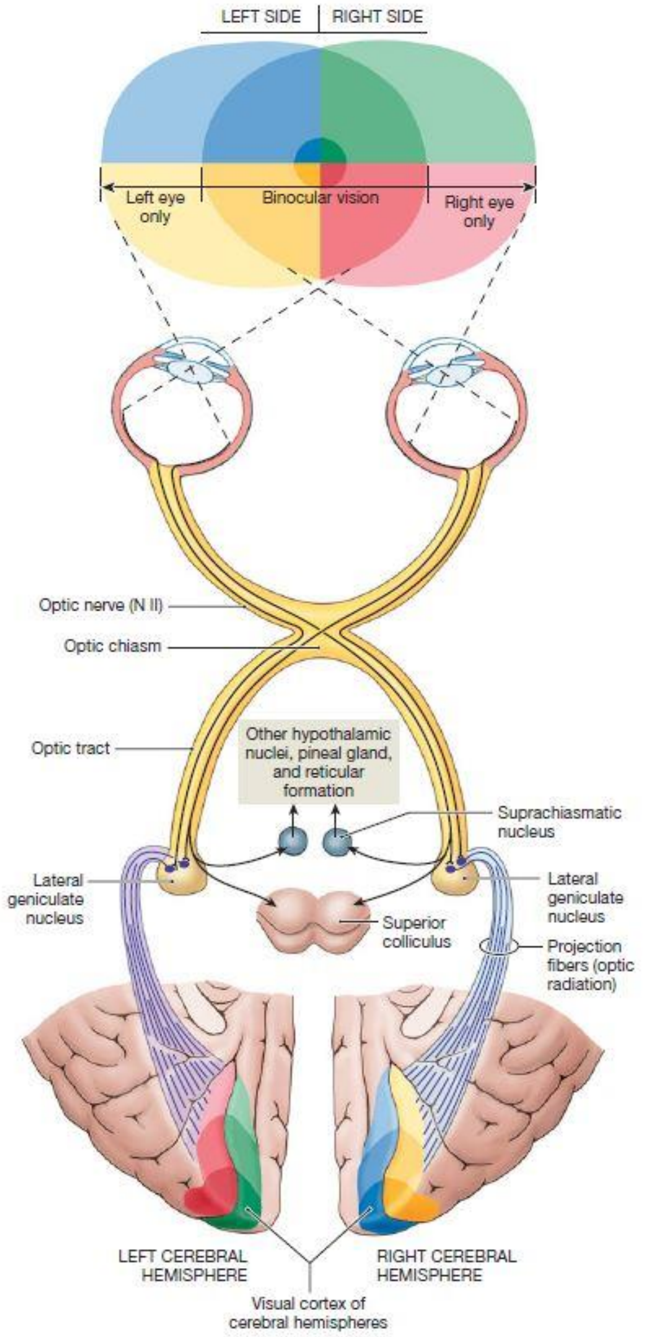


Fig. 9. Visual system (Martini *et al.*, 2014, p. 500)

Four main stages are observed in vision. First, light ray refraction and image focusing occurs onto the eye sensory receptors. This occurs through the complex structural design of the eyes. Second, transduction takes place, which is the process of converting light energy into nerve impulses. This happens through the photochemical processes of the retina. Next, neural processing and impulse transmission to the brain are achieved via the neural structure of the retina and optical nerve. Finally, the brain processes the visual information and visual perception occurs, which is achieved at multiple higher centres in the brain (Abernethy, 2013).

The optical nerve involves two major pathways responsible for the transmission of the visual signals (distinct by their structure and function). Fig. 9 shows the structure and schematic representation of the visual pathways to the brain. In fact, 70% of the signals are transmitted to the Lateral Geniculate Nucleus, an area of the mid-brain, and then onto the Visual Cortex, located towards the rear of the cerebellum (Martini *et al.*, 2014).

2.2 *Inter-sensory integration and sensory dominance*

Most of the time the pieces of information from the different sources are in harmony. However, sometimes conflicting information relating to body orientation occurs between the sources and postural adjustments are necessary to maintain the stance - for instance, in environmental conditions such as standing on an unstable supporting surface (inaccuracy between senses) or when the eyes are closed (the visual system is unavailable) (Peterka, 2002).

The human brain and CNS require a systematic method of resolving sensory conflict (A. Shumway-Cook & Horak, 1986). According to the literature, conflicts are resolved in favour of vision, as sight is regarded as the dominant sensory modality. Thus, actions may be misguided if the visual system senses incorrect information (Abernethy, 2013).

This intersensory conflict produced a consistent response where participants were observed to make compensatory adjustments in the direction opposite to the perceived overbalancing, thus indicating that visual information is the most favoured sensory source by the CNS. Surprisingly, small postural adjustments of even 6 mm, induced significant postural sway in adults, reiterating the dominance of the visual system (Abernethy, 2013).

2.3 *Integration of the sensory inputs into motor output*

Sensory processes in the case of balance control involve a strong interaction among the sensory inputs received from the somatosensory, vestibular and visual systems. However, some studies purport that negligible information is available regarding the manner the sensory inputs from these sensory systems are actually processed and integrated in order to induce the appropriate responses in the case of some conflicting sensory information being received from any of the sensory systems. The possibility of detection of an error by the sensory systems is a possibility, which indicates the deviation of the body from a specific reference position. The vestibular system detects the deviation in the case of head deviation with respect to the support surface, while the visual system detects head orientation with reference to the external visual surroundings, and the proprioceptive system senses the lower limb orientation with reference to the surface of the support (Peterka, 2002).

Although multiple sensory inputs are accessible, the CNS generally relies for orientation information only on one sense at a time for perception. In the case of healthy adults, the preferred sensory input for balance control is the proprioceptive information, which is detected and received via the feet being in contact with the support surface. The CNS has this great ability of adaptation, and it provides an alternative sensory input if some inaccurate or conflicting information is detected from the sensory inputs. Therefore, in the event of such conflict among the senses, the CNS uses orientationally correct information drawn from the vestibular system to solve the problem (Lewis M. Nashner, 1982). For example, a person standing near a moving bus would sense this sensory conflict with the vestibular and somatosensory systems due to false visual inputs, which actually pass on information of relative self-to-object motion. Therefore, to resolve this conflict, the CNS will ignore the visual inputs and consider only the accurate orientation-related inputs from the vestibular and proprioceptive systems and maintain the equilibrium (Shumway-Cook & Horak, 1986).

To interpret the complex sensory environment, all the sensory inputs from the sensory systems must be integrated. As the individuals periodically change their sensory surroundings, they need to reassess their corresponding reliance on each sense accordingly. In a normal environment and under stable conditions with a firm BOS, healthy persons show about 70% dependence on the somatosensory inputs, 20% on the vestibular and 10% on the visual ones (Peterka, 2002). However, when the base of support shows some instability, reliance on the vestibular (60%) and visual information (30%) increases, whereas the reliance on the somatosensory (10%) inputs decreases (Horak, 2006). Ultimately, all the three sensory systems together help in maintaining the balance of an individual. Some of the theories proposed by researchers state that the young adults primarily use the visual system in their 20s and 30s for balance control. However, they also utilise some of the control strategies that can work effectively even in the absence of vision, in balance maintenance. Particularly, in the event of either the visual or vestibular systems not fully working, then the somatosensory system frequently takes on control to maintain the balance (Grace Gaerlan *et al.*, 2012).

It is the cerebral cortex in the CNS which can perceive, understand and integrate all the sensory information. It provides the transition from perception to the required responses as shown in Fig. 10. The mechanism of postural feedback after the organisation and integration of the sensory information involves not only the muscle movement but also the feedback for the head to move via the vestibular system in the inner ear, feedback from the visual inputs and also the feedback regarding the pressure changes from the proprioceptive system through the support surfaces. Thus, the cerebral cortex or the principal centre controls the voluntary movements by coordinating the sensory information received from the cerebellum and basal ganglia in the CNS, with the feedback received from the periphery to affect the movements under voluntary control, in order to maintain balance (Haas, 2010). According to some studies, the total time delay of the response, inclusive of the time delay within the sensors, processing in the brain centres, transmission of impulses to the postural muscles and then generating the muscle response is about 225 m-seconds (Nashner, 1971).

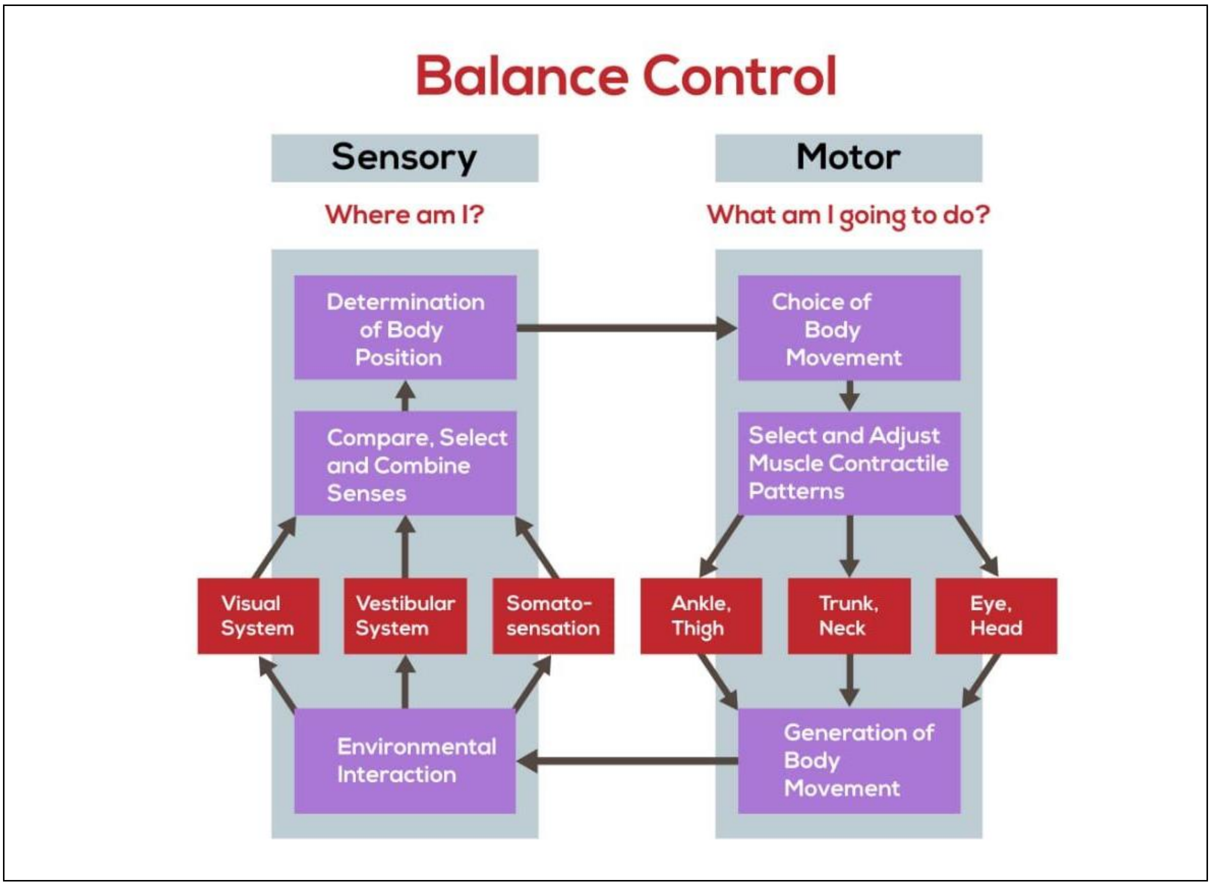


Fig. 10. The conscious interplay between sensory and motor systems for successful control of balance (NeuroCom International, 1991, p.1)

According to the works of Nashner (1982), the process of upright posture maintenance by the CNS involves two components. First, a sensory organisation based on the information received from three sensory inputs which determine the direction, timing, and amplitude of the correct posture. Therefore, despite the availability of multiple sensory inputs, the CNS generally depends only on one sense at a time, for the orientation of information (Guskiewicz & Perrin, 1996). In the case of healthy adults, among the three sensory inputs, the somatosensory information is the preferred sense for balance control when the feet are in contact with the support surface (Nashner, 1982). Second, muscle coordination includes the processes which regulate the contractile activity and temporal sequencing of the leg and trunk muscles, ultimately supporting the reactions to maintain the balance (Guskiewicz & Perrin, 1996). According to several studies, inappropriate interaction or conflict among the three sensory inputs can result in balance disorders among those individuals with neurological problems (Shumway-Cook & Horak, 1986). This is the reason that the increased postural sway is related to the impaired senses in the legs and feet (Era & Heikkinen, 1985). Therefore, a patient may be relatively more dependent on one sense for specific situations due to these inter-sensory conflicts (Nashner, 1976).

Interestingly, very little is known regarding the actual manner in which the sensory information is processed and integrated to generate the corrective torque when the input information is inaccurate or conflicting. It is suggested that the sensory cues are linearly combined. Thus, each system detects an error; for instance, vestibular (deviations of head orientation with regards to gravity), visual (head orientation relative to the visual world) and proprioceptive (leg orientation relative to the support surface). Once transmitted to the CNS and brain, the individual signals add up and induce an appropriate corrective torque (Peterka, 2002).

The concept of postural balance, role, and function of the sensory information is to balance the posture, and the pathway of the sensory organisation has been discussed earlier. The first stage in the postural balance system loop is the CNS which receives the information to process and generates the motoric response to stabilise the posture (Jacobs & Horak, 2007; Okada, Hirakawa, Takada, & Kinoshita, 2001; Peterka *et al.*, 2015; Peterka & Loughlin, 2004; Rosenbaum, 2004; Teplan, 2002).

2.4 *Central nervous system and postural balance*

Postural balance is a motor skill, controlled by the CNS (Horak, 2006). The CNS functions as the central control station, which collects the sensory information, processes it and generates the response in accordance with the task (Jacobson, 2005; Koenderink & Physics, 1979).

The CNS thus adapts and develops the response against any movement to balance the posture, and it is under the control of the cerebellum and cerebrum (Bloem, Steijns, & Smits-Engelsman, 2003). The cerebellar-cortical loop responds in a different way to balance the posture and depends on the long or short latency, while the basal ganglia are responsible for the pre-selection and optimum postural response (Jacobs & Horak, 2007).

The CNS has three components - 1. Spinal cord, 2. Brain stem and 3. Brain; further, the brain includes the cerebrum and cerebellum. (Saltuari, 2018). The spinal cord is the ground level of the CNS and includes the motor neurons and also the descending and ascending pathways of the information from the brain stem and brain. The brain stem regions reticular formation and the vestibular nuclei play a vital role in the spinal repertoire, which depends on the oscillation pattern for locomotion; the higher level is the brain or cerebral cortex, which is involved in motor planning (Loram, 2015).

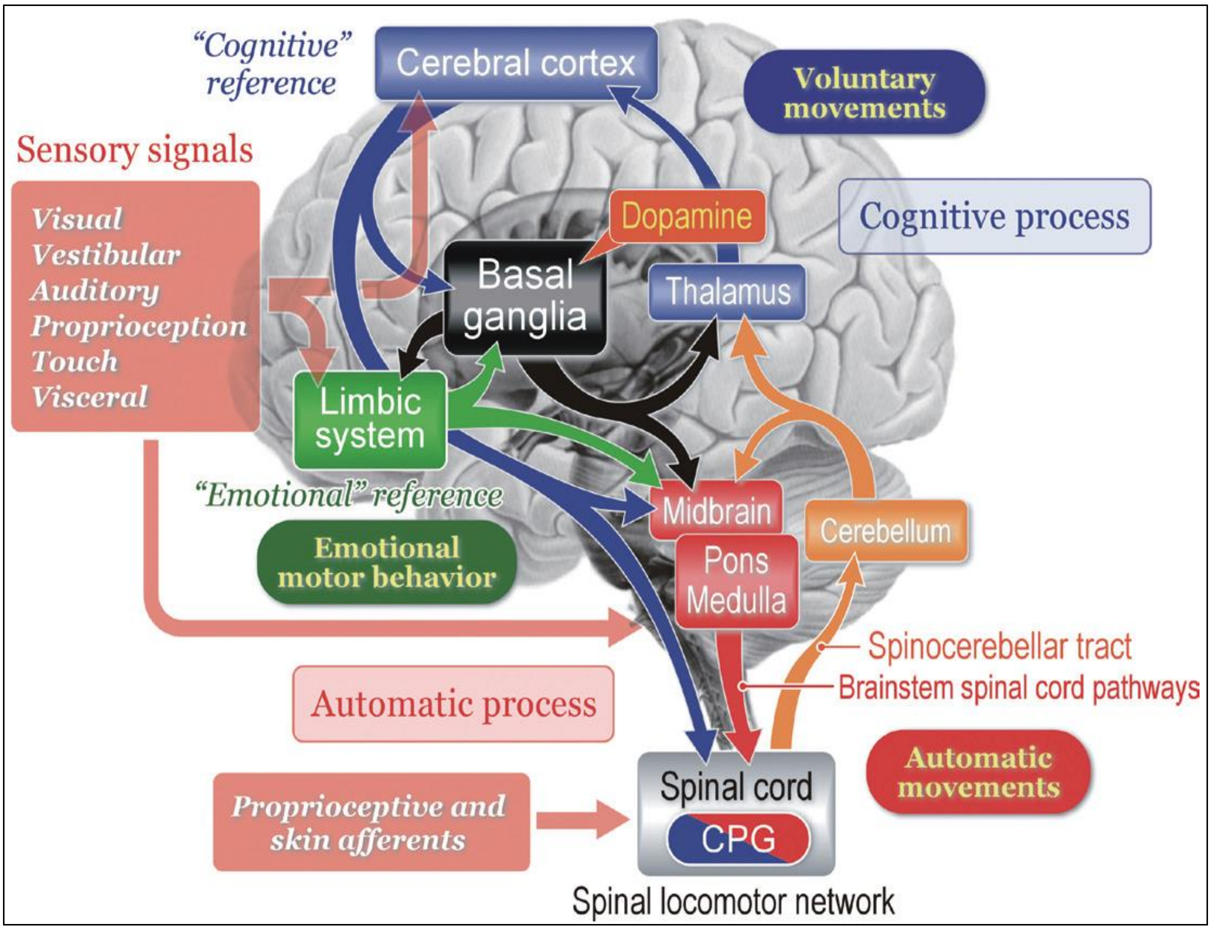


Fig. 11. Signal flow model of postural balance (Takakusaki, 2017, p. 2)

Takakusaki (2017) demonstrated the spinal locomotor network of information flow in the CNS to balance the posture. The information comes in from the spinal central pattern generators (CPG) to the cerebellum, and from the cerebellum, it is diverted in two directions, one moving towards the midbrain, pons medulla, and again to the CPG, while the other travels towards the cerebral cortex via the thalamus. The information after being processed in the cerebral cortex travels to the basal ganglia, CPG via midbrain. The information which comes from the cerebral cortex to the basal ganglia can be transferred to three regions, viz., the limbic, midbrain and thalamus systems, and after being processed in the limbic system, it makes a loop with the basal ganglia and also sends some information to the CPG through the midbrain Fig. 11.

The cerebral cortex includes a complex system. In relation to postural balance, the primary motor cortex plays a significant role in stabilising the posture. It receives the information from the primary visual cortex, a region of the posterior parietal cortex, dorsal premotor cortex, supplementary motor area and prefrontal cortex. Besides this, the primary motor cortex is involved in motor planning and transmits a large number of axons to the corticospinal tract to balance the posture (Loram, 2015). The cortex receives the information from the body and also processes it in the cortex and again sends it to the body. This is one of the most complicated phenomena to understand, and this process can be investigated from four different perspectives: 1. Receiving information from the body, 2. Transmitting the body information to different parts of the cortex, 3. Motor programming or processing in the cortex and 4. Providing information to the body, to balance the posture (Takakusaki, 2017). The flow of information for these parts is shown in Fig. 12.

The afferent information from the cortex to the body generates the motoric response to stabilise the posture, and gain information about the body is transmitted to the cortex by the sensory systems, and this loop can balance the posture. (Shumway-Cook & Woollacott, 2017).

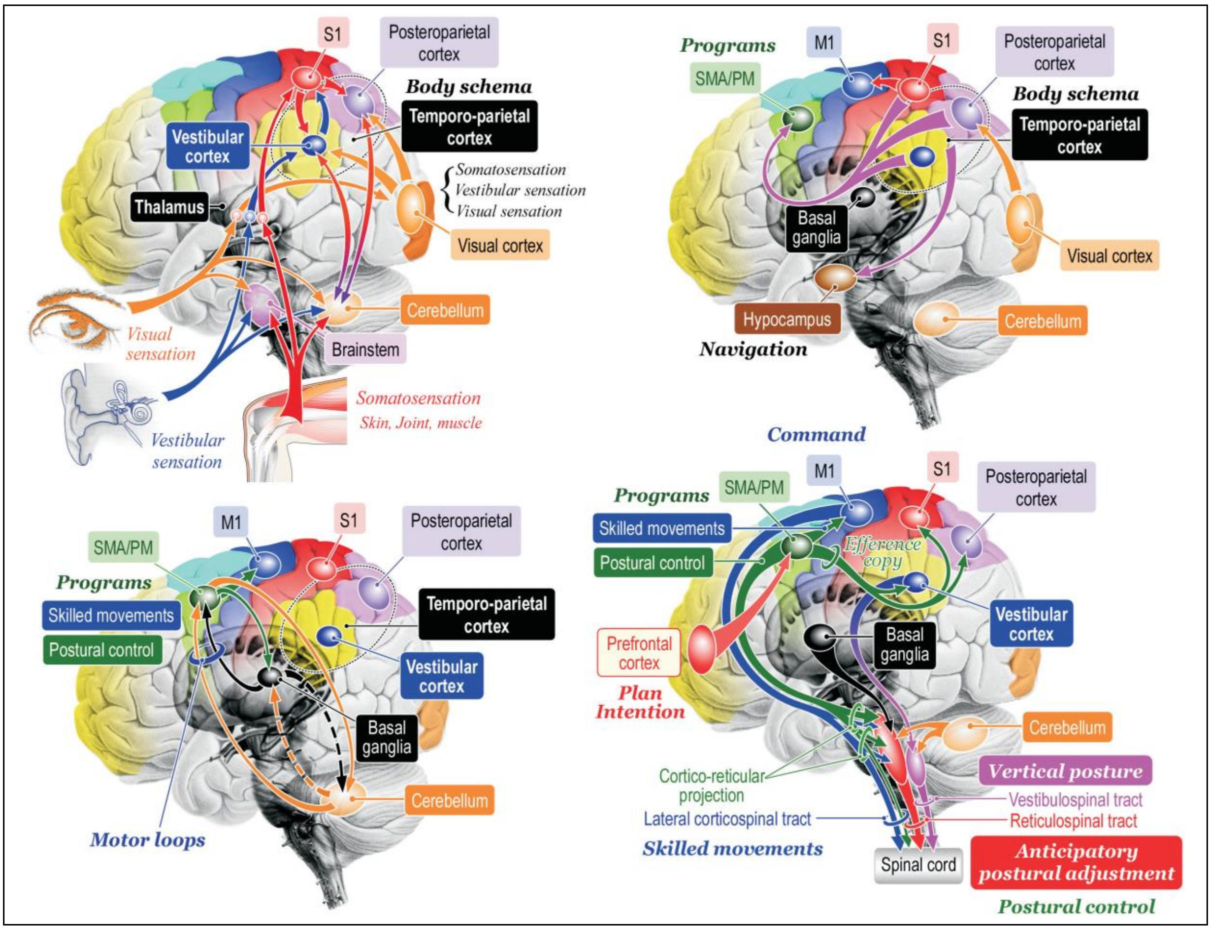


Fig. 12. Cortical signal flow while receiving information, processing, and transmitting to the body. (Takakusaki, 2017, p. 8)

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3 Status of research

A detailed review of the effect of aging on postural balance, strategies to balance the posture and sensory integration to balance the posture are presented. Further cortical activity during postural balance and sensory integration to balance the posture have been discussed in this section.

3.1 *Effect of aging on postural balance*

The decline in the ability for postural balance with the aging process is widely recognised (Barbieri & Vitório, 2017; Bradley, 2011a). A significant decline was found in the seniors with increase in the sway of the COP in the anteroposterior (AP) direction by Amiridis, Hatzitaki, & Arabatzi (2003). In this cross-sectional experimental study, 19 seniors in the age group of 70.1 ± 4.3 and 20 young individuals, aged 20.1 ± 2.4 participated. The participants underwent a postural balance test on a force plate. Electromyographic (EMG) activity of the ankle and hip muscles and kinematic data of the participants were measured during the experiments. The senior participants demonstrated a decline in the posture balance with force plate measurement of the centre of pressure (COP) under three conditions, viz., normal static stand, Romberg stance and one leg stand. Further, from the kinematic and EMG data it was evident that the seniors showed the greater involvement of the hip joints to balance the posture in comparison to the young participants.

A follow up experimental study after three years using 72 subjects (37 men and 35 women) with a mean age of 82.3 ± 3.0 was done by Baloh, Corona, Jacobson, Enrietto, & Bell (1998). They examined the subjects every year, and their assessed postural balance with the Chattecx Balance System to identify the changes in the centre of pressure (COP) in x (ML) and y (AP) direction, under conditions of the eyes kept open and closed on a static and a moving platform. The results of that study showed that postural sway was observed to be higher over time on the static and moving platform. Further, no difference was observed between the subjects who had a fall history and those who did not have one.

The postural balance abilities during the lifespan of an individual gradually declined from childhood to old age. Hytönen, Pyykkö, Aalto, & Starck (1993) conducted an experimental study using 212 participants between 6 and 90 years. They considered sway velocity (SV) as a predictor of posture balance on a computerised force platform. In the results of the study, they showed a U-shaped curve during lifespan (Fig. 13), which was developed based on the postural sway data. The younger participants from 6 years to 15 years of age, as well as those aged 50 and above, showed high sway velocities, which revealed less postural balance.

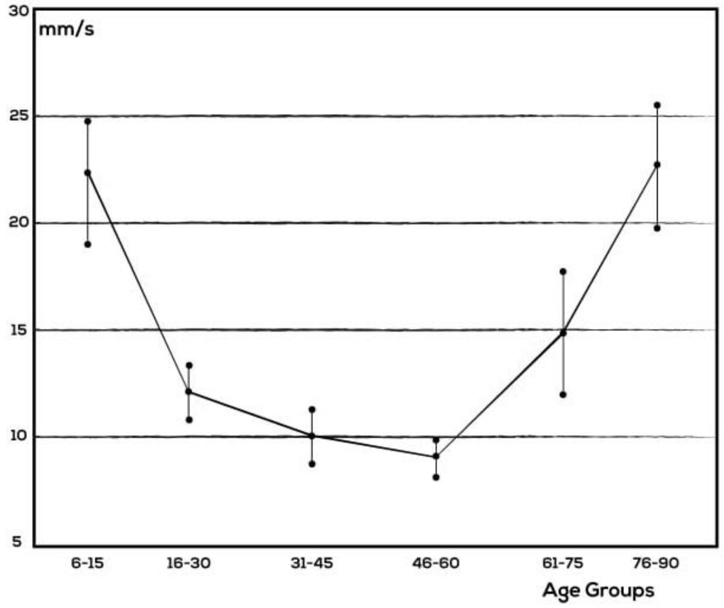


Fig. 13. The postural sway within an individual’s lifespan (Malta Hytönen, Pyykkö, Aalto, & Starck, 1993, P.113)

The normative data of postural balance of 7,979 subjects between 30 and 80 years of age, of both sexes, were presented by Era *et al.* (2006) in a cross-sectional study in Finland. Both instrumental and non-instrumental examinations were performed to check the postural balance. A force plate was used to record the instrumental data, with the measurements from x (ML) and y (AP) and the COP was calculated. Four conditions were tested on the force plate viz., (i) Feet apart eyes open, (ii) Feet apart eyes closed for 30 seconds, (iii) semi-tandem position for 20 seconds and (iv) tandem for 20 seconds. Tandem, semi-tandem and side-by-side standing on the stable surface were used for the non-instrumental balance, testing each condition for 10 seconds. The findings of the study showed balance abilities decreasing from middle age onwards; the subjects from 40-50 years of age showed poorer postural balance abilities than those in the 30 to 39 age group. The worst decline was identified after 60 years of age. However, the non-instrumental test was not found sensitive until the age of 60 years; therefore, the force plate is recommended for providing reliable data on postural balance.

Studies by Baloh, Fife, Zwerling, Socotch, Jacobson, Bell (1994) also revealed sway velocity and high to low frequency, increasing with aging; these are two predictors of decline in the postural balance abilities. Baloh, Fife, Zwerling, Socotch, Jacobson, Bell (1994) investigated 30 young participants in the age group of 26.6 ± 5.9 years and compared them to 82 subjects who were 79.6 ±

4 years old. In this cross-sectional experimental study, the anteroposterior sway velocity under the conditions of eyes open and eyes closed on the Chattecx Balance System was measured. A significant difference was observed in the balance abilities between the young and senior subjects in the static condition and this difference waxed higher in the dynamic condition. However, no difference was reported between the subjects who experienced falls and no falls.

Standing for a long time also poses the danger of changes in postural balance in seniors. The postural balance ability of seniors is affected after standing for long periods of time (Freitas, Wieczorek, Marchetti, & Duarte, 2005). In the cross-sectional experimental study by Freitas, Wieczorek, Marchetti, & Duarte (2005) 14 young participants in the 28 ± 7 age group and 14 seniors aged 68 ± 4 were investigated. Subjects performed one-time 30-min standing, and during follow up two-times 60-seconds standing test on a force plate. The anteroposterior (AP) and mediolateral (ML) directions of the centre of pressure (COP) were measured to assess the postural balance abilities with the force plate. Senior subjects showed more sway after standing for a long time compared to the young subjects. This decrease in the postural balance ability can be the cause for falls in the elderly.

Pertti Era, Heikkinen, Gause-Nilsson, & Schroll (2002) investigated a follow up the experimental study spanning 5 years, using 757 subjects from Denmark, Sweden, and Finland. Era, Heikkinen, Gause-Nilsson, & Schroll (2002) began their study on 75-year-old subjects, but 434 subjects reached the age of 80. He used a simple balance test under three conditions. 1. Standing with eyes open, 2. Standing with eyes closed, 3. Tandem stand. A significant longitudinal decline was found between this 5-year period, which showed deterioration and decline in the posture balance abilities from age 75 to 80 years.

In another study by Guralnik *et al.* (1994), 5,000 persons aged 71 years and older were tested for postural balance abilities using a simple balance test under three conditions. Tandem, semi-tandem and side-by-side stand on a stable surface. They observed a significant decline in the 80-year group compared to the group of those who were 71-79 years of age.

To summarise, the sway of posture increases with the aging process (Amiridis *et al.*, 2003; Baloh *et al.*, 1998). The younger ones 6 years of age and those above 50 years of age show high sway velocities (Hytönen *et al.*, 1993). The postural balance abilities decrease from the age of 40 years (Era *et al.*, 2006). The postural balance abilities decrease under conditions of static postural balance, but they also further decrease under conditions of dynamic balance

(Baloh, Fife, Zwerling, Socotch, Jacobson, Bell, 1994). Sway in the posture of seniors increases even more with the duration of standing (Freitas *et al.*, 2005). The decline in the ability to maintain posture reduces to a greater degree from the age of 75 years (Era *et al.*, 2002) and is even worse after the age of 80 (Guralnik *et al.*, 1994).

Several factors like biomechanical constraints, movement strategies, sensory strategies, orientation in space, control of dynamics and cognitive processing (see Fig.14) can influence the decline in the postural balance and while it does not depend on a particular factor for all seniors, it depends only on the individual (Horak, 2006).

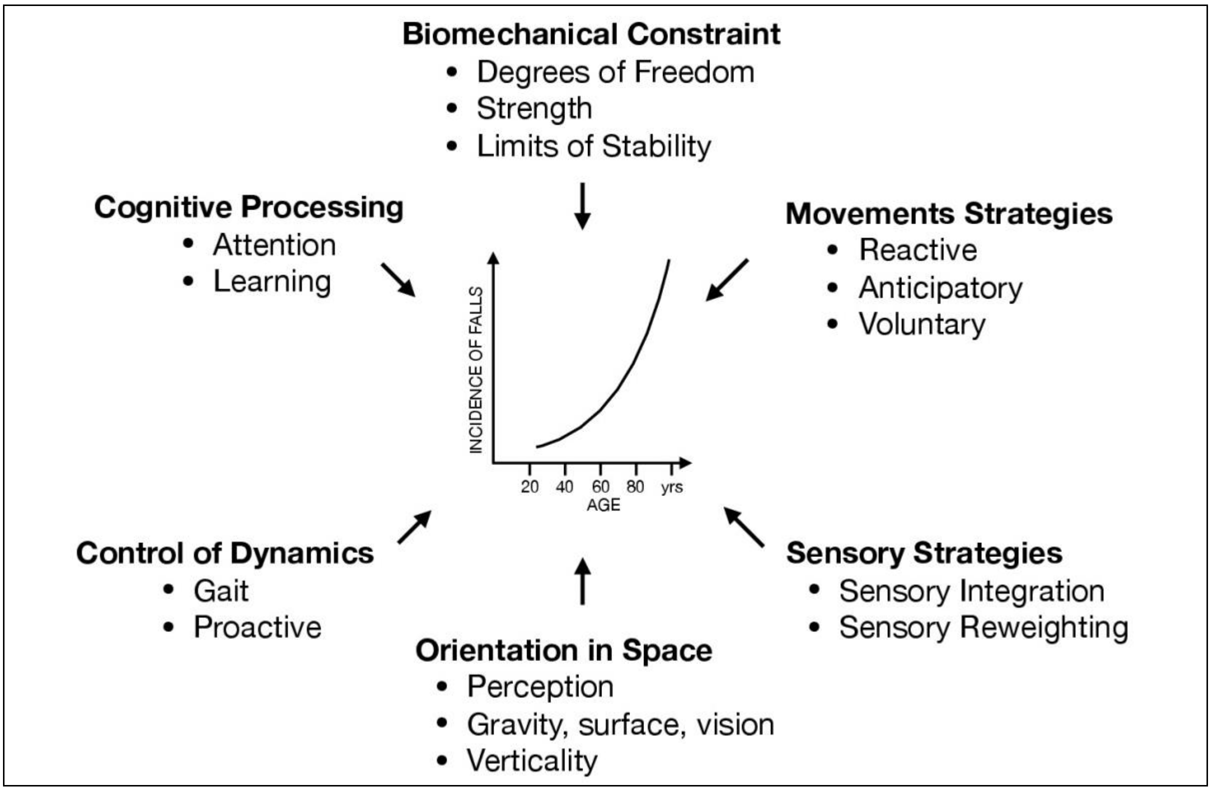


Fig. 14. Components which can influence postural balance (Fay B. Horak, 2006)

The biomechanical constraints depend on the degree of freedom, which in turn depends on the limit of stability (Chiel & Beer, 1997; Demyelinated & Fiber, 1988). The limit of stability which is dependent on the somatosensory, visual, vestibular sensory information, and motoric responses (Yaggie & McGregor, 2002) and strength which decrease with aging, both contribute to the stability of posture (Barbieri & Vitório, 2017; Laughton *et al.*, 2003). Movement strategies including reactive, anticipatory and voluntary movements and body orientation are controlled by the CNS (Donna. Cech & Martin, 2012). The control of dynamics during walking, especially when the shift in the posture changes, from one foot to the other, calls for complex motor skills to balance the posture (Winter, MacKinnon, Ruder, & Wieman, 1993). Besides this, cognitive processing is the essential factor in postural balance (Teasdale & Simoneau, 2001).

Based on the components mentioned above and the past research, the ability to balance posture depends on the integration of the sensory information with the motor response, cognitive abilities and environmental factors (Gehlsen & Whaley, 1990; Nevitt, Cummings, Kidd, & Black, 1989; Rubenstein, Josephson, & Robbins, 1994; Studenski, Duncan, & Chandler, 1991).

Several factors can contribute to the decline in postural balance related to aging, which can contribute to the sensory information to balance the posture and motor response.

The aging process changes the muscle spindle structure (Liu, Eriksson, Thornell, & Pedrosa-Domellöf, 2005; Swash & Fox, 1972). It increases the thinness but reduces the intrafusal fibres in each spindle, and the distal sensory axons get reduced (Swash & Fox, 1972). Besides, aging reduces the sensitivity of the muscle spindles (Miwa, Miwa, & Kanda, 1995), muscle length and JPS (Liu *et al.*, 2005). These changes can also influence the response of the tendon organ (Proske & Gandevia, 2012). The mechanoreceptors in the foot decrease with the aging process (Lord & Ward, 1994), which reduces the plantar sensitivity, and the cutaneous receptors also decline in number (Cauna & Mannan, 1958) along with vibration perception (Verrillo, 1979; Ronald. Verrillo, Bolanowski, & Gescheider, 2002). This reduction makes postural balance even harder for the senior population.

The phenomenon of the decline in the vestibular system with aging also causes a reduction in the nerve fibres (Park, Tang, Lopez, & Ishiyama, 2001), and the neuron of the vestibular nucleus decreases by 3 % every 10 years after the age of 40 (Park *et al.*, 2001). The ability to detect the rotation of head movement and shorter VOR time duration decreases with the aging process because of the hair cell loss in the semicircular canals (Park *et al.*, 2001). Also about 40 % of hair cells are lost, and while in the saccule and utricle there is nearly 25 % hair cell loss with aging (Anson & Jeka, 2015; Matheson, Darlington, & Smith, 1999), and the decline in the vestibular system affects the postural balance in the senior population (Zalewski, 2015). Besides, with the aging process, the senior population has reduced contrast sensitivity, the perception of depth, adaptation to environment and light, judgement of the distance of the objects, loss of sensors and reduced acuity, all of which can cause a fall (Barbieri & Vitório, 2017b). However, the decline in postural balance can be counteracted with physical activities and exercise (Giangregorio & El-Kotob, 2017; Kujawski *et al.*, 2018; Low, Walsh, &

Arkesteijn, 2017; Marques, Figueiredo, Harris, Wanderley, & Carvalho, 2017; Melanson, 2017; Mikó, Szerb, Szerb, & Poor, 2017).

3.2 *Postural balance strategies*

To maintain the balance in posture the most important task is to recover from the loss of balance or maintain the posture in a balanced condition. Human beings use two strategies to accomplish this: they rely either on the hip or ankle to maintain a stable posture (Robinovitch, Heller, Lui, & Cortez, 2002).

Nashner (1977), in his research, pioneered a significant part of his work on the human body relating to the perturbations applied by a moving platform. He studied 12 young subjects picked at random and 4 patients with cerebellar deficits, and conducted experiments on platforms which could be translated in an anteroposterior direction. It was observed that when the platform was translated forwards (i.e., tilted backwards), the calf muscles and hamstrings showed the first response by stretching. However, as this forward translation of the platform did not shift the COM in an anterior direction, this response resulted in the backward shift of the COM by the second response of the anterior muscles of the leg (quadriceps and tibialis anterior muscles) by their contraction, in order to maintain the balance and prevent the fall. On the other hand, the identical body response was observed when the platform was translated backward (tilted in the forward direction), with the difference being that the posterior muscles of the leg (calf muscles and hamstrings) contracted to defend the perturbation and thus prevent the balance loss. As these responses radiated, starting from the ankle to the body's COM, these responses were termed 'ankle strategy.' The 'hip strategy' has been observed in action when the ankle muscles alone were unable to withstand a greater sway force applied by the platform. As the platform translated forward, the hip flexor muscles (iliopsoas, quadriceps, and abdominals) responded, and as mentioned, the hip flexor response was more effective in shifting the COM. The opposite response exhibited by the extensor muscles (erector spinae and hamstrings) was also observed as the platform translated backward (i.e., tilted forward).

Horak & Nashner (1986) identified that the strategies to control postural balance were related to the base of support, current feedback and external influence of the environment, from their experimental study using 10 healthy participants (4 males and 6 females, 20 to 40 years in age). Who underwent the postural balance test on the moveable platform with the hydraulic servomotor, which can move in the forward and backward directions at a velocity of 13 cm/s, for 250 m/s, while the angular trajectories were measured from the ankle, knee and hip joint, with video analysis. During the experiment, the ankle torque was measured using strain gauges, attached to the platform while the muscle activity was measured using an EMG from the medial gastrocnemius, tibialis anterior, hamstrings (primarily biceps femoris), quadriceps (primarily rectus femoris), paraspinal and rectus femoris. Each participant performed 20 trials in the forwards and backwards direction on the base of support, which was initially equal to the foot length and gradually shortened till 9 cm. The results of this study showed participants having 73-110 ms latencies with muscle activation from the ankle, thigh, and trunk, respectively, and restored the equilibrium with 'ankle strategy' on the usual base of support. In the event of a shorter base of support, the muscle activates a similar latency but in the opposite direction and generates a 'hip strategy' to stabilise the posture. The mixed hip and ankle strategies were found on the medium base of support.

The ankle dominates in the balance of posture in the normal standing position; however, as the base of support decreases, the involvement of the hip movement increases to control the posture (Gatev, Thomas, Kepple, & Hallett, 1999). In the experimental study performed by Gatev, Thomas, Kepple, & Hallett (1999) 7 random subjects aged 24 to 54 ± 42.3 years by kinetic data were selected and using the force platform to calculate centre of pressure (COP), the kinematic data were measured using 5 CCD (charge-coupled device) cameras Vicon Motion Systems Ltd., Oxford, UK system to measure the postural alignment and electromyography EMG measured the activation of the muscles. The four conditions under which they were analysed include,1) standing with eyes open in the natural position 2) standing with eyes closed in the natural position 3) standing with eyes open and feet together and 4) standing with eyes closed and feet together. In this small study, the base of support was seen to increase the ankle and hip angular movements. The hip angular movement showed a correlation between the size of support and availability of vision.

Runge, Shupert, Horak, & Zajac (1999) studied the strategies during postural balance in an experimental study with 7 young subjects aged 31.3 ± 5.1 years using three trials beginning with the intensive velocity on the Servo-controlled, hydraulically-driven movable platform, which was translated backward at a range of velocities from 55 cm/s to 5 cm/s. Meanwhile, electromyography EMGs from eight muscles (medial gastrocnemius, tibialis anterior, rectus femoris, biceps femoris, rectus abdominis, lumbar paraspinals, sternocleidomastoid, and upper trapezius) were recorded. In this study, two 60 Hz cameras were used to analyse the body movement. The conclusion reached by this study was that ankle strategy continued to provide support during postural balance together with hip strategy, and hip strategy alone was not active during postural balance. Further, the authors stated that joint torques could facilitate examination of the strategies during postural balance.

The same trend was reported by Hwang *et al.* (2009) in terms of postural balance recovery in an experimental study. As the difficulty of the postural balance tasks was increased, the young people used the mixed hip and ankle strategies, while in the event of slow perturbation they used ankle strategy alone (Hwang *et al.*, 2009). Hwang *et al.* (2009) investigated 13 young people selected at random (10 men and 3 women aged 24 ± 1.8) using the force plate which was kept moving in the forward and backward directions using an AC servo-motor. The centre of pressure was measured from the force plate, and a joint motion was measured with joint angles from ankle, knee, and hip in sequence and the muscle activity was measured using the EMG from the gastrocnemius and rectus femoris. In this study, besides the dependence on the ankle to balance the posture, the researchers also found that during high perturbation the centre of pressure also moved higher.

Ankle strategy is normally used 90 % of the time to control the posture under the perturbed (Blenkinsop, Pain, & Hiley, 2017). Blenkinsop, Pain, & Hiley (2017) investigated in an experimental study using 12 young males aged 23.1 ± 3.6 years and 3 females aged 20.5 ± 0.7 years who performed a balance task on the CAREN (Motek Medical) balance measurement system. The kinematic data were collected using the T20 Vicon camera (Vicon, Oxford Metrics Group) during the postural balance tasks under perturbed and unperturbed conditions with eyes in the closed and open states.

The relationship between the postural balance and strategy was identified by Day, Steiger, Thompson, & Marsden (1993) in an experimental study on 35 male subjects between 29 to 63 years of age (45.9 ± 10.7). They investigated the body movements of the subjects in the upright position under the eyes open and closed conditions, in three dimensions, with eight fixed markers on the backs of the subjects from shoulder to ankles, for motion analysis. The force platform of Kistler 9281B was used to measure the postural balance during the experiment. Subjects were made to stand still for 32 seconds on the force platform in each condition, by using the inverse pendulum method with anteroposterior (AP) movement. As the postural balance got worse, the subjects moved from hip strategy to ankle strategy, and stance position also played a significant role. Further, a relationship was identified between postural balance and the strategy used to maintain the balance. If the subjects used ankle strategy, the postural balance abilities were better than if the subjects used hip strategy.

Amiridis *et al.* (2003) demonstrated a change in the strategy during postural balance between the young and senior participants in an experimental study performed on 9 randomly selected seniors aged 70.1 ± 4.3 years and 20 young participants aged 20.1 ± 2.4 years. Using the EMG to measure the hip and ankle muscle responses, the seniors' hip muscles were found to be more active than the young subjects during postural balance and activation in the hip muscles increased as the difficulty level of the task was increased. The young subjects showed high activation of the ankle muscles which indicated that the seniors used more hip strategy to maintain postural balance in comparison to them.

In summary, Nashner (1977) defined the ankle and hip strategy contribution in postural balance. Further, they reported that when the ankle was unable to control the sway during postural balance, then the hip muscles were activated to support the postural balance. The strategies to balance the posture were dependent on the base of support (Gatev *et al.*, 1999; Horak & Nashner, 1986). The hip and ankle strategies cannot stand alone to balance the posture (Runge *et al.*, 1999; Hwang *et al.*, 2009). Healthy people use 90% ankle strategy to balance their posture (Blenkinsop *et al.*, 2017) as there is a relationship with the strategy to balance the posture: as the balance abilities get worse people to depend more on the hip than the ankle strategy (Day *et al.*, 1993). Aging affects the strategies selected to balance the posture and seniors depend more on the hip muscles and on hip strategy (Amiridis *et al.*, 2003).

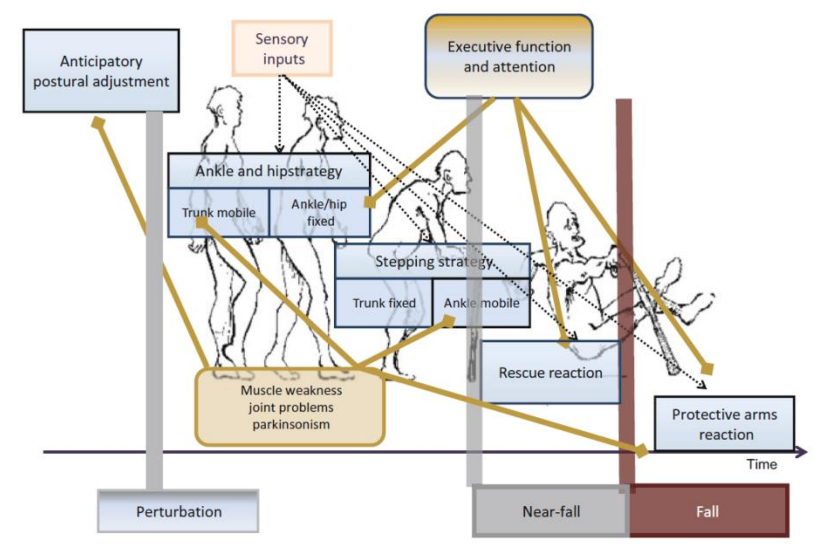


Fig. 15. Schema of strategies to prevent a fall from a single perturbation (Barbieri & Vitório, 2017 p. 96)

In the case of high sway or worse balance condition, individuals are inclined to use the hip strategy. In case the hip strategy to fails to support the posture, another motor plan provides the support needed to maintain the posture and keep the individual from having a fall, and it generates a response to initiate the stepping strategy to prevent the fall from happening. In the stepping strategy, one or more steps are taken to prevent the fall, and even if they cannot balance the posture, they try to use the upper limbs to protect them from the fall (Fig. 15). The strategies to balance the posture require the same abilities like sensory input, cognitive abilities, motor response and environment (Barbieri & Vitório, 2017; Fasano, Plotnik, Bove, & Berardelli, 2012).

3.3 *Sensory information influences the postural balance*

The processing of sensory information develops from age 3 until 15 years and from 20 till 60 years as investigated by Hirabayashi & Iwasaki (1995). In this experimental study, computerised dynamic posturography and EquiTest System (NeuroCom® International, Inc., USA) were used to measure the centre of pressure, and a sensory organisation test (SOT) was performed. The SOT includes six different static postural balance conditions. In condition 1 the participant stabilises the posture with eyes open on a stable platform and surroundings; in condition 2 the eyes are closed on a stable platform and static surroundings; in condition 3 the eyes open on a stable platform and moving surroundings; in condition 4 the eyes are open on a moving platform (anterior and posterior) and static surroundings; in condition 5 the eyes are closed on a moving platform (anterior and posterior) and static surroundings; and in condition 6 the eyes are open and both the surrounding and platform (anterior and posterior) are moving. The postural balance under the conditions listed above was computed in theoretical maximum displacement without losing balance was assumed to be in the range of 12.5° (6.25° anterior, 6.25° posterior). Condition 1 was considered baseline, and the somatosensory, visual and vestibular systems were computed with conditions 2, 4 and 5, respectively.

In the study conducted by Hirabayashi & Iwasaki (1995) 7 groups of 112 subjects from ages 3 to 60 years underwent the SOT; n = 12 (5 boys and 7 girls aged 3-4 years); n = 21 (11 boys and 10 girls aged 5-6 years); n = 18 (9 boys and 9 girls aged 7-8 years); n = 22 (11 boys and 11 girls aged 9-10 years); n = 20 (10 boys and 10 girls aged 11-13 years); n = 19 (10 boys and 9 girls aged 14-15 years); and n = 26 (15 males and 11 females aged 20 to 60 years). The SOT findings were compared with the 7th group of the investigation aged 20 to 60 years.

Hirabayashi & Iwasaki (1995) stated that postural balance develops with the passage of age and can be reached at the same level of an adult by 15 years of age and in relation to the sensory development. The somatosensory system develops at between 3 to 4 years of age, the visual function develops until the age of 15 years, and the vestibular functions develop after 15 years of age. He also reported that the vestibular functions in a girl develop faster than in boys (Hirabayashi & Iwasaki, 1995).

The role of each source of sensory information to enable postural balance was identified in young adults by Grace Gaerlan *et al.* (2012) with a descriptive cross-sectional study on 194 subjects between 20 and 30 years of age, of which 28% were male, and 72 % were female. In this study, 134 participants reported involvement in physical activity, while 59 participants reported no physical activity in their life routine. All participants were subjected to the SOT on the SMART Balance Master (NeuroCom® International, Inc., USA). The physically active group showed significantly higher postural balance abilities under SOT in comparison with the non-active group: In relation to the SOT individual component, the non-active group showed significantly higher postural balance abilities under visual information 93.7 ± 2.07 % when compared with the vestibular 90.04 ± 2.7 ratio and the somatosensory one of 90.0 ± 3.13 %. Non-exercise participants showed the dominance of the visual system to balance the posture, while active participants showed the dominance of the somatosensory information to balance the posture, with overall better sensory integration during postural balance.

The somatosensory visual and vestibular systems influence postural balance in the active young people (Johnson *et al.*, 2018). Johnson *et al.* (2018) used the SOT test to identify the relationship of the landing characteristics of the active Tactics Operators aged 27 ± 4.8 years. The results showed a higher visual preference of 100.3%, somatosensory score of 97.5 %, followed by visual of 89.3%, and then vestibular of 69.5 %.

The influence of the sensory system is dependent on the lifestyle, type of daily activities or physical demands of the young people and changes according to the requirements. The normative profile of the SOT during postural balance was developed with 542 participants aged 29.57 ± 6.37 years who were active military soldiers (Pletcher *et al.*, 2017a). All the participants in the study underwent the SOT test on the SMART Balance Master (NeuroCom® International, Inc., USA): All the groups in the study were physically active and showed significant differences in their postural balance abilities under conditions 1, 2, 4, 5, and 6 of SOT, but no significant difference was found in condition 3 of the SOT. The further significant difference was reported on the postural balance abilities under the somatosensory visual, vestibular and visual preferences between the groups.

The results of the study by Pletcher *et al.* (2017a) showed that naval special warfare combatant-craft crewmen aged 29.87 ± 6.38 years group exhibited no significant difference in their postural balance abilities using the sensory information compared with the naval special warfare command sea, air, and land in the 26.47 ± 4.91 years age group, but showed lower postural balance abilities under conditions 1, 2 and 4 of SOT. Further, they showed less postural balance abilities under condition 2, using the somatosensory and vestibular information, and higher postural balance abilities under condition 4 than the US army special operations command in the 33.46 ± 6.40 years age group. The navy crew group showed higher postural balance abilities under conditions 4, 5, and 6, composite score and the visual environment of the SOT when compared with the air force special operations command in the 27.63 ± 4.90 years age group. The naval special warfare command sea, air, and the land group showed better postural abilities under condition 4 of the SOT, composite score, using somatosensory and visual feedbacks, and showed less postural balance abilities under conditions 5, and 6, using somatosensory and vestibular influence to balance the posture than the US army special operations command. Further, this group showed higher postural balance abilities under conditions 1, 2 3, and 6 of SOT and composite score using somatosensory feedback compared to the Air Force Special Operations Command group.

Further, Pletcher *et al.* (2017a) showed that the Air force special operations command showed less postural balance abilities than did the USA special operational command group under conditions 1, 2, 5, and 6 and the composite score of SOT. Thus, this group also exhibited less postural balance abilities in the somatosensory, vestibular conditions; however, they showed higher postural balance abilities under visual conditions. All four groups represented in the normative profile of SOT test were young but belonged to different branches of the armed forces. Besides age, the sensory influence on the postural balance can be changed according to the physical status of the young individuals (Pletcher *et al.*, 2017).

The postural balance abilities change under the influence of different sensory information. In the same way, the strategies used to balance the posture also change under the influence of the sensory information (Horak, Shupert, & Mirka, 1989). The effect of the somatosensory and vestibular information on the postural balance strategies were observed in a cross-sectional study by Horak, Nashner, & Diener (1990). In this study, 6 healthy subjects aged 30 to 55 years were subjected to anaesthesia on their feet and ankles (to be considered somatosensory loss) and 4 patients with a vestibular loss from 55 to 63 years in age were recruited for this study. Horak, Nashner, & Diener

(1990) used SOT to identify the effect of the somatosensory and vestibular inputs to maintain posture. The findings of this study were compared with the healthy subjects of the Horak & Nashner, 1986 study. The subjects with somatosensory loss showed more hip strategy compared to the ones with vestibular loss and the control subjects of the study of Horak & Nashner, 1986. The results of this study confirm the concept that information which comes from the ankle plays a great role in maintaining the posture and when the subjects use hip strategy, they use the vestibular function to support them to balance their posture.

The postural balance strategies are also dependent on the physical activity and type of activity or physical requirements of the daily life routine of the individual (Chow *et al.*, 2016b). In the cross-sectional study on rugby players, the influence of sensory integration on postural balance and balance strategies were identified by Chow *et al.* (2016b). Two groups were subjected to the SOT. The rugby group included 45 players aged 21.9 ± 2.9 years, and the control group consisted of 41 active university students without any specific sports training, aged 21.0 ± 1.4 years. The control group showed significantly higher postural balance under conditions 1, 2, 4, and 6 and a composite score of the SOT than did the rugby players, as well as higher ankle strategies from condition 1 till 6 and strategies composite score. The control group showed higher balance abilities under conditions 1, 3, 2, 4, 6 and 5, respectively, while the rugby group showed a decline in postural balance abilities from condition 1 to 6, accordingly. The postural balance strategies in the active university students were higher under conditions 1, 2, 3, 4, 6 and 5 accordingly, while the rugby group showed the same trend as the student group. The strategy during SOT was also dependent on the specific training and requirement of the activities. This study showed the composite score of strategies, which was not recommended or proposed by the manufacturer of the Balance Master (NeuroCom® International, Inc., USA) due to possible artifacts under conditions 4, 5 and 6 because the force plate moved during these conditions (NeuroCom International, 1991).

In summary, therefore, postural balance develops with the passage of age and can be reached to the level of an adult by the age of 15 years. The somatosensory system develops between the age of 3 to 4 years; while the visual function develops until15 years of age, the vestibular function develops after 15 years of age. (Hirabayashi & Iwasaki, 1995). Physical activity improves sensory integration in young people. It can be stated that the exercise group showed better SOT than the non-active group. Nonactive people dominated with visual information while the active group dominated with somatosensory information to balance the posture (Grace Gaerlan *et al.*, 2012). Johnson *et al.* (2018) also noted that the active young people dominated with the influence of the somatosensory, visual and vestibular systems to balance the posture.

Further Chow *et al.* (2016) and Pletcher *et al.* (2017) found that even in the young subjects, the influence of sensory integration was dependent upon the individual lifestyle, job requirements and physical demands of the daily life routine. Besides this, the sensory integration during balancing the posture also affected the strategies (Horak *et al*., 1989). Similar to Horak, Nashner, & Diener (1989) discovered that somatosensory impaired people use more hip strategies compared with the individuals with vestibular loss, and the strategies in young subjects under sensory integration too were dependent upon the type of physical activity and requirement of the specific tasks (Chow *et al*., 2016).

3.4 *Effect of aging on sensory integration in postural balance*

Visual, vestibular and somatosensory contributions to postural balance, muscle activation pattern and balance between the young and seniors was examined in a cross-sectional study by (Manchester, Woollacott, Zederbauer-Hylton, & Marin, 1989). They investigated, in a cross-sectional study, 32 subjects 18 to 32 ± 4 years of age young and neurological disorder-free 60 to 78 ± 5 years senior subjects including an equal number of women. In this study, the EMG was applied on four leg muscles (tibialis anterior, gastrocnemius, quadriceps, and hamstrings) of the left leg of each participant along with a hydraulically activated, movable platform (50 cm by 52 cm). This platform was capable of measuring the anterior and posterior displacement, moving 33 mm in 106 ms (velocity of 31.13 cm/s). The subjects performed five visual conditions with eyes open, foveal vision; peripheral; visual feedback unrelated to body sway, and eyes closed on four conditions of the platform: anterior, posterior, anterior servo-, and posterior servo- translations. The authors concluded that the young subjects demonstrated better balance abilities under the influence of the visual and somatosensory inputs; further, the muscle activation pattern of the seniors were found different from that of the young subjects in the results of the hip, using the hip strategy to maintain the balance.

Besides, age-related changes on sensory integration were investigated by Peterka & Black (1990) in an experimental study using subjects from 7 to 81 years of age in a sensory organisation to control posture. The authors investigated 214 subjects (90 male and 124 female). They used the AP angle to measure postural sway with the SOT. The postural balance abilities declined with age in terms of the somatosensory and visual feedbacks, especially in participants 50 years of age and older. Besides this, participants below 15 years of age felt challenged in maintaining the posture in the presence of somatosensory feedback compared to the elders. There were no age-related changes reported under balancing the posture on a stable surface and surroundings, with eyes in the open and closed conditions.

Furthermore, aging was found to exert an effect on postural balance under the influence of sensory information using the SOT, as shown by Cohen, Heaten, *et al.* (1996). A total of 94 participants without any neurological disorders were divided into four groups. Young 30 ± 7.7 years (17 males – 15 females), middle-aged 58.1 ± 6.9 years (10 males – 20 females), old 76.7 ± 2.5 years (11 males – 8 females) and elderly 83.5 ± 2.9 years (3 males – 10 females). The results of the study showed a significant decline in the composite sensory score, test conditions and strategies score with age, apart from condition one on the SOT. As there are more variations in the results of this study, normative data was recommended to be used to evaluate the sensory integration during postural balance in seniors.

Dettmer, Pourmoghaddam, Lee, & Layne (2015) presented the effect of aging on postural balance and tactile stochastic resonance stimulus (TSRS) in a cross-sectional interventional study using 10 young participants aged 25.1 ± 2.3 years (5 male and 5 female) and 9 seniors aged 78.6 ± 5.4 years (2 male and 7 female). A Mini-Mental State Examination was used to ensure that the subjects had no cognitive impairments. Then foot-sole embedding of three vibration tactors was done in each sole of the foot to measure the TSRS, and Balance Master (NeuroCom® International, Inc., USA) was used to measure the equilibrium score to analyse the postural balance during SOT. This study was conducted with and without the TSRS device. The study concluded that while the TSRS exerted a negative impact on the postural balance of the young subjects, it had a worse impact on the postural balance in the seniors. However, it had a positive impact on the interventions because the training with vibration support improved the postural balance in the seniors. Besides this, the significantly lower postural balance was reported in the senior subjects as they used hip strategy more than the young subjects.

The senior participants showed a significant relationship between the exercise and non-exercise group and the effect of lifestyle and sensory integration on postural balance. Rehfeld *et al.* (2017) reported the effect of physical activity on the sensory integration during the postural balance of seniors. In this study, 26 senior participants aged 67.9 ± 3.3 years, were divided into two groups. Group 1: n = 12 sports group and Group 2: n = 14 dance group. Both groups were free from any cognitive or physical disorder and followed the planned training for 18 months. The dance group took dance training, while the sports group underwent general fitness training like strength, endurance, and flexibility. The sensory influence on the postural balance ability in this study was measured using the SOT of the Balance Master (NeuroCom® International, Inc., USA). In the study of Rehfeld *et al.* (2017) the dance group showed significant improvement in the postural balance abilities of the somatosensory, vestibular and visual systems. The sports group showed improvement in the somatosensory and vestibular influence. Hence, physical activity was shown to influence the sensory integration in seniors for postural balance.

To summarise, Manchester *et al.* (1989) demonstrated that young people could balance posture better than the seniors under the influence of visual and somatosensory influence. Peterka & Black (1990) reported that postural balance abilities decreased under the visual and somatosensory information after 50 years of age. The composite sensory integration score decreases with aging, and normative data was proposed to be used to report the results Cohen, *et al.*, 1996 and Dettmer, Pourmoghaddam, Lee, & Layne (2015) showed TSRS to be an effective tool to improve the sensory integration and exert a positive effect on the sensory integration to balance the posture as reported by Rehfeld *et al.* (2017).

3.5 *Cortical activity during postural balance*

The cortical activity and cognitive process are highly involved in postural balance (Dubost *et al.*, 2006; Plummer, Apple, Dowd, & Keith, 2015; Priest, Salamon, & Hollman, 2008; Takakusaki, 2017). The subcortical structure were found to contribute to postural balance in animal studies (Armstrong, 1988; Drew, Prentice, & Schepens, 2004) and the cerebral cortices were also involved in the balance of posture in humans (Mihara, Miyai, Hatakenaka, Kubota, & Sakoda, 2008a).

In a controlled longitudinal study performed by Fujimoto *et al.* (2014) using 20 patients aged 60.2 ± 9 years, all having a subcortical stroke, the role of the supplementary motor area (SMA) of the cortex was investigated in the recovery of postural balance. The subjects went through seven-days-a-week rehabilitation sessions focused on muscle strength, balance, gait control and abilities for activities of daily life. The pre- and post- tests for postural balance were performed on a horizontal moving force platform with 15 random perturbations of 5 to 15 seconds each. The static and dynamic postural balance abilities were assessed using a tactile sensor sheet. The subjects were made to stand for static postural balance and for dynamic postural balance using the COP sway of the first 3 seconds. The cortical activity was measured by functional near-infrared spectroscopy (fNIRS) which included 16 light sources and 16 detectors. After the intervention, no significant difference was noted in the recovery of postural balance. However, it showed the correlation with improvement in the activities of daily life. Before rehabilitation and during the perturbation higher activity was observed in the affected prefrontal cortex (Ch. 47, t = 3.63). Even after the rehabilitation, the prefrontal cortex and SMA (Ch. 1, t = 3.8 and Ch.47, t = 2.9) (Ch. 21, t = 3.5, Ch 22, t = 3.0, and Ch.29, t = 3.2) showed significantly highly oxygenated haemoglobin (oxyHb) in relation to postural perturbation. Further, a positive correlation was found in the cortical activity between postural perturbation and postural balance recovery. The SMA performs a fundamental role in postural balance and its recovery.

Furthermore, the responsibility of the frontal lobe during postural balance was examined by Mihara, Miyai, Hatakenaka, Kubota, & Sakoda (2008) in an experimental study. They used 15 individuals aged 29.4 ± 6.7 years, in their study. The subjects were made to stand on the centre of a custom-made platform, and horizontal translation backward and forward stimuli were given to the subjects on the platform, at a velocity of 0.5 m/s under two conditions. The first condition was notified by an auditory signal before 2 seconds of the perturbation of the platform while the second condition occurred without notification. For each condition, 20-30 trials were performed for 5 to 20 seconds each. The cortical activity during postural balance was examined by a 50-channel functional near-infrared spectroscopy (NIRS) system with 16 light sources and detectors, placed on the frontoparietal skull surface with 3 cm distance from each other. Due to the perturbation, the dorsolateral prefrontal cortices (DLPFC) and frontal eye field (FEF) showed high activation regardless of feedback, which showed involvement in postural balance under the condition of no auditory feedback. The SMA and superior parietal lobule (SPL) were activated in response to the perturbation with auditory feedback, which involved the attention ability. Hence, this study showed the involvement of the prefrontal cortex in postural balance.

The cortical involvement in the anticipatory postural adjustments (APAs) during the standing and sitting conditions in relation to movement-related cortical potentials (MRCP) was reported in an experimental study by Yoshida, Nakazawa, Shimizu, & Shimoyama (2008) with 12 right-handed participants (9 males and 3 females) aged 21-39 years (mean age 25.5 years). These individuals performed unilateral shoulder flexion during the sitting and standing conditions 50 times. The EEG was recorded from 9 channels F3, F4, FZ, C3, CZ, C4, P3, PZ and P4 by the 10-20 system and the EMG was recorded from the deltoid anterior, erector spinae, rectus abdominis, biceps femoris and rectus femoris muscles on the right side. The MRCP component was greater during the standing position, while the readiness potential showed a significant difference in the frontal and pre-central electrode sites. The motor potential was higher in the standing position, and the movement-monitoring potential frontal and pre-central electrode sites also showed a significant difference. In the light of these results, it is clear that the SMA plays a vital role in APAs during voluntary movements.

The N1 potential in postural balance is defined as a predictor of sensory processing during postural balance (Quant, Adkin, Staines, & McIlroy, 2004). The effect of the predictable and unpredictable external perturbations during postural balance on the N1 event-related potential was examined by Adkin, Quant, Maki, & McIlroy (2006) in an experimental study using 8 young subjects aged 17–32 years. The subjects were made to stand still with the eyes closed for 30 predictable, surprise and unpredictable perturbations applied on them from the forwards, backwards and sideways directions. The force-sensitive resistor (FSR) recorded both intensity and timing. Postural balance was measured by AP direction of COP on a force plate. The EMG was recorded from the muscle activation of the medial gastrocnemius, and electroencephalographic (EEG) activity was recorded from the AFz, Fz, F3, F4, FC3, FC4, C3, C4, CP3, CP4, Pz, P3, P4, and Oz, but for the analysis only three central channels FCz, Cz, and CPz were used. The results of the EEG were limited to the N1 event-related potential or perturbation-evoked responses (PERs). In unpredictable perturbation the N1 was found to be high in the Cz, FCz and CPz channels at -19.9 ± 5.1 μV, -22.1 ± 5.0 μV, -7.6 ± 2.8 μV and similar to the surprise perturbation condition. A predictable condition produced a negative impact on the N1, and the amplitude became reduced and showed positive polarity. No significant difference was seen in the muscle activation under any condition; however, in postural balance, a significantly high backward direction COP was found in the predictable perturbation. The high amplitude in the surprise condition shows that the subjects expected feedback similar to unpredictable perturbation, so the amplitude in N1 was similar to the unpredictable condition. In this study, large amplitude was not related to providing perturbation; rather it is related to expect the information regarding a challenge to reach the CNS in order to modify the anticipatory adjustments which are self-reliant and not associated with the sensory information or motoric response.

The effect of the cognitive loads on the cortical activity before and after the perturbation to the postural balance was identified by Mochizuki, Boe, Marlin, & McIlroy (2017) in their experimental study on 10 healthy subjects. Subjects underwent predictable and unpredictable perturbations, including concurrent cognitive tasks, which demanded attention ability. In this study, the COP and lean force were measured using the force platform, while the cortical activity was assessed from the EEG data from Fz, FCz, Cz, CPz, Pz, C3, C4, FP1 and FP2 on the 10-20 base system. Only the Cz electrode was selected, and the data was averaged over 25 to 35 trials, across all the conditions. In the meantime, the EMG from the medial gastrocnemius and tibialis anterior muscles, bilaterally, was measured. The cognitive task reduced the amplitude in the event-related N1 potential cortical activity during the pre-perturbation of the predictable condition with the cognitive load and compared to the value without the cognitive load in the predictable condition - Mean 18.7(3.0) mV ms; predictable with the cognitive load; 14.0(2.3) mV ms. The opposite trend was observed after the perturbation under the same conditions and the amplitude was increased after the predictable perturbation condition -32.1(3.2) mV; predictable condition with cognitive load -50.8 (8.4) mV. The cognitive task did not influence the cortical activity in relation to the unpredictable task in postural balance. The EMG results revealed a delay and reduced activity in the value of the initial gastrocnemius in the presence of a cognitive load. It was therefore concluded that the cognitive load could affect postural balance in the pre- and post-conditions.

Varghese *et al.* (2014) explored the aspect of EEG frequencies during postural balance in an experimental study on 14 subjects aged 26.6 ± 4.4 years, who were subjected to perturbation on a force plate with 40 trials each. The postural balance was assessed on a force plate with the lean and release cable system. The EMG was recorded from the gastrocnemius, and tibialis anterior and the EEG was recorded by 64 channels. The reaction of postural balance occurred at 182.4 ms, 184.1 ms on the right and left right medial gastrocnemius and evoked a negative potential (N1) response at the FCz frontocentral area of the cortex found at 107.9 ms with a mean amplitude of 30.85 µV. The power at the frontocentral electrodes increased with the postural perturbation-evoked delta, theta, alpha, and beta frequencies and revealed a relationship with N1. These results suggested that the EEG power spectrum increased with respect to postural perturbation.

The cortical response during reactive balance and its relation to cortical activation was explored by Varghese, Beyer, Williams, Miyasike-daSilva, & McIlroy (2015a). In this study, 20 subjects aged 19-37 years performed feet parallel stand and tandem stand for 30 seconds for 3 trials. Meanwhile, the 32 channel EEG 10-20 system was used to measure the cortical activity and the epoch of 2 seconds prior to and 2 seconds post the ML displacement peak was considered. The subjects showed decreased postural balance abilities in the tandem stand. The N1 evoked potential was higher in the tandem stand

and before the ML displacement peak in the Cz channel, and the frontocentral component was responsible for that. The high trends observed in the delta (1–4 Hz), theta (4.1–7 Hz), and gamma (28-30Hz and 33-50Hz) sites of the frontocentral-parietal areas of the cortex, which were higher during the tandem stand. This study contributes to a better understanding of the role of N1-evoked potential during postural balance, in that the power spectrum increased before and during reactive postural balance.

Saitou, Washimi, Koike, Takahashi, & Kaneoke (1996) investigated via an experimental study a mechanism of the CNS, which performed postural movements. They investigated 10 males aged 28 to 45 years (mean age 34 years). These individuals were made to stand still and rise on tiptoe on a self-selected pace for 10 seconds for 50 trials. Meanwhile, the EEG was recorded from the Cz, Cza, Czp, LC, RC, LCa, RCa, LCp, and RCp sites with a common reference and an EMG was recorded from the left soleus muscle to identify the pre-motion silent period. It was identified that prior to the voluntary movement of the foot, the readiness potential and negative potential were similar in relation to the EMG, which in turn is related to the time prior to the postural adjustment, especially on the frontal electrode. This cortical potential anticipates postural orientation.

The response of the neural detectors, which act in the cortex to compensate for the stability required for fall prevention was examined by Slobounov, Hallett, Stanhope, & Shibasaki (2005) in an experimental study. They selected 12 subjects aged 21-25 years for this study and subjected them to two tasks on the force plate: first, they moved voluntarily in the AP direction for 30 seconds and 5 times, and second, they just moved only in an anterior direction for 10 seconds and 60 sways. These tasks were conducted two times. While the postural balance was recorded by the force plate, the muscle activation was recorded by the EMG from the tibialis anterior and right gastrocnemius muscles and the EEG was recorded by 25 electrodes on the 10-20 system: FP1, FP2, F3, Fz, F4, FC3, FCz, FC4, C3, C1, Cz, C2, C4, CP3, CPz, CP4, T3, T4, P3, Pz, P4, O1, Oz, O2. The highest activation in the gastrocnemius muscle was observed in the forward sway, followed by the tibialis muscle. The voluntary postural adjustment resulted in the slow negative potential, which was similar to the movement-related cortical potentials (MRCP) on the frontocentral electrode sites (F3, Fz, F4, Fcz, C3, C4, P) and the maximum motor potential found at the Cz electrode site. With regards to compensating the postural balance, the gamma frequency increased in the frontocentral and parietal lobes (Fz, Fcz, F3, F4, Cz, C4, Pz,), especially at the Cz electrode site. This study concluded that the gamma activity triggered the prevention measures to the central command to react for stabilising the posture under dynamic conditions.

In another experimental study performed by Semyon Slobounov, Hallett, Cao, & Newell (2008) the cortical response was reported in terms of directional postural movement when 12 subjects were made to move in the AP and ML (left and right) directions on the force plate. The EEG was recorded from 19 channels viz., FP1, FP2, Fz, F3, F4, FCz, FC3, FC4, Cz, C3, C4, CP3, CP4, Pz, P3, P4, O1, and O2, which were placed according to the 10-20 system. A total of 60 artifact-free trials were analysed. However, the subjects demonstrated no differences in the COP. The subjects revealed high MRCP during the ML movement and the alpha (8–12 Hz), beta (14–25 Hz) frequencies declined before the start of the movement in the frontal area of the cortex (FP1, FP2, Fz, F3, F4) under all the conditions tested, showing an especially high decline in the ML postural movement. The gamma activity displayed the same trend as in the previous study at the maximum movement burst of activity and the Cz electrode. The gamma activity in the frontocentral region initiated the compensation response to balance the posture.

The cortical response during the upcoming challenge to control posture was explored with virtual time to contact (VTC) in an experimental study by Semyon Slobounov, Cao, Jaiswal, & Newell (2009). The COP was recorded using a force plate when 12 subjects aged 22 to 24 years were made to stand on one foot for as long as they could. The pre-falling, transition and falling periods were derived from the force plate. The cortical activity was measured by 64 channels on the 10-20 system. The alpha (8–12 Hz) frequency showed a decline during the falling period in the occipital lobe. Bursts of gamma (30–50 Hz) and higher Theta (4–5 Hz) frequencies were recorded during the transition period in the central frontal cortical region. The ICA components of low-resolution brain electromagnetic tomography (LORETA) demonstrated sources in the anterior cingulate gyrus (ACC), precuneus part of the limbic lobe and the occipital lobe. In terms of a future challenge to postural balance, the frontocentral and parietal-occipital regions play a role in anticipation of the future challenge.

The cortical response to balance the posture in static condition was also reported in a few studies. The impact of the theta activity in the cortex during the postural balance task was the focus of the experimental study performed by Hülsdünker, Mierau, Neeb, Kleinöder, & Strüder (2015). The EEG data was recorded of 37 participants aged 24.7 ± 3 years, who were subjected to three balance conditions viz., both legs standing, and one-leg stand on the dominant and non-dominant leg, with three levels of postural balance tasks; static surface, unstable surface and highly unstable surface. The postural balance was assessed by the oscillation observed in the AP and ML directions. The EEG was recorded from 32 channels on the 10-20 system. The subjects showed significant difficulty with a postural balance under all three conditions. The frontal, central, and parietal lobes of the cortex showed higher activity in the theta frequencies in relation to the increase in the difficulty of the tasks. Besides this, the centroparietal and frontocentral cortices showed an increase in the theta activity with the increase in the difficulty of the postural balance tasks. This study demonstrated the role of the theta activity in the frontal and parietal lobes of the cortex.

In another experimental study related to the individual alpha peak frequency (iAPF), Hülsdünker, Mierau, & Strüder (2016) explored the role of the iAPF in postural balance in an experimental study following the (Hülsdünker, Mierau, Neeb, Kleinöder, & Strüder, 2015) method, with extended focus on the theta (4–7 Hz), lower alpha (8–10 Hz) and upper alpha (11–13 Hz) frequencies during the postural balance tasks. They found that the iAPF was higher in the centroparietal cortex, and the theta frequencies were high in the centroparietal region compared to the frontal and frontocentral cortex. The lower alpha was reduced in the frontocentral region, while the high alpha frequencies increased in the frontocentral cortex when the subjects moved from both legs to the single leg task, which made the task difficult for them. Further, the theta, alpha and iAPF showed correlation with the difficulty of the task. This study showed the behaviour of the different frequencies during postural balance.

Del *et al.* (2009) analysed the cortical activity between athletes and non-athletes in postural balance in a cross-sectional experimental study on 10 karate athletes aged 23.9 ± 1.3 years and 10 fencers aged 26.2 ± 1.4 years and 12 non-athletes aged 26.5 ± 1.7 years. In the study performed by Del *et al.* (2009) the subjects stood on the stabilometric force plate for 60 seconds each, first with feet together and then made a one-leg stand. At the same time, their sway in the AP and ML directions was recorded to identify their postural balance abilities. The EEG was recorded from 56 channels according to the 10-20 system to observe the cortical response during this balancing task, and the data from nine EEG channels were reported per the region of interest of the researcher. Here, the F3, Fz, F4, C3, Cz, C4, P3, Pz, and P4 and iAPF band was considered for analyses. The data from only 10 to 40 seconds was considered for analysis, to ignore the effect of fatigue. The subjects showed better balance with feet together compared to the single leg stand, with no significant difference in the conditions. Non-athletes generated more alpha-1 activity (8-10 Hz) in the left centre, right centre, middle parietal and right parietal cortex in the feet together condition. The same trend was observed in the one-leg stand condition where fewer alpha-2 activities (10-12Hz) were generated by the athletes in the right frontal, left the centre, right centre, and middle parietal regions of the cortex. The alpha activity was lower due to well-established postural balance abilities in the athletes, and they required less processing of the thalamocortical and cortico-cortical loops to balance the posture.

In summarising, the SMA plays a fundamental role in the balance and recovery of the posture (Fujimoto *et al.*, 2014). The SMA and superior parietal lobule (SPL) was first activated after the perturbation and involved attention abilities (Mihara *et al.*, 2008b); the SMA also had an important role to play during voluntary movements (Yoshida *et al.*, 2008).

The cortical activity in N1 is less during the unpredictable condition compared to the predictable one in postural balance. This is related to the information regarding the expected challenge going to the CNS to modify the anticipatory adjustments which are self-reliant and not associated with either the sensory information or motoric response (Adkin *et al.*, 2006). The N1 also responds in similar fashion during the concurrent cognitive tasks (Mochizuki *et al.*, 2017). Besides, less amplitude is noted to evoke a negative potential (N1) and the delta, theta and gamma activities get higher in the frontocentral regions in relation to the difficulty of the task under perturbation (Varghese *et al.*, 2014; Varghese, Beyer, Williams, Miyasike-daSilva, & McIlroy, 2015). Before voluntary perturbation of the foot, the readiness potential and negative potential are similar (Saitou *et al.*, 1996). S. Slobounov, Hallett, Stanhope, & Shibasaki (2005) reported higher gamma activity in the frontocentral and parietal lobes with regards to the difficulty of the task in posture balance. Semyon Slobounov, Hallett, Cao, & Newell (2008) showed a decline in the alpha and beta activities of the frontal lobe before perturbation and the gamma activity was higher before instability in the central lobe of the cortex to initiate the compensation response to balance the posture. In relation to falling down Semyon Slobounov, Cao, Jaiswal, & Newell (2009) reported that the alpha activity declined in the occipital lobe just prior to falling down while the theta and gamma activities showed an increase in the centre frontal region, and the anterior cingulate gyrus (ACC), precuneus part of the limbic lobe and the occipital lobe sources are involved behind these EEG frequencies. In terms of a future challenge to postural balance, the frontocentral and parietal-occipital regions play a role in anticipation of the future challenge.

With respect to the continuous static postural balance task, T. Hülsdünker, Mierau, Neeb, Kleinöder, & Strüder (2015) reported higher theta activity in the frontal, central, and parietal lobes, which increased as the task became harder. In another study, Hülsdünker, Mierau, & Strüder (2016) reported higher alpha and theta activities in the centroparietal cortex compared to that observed in the frontal and frontocentral cortex in response to task difficulty. Del *et al.* (2009) also reported higher alpha 1 activity and lower alpha 2 activity in the young non-players in the left centre, right central, middle parietal and right parietal cortex, compared with that of the active young players.

Further, the influence exerted by aging on the supraspinal locomotor during imaginary locomotion and stand was reported using functional magnetic resonance imaging (fMRI) by Zwergal *et al.* (2012a). In this study, 60 subjects aged 28 to 78 years were given training in the lying, standing, walking, and running conditions to imagine the situation in an MRI scanner which was performed during the experiment. From the results of that study, it was reported that the supraspinal locomotor centres were not influenced by the aging process, although the multisensory cortical control had been affected. The young participants showed activation in the motion-sensitive visual cortex (MT/V5) (red colour), while the multisensory vestibular cortical areas (PIVC) and somatosensory cortical regions (Brodmann areas [BA] 3/4) were deactivated (blue colour). Senior persons (right) during locomotion reveal multisensory cortical activation (visual, vestibular, somatosensory) due to the reduced reciprocal inhibitory sensory interaction. This may act as a compensatory mechanism for the decline with age of the peripheral sensory system and may indicate a more conscious mode of locomotion in the elderly participants (Fig.16).

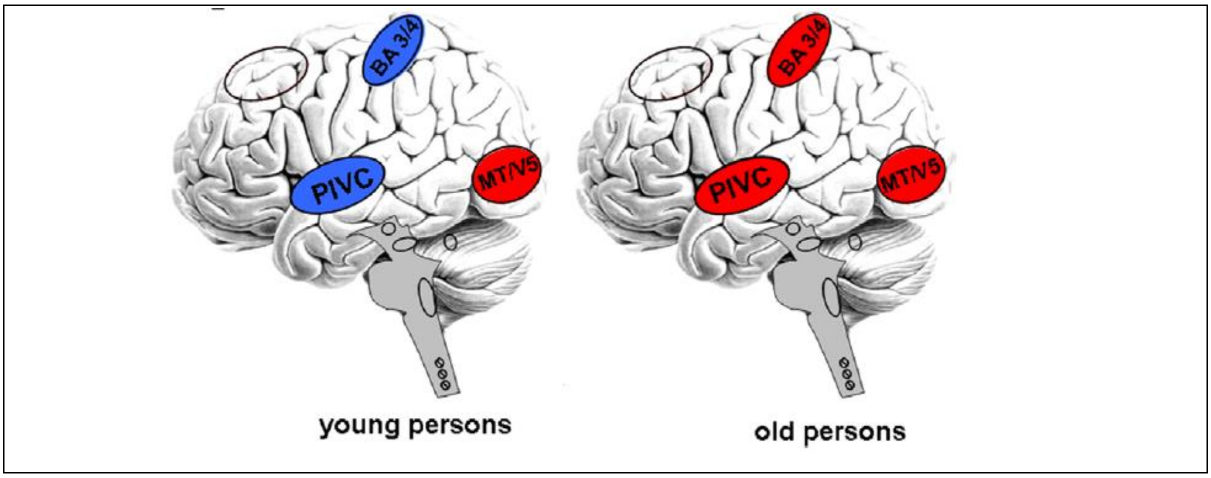


Fig. 16. The changes that occurred due to aging in the activation of during imaginary locomotion and standing tasks (Zwergal *et al.*, 2012b, p. 1082)

3.6 *Cortical activity under the sensory influence*

The cortical response in relation to visual feedback to balance posture between active and non-athletes was discovered by Del *et al.* (2007) in his cross-sectional experimental study. Further, in the absence of visual feedback, the subjects depend on the somatosensory feedback, and as there was no movement of the platform, the influence of vestibular system could also be ignored. It is for this reason that this study helps to give a better understanding of the cortical response with respect to the somatosensory input to balance posture. In this study, 19 karate, 18 fencing and 10 non-athletic individuals aged 19-32, 19-36 and 21-34 years, respectively, underwent postural balance tasks on a force platform which could record the COP in the anteroposterior and ML directions. Each subject accomplished two trials under eyes open and eyes closed conditions each lasting for 40 seconds. The cortical response during the experiment was measured with 56 channels on the 10-20 system, and an EEG. Meanwhile, an EMG was recorded from the tibialis and gastrocnemius lateralis muscle. The participants showed low postural balance under the eyes closed condition. Further, no effect was found between the groups. The alpha activity (event-related desynchronization, ERD) was higher in amplitude at C6 channel in the karate athletes, at channels CP6 and C6 in fencing athletes compared to the non-athletes. The parietal-occipital regions showed the higher presence of the ERD in the cortex. The alpha activity increased during balancing posture under the eyes closed condition when compared to the eyes open condition in the parietal-occipital regions, which represent the high demand of cortical processing during the eyes open condition. The alpha ERD also showed a positive correlation with postural balance abilities, and its presence in the right hemisphere demonstrated the effect of long-term training to control posture.

The frequency changes in the cortical activity with the eyes open and closed with auditory biofeedback (ABF) were analysed in an experimental study with 10 subjects from age 24-72 years by Pirini, Mancini, Farella, & Chiari (2011). Postural balance was measured using a 3D accelerometer, which can provide information regarding the AP and the ML positions of the subjects. The subjects balanced the posture for 90 seconds in the eyes open and closed conditions, with and without ABF. The cortical activity was measured with 19 channel EEG on the 10-20 system. The subjects demonstrated low postural balance abilities in the eyes closed conditions with and without ABF. In terms of cortical activity, the alpha activity decreased in the eyes open condition in the inferior parietal lobe, while the gamma frequency increased in the left temporoparietal region of the cortex during the eyes closed task. These areas in the cortex are responsible for the multi-sensory, perceptual integration, and sensorimotor influence.

The effect of the visual and somatosensory challenges on the cortical response in relation to the alpha (8-12), beta (13-19) and sigma (30-40) frequencies was explored with eight balance tasks with the EEG Power Spectrum Density (PSD) by Tse *et al.* (2013) in their experimental study. They selected 17 subjects aged 24-32 years and passed them 8 postural balance tasks on the postural balance measurement platform. Four tasks included parallel feet, tandem feet, eyes open parallel feet and eyes closed in the tandem stand. The same tasks were performed on foam, while the EEG was recorded from 9 channels. The PSD beta and PSD sigma band increased when foam was included to control the posture at the parietal and central cortex (Fz, Cz, and POz) during the vision, change of base to tandem and change of surface. The results revealed that as the task increased in difficulty, the PSD beta and gamma activities became higher in the cortex to balance the posture.

The psychological state of the cortex was investigated during the postural balance with high-resolution Positron Emission Tomography (PET) by Ouchi, Okada, Yoshikawa, Nobezawa, & Futatsubashi (1999) in an experimental study. Eight healthy subjects aged 31.8 ± 6.1 years underwent baseline, in which they were made to lie down and focus on a spinning target rotating at a distance of 1m. Further, they controlled the posture for 60 seconds under four conditions and focused on the rotating object, except for the 4th condition. Condition 1. Standing with parallel feet; Condition 2. Standing on one foot; Condition 3. Standing on tandem feet and Condition 4. Parallel feet with eyes closed. A high-resolution mobile gantry enabled vertical movement. The PET scanner was used to measure the cortical activity. Regional cerebral blood flow (rCBF) increased in the right primary and secondary visual cortex and cerebellar anterior lobe during the standing condition. One-leg stands were observed to increase the anterior cerebellar vermis and the posterior lobe lateral cortex on the side of the supporting leg. During tandem stand, the rCBF increased in the visual association cortex, anterior and posterior vermis and the midbrain. Standing with the eyes closed increased the rCBF in the prefrontal cortex. This study concluded that the cerebellar vermis efferent system is an essential component of postural balance. Further, in the absence of visual feedback, the prefrontal cortex is highly active and helpful in compensating for the absence of visual information to balance posture.

Chang, Yang, Yang, & Chern (2016) explored the cortical responses during postural balance and visual interference with an augmented reality (AR) environment. In this cross-sectional experimental study, the 31 participants were divided into two groups. The group with low fall included 15 subjects aged 68.4 ± 2.58 years and the one with high fall included 16 subjects aged 70.2 ± 2.2 years. The subjects stood on 6 degrees of freedom (DOF) moving platform, which was attached to virtual reality (VR) system, which provided the environment of riding a bus. The participants were subjected to the following conditions during the experiment: with and without VR; (S) stand on static platform for 5 to 10 seconds; (F) moving forward 10 to 11 cm in 1 second; (D) downwards 0° to 10° with forward movement of 11 to 14 cm in 0.5 seconds; (U) upward with backward movement from 14 to 11cm in 0.5 seconds; (R) recovery till start point in 15 seconds. The EEG from 32 channels was recorded to identify the response of the cortical activity through the entire experiment and the results of Fz, Cz, Pz, and Oz were considered. Significantly high theta and alpha frequencies of the power spectral density were observed for the low fall group in the Cz channel under VR conditions. The Pz and showed higher activity in the theta, alpha, beta and gamma frequencies under the VR condition and between the groups. The Oz channel showed higher activity in the frequencies mentioned earlier only under the VR and non-VR conditions but showed no difference between the groups. In this study, the subjects showed dependence on visual information to balance posture. The prefrontal lobe, visual cortex, and parietal lobe showed higher activity with the visual tasks. In relation to the frequency, the gamma and beta activities showed sensorimotor integration in the parietal-occipital region. The theta band facilitated error detection via the frontal and central regions. In the presence of high visual processing, the alpha frequency shows high activities in the occipital lobe. In conclusion, higher cortical activity is required to face the challenge of postural balance. The cortical response can be one of the internal factors, which can cause falls in seniors even in the absence of any neurological disorder.

Ozdemir, Contreras-Vidal, & Paloski (2018) investigated the effect of aging on the cortical activity under the somatosensory and vestibular influence to balance the posture with a cross-sectional experimental study on the dynamic posturography platform (NeuroCom® Balance Master). Ten young individuals aged 26.20 ± 2.77 years and 9 seniors aged 81.42 ± 6.30 years were subjected to the postural balance test during static and eyes open condition and eyes closed condition, and eyes closed condition with the moving platform. The ROI report results were considered as frontal (F3, F1, Fz, F2, F4), central-frontal (Fc5, Fc3, Fc1, Fc2, Fc4, Fc6), central (C3, C1, Cz, C2, C4), central-parietal (Cp3, Cp1, Cpz, Cp2, Cp4) and parietal lobe (P3, P1, Pz, P2, P4). While the delta activity was found to be 0.2 to 4 Hz and gamma 30-50 Hz higher in the central-frontal, central, and central parietal lobes of the cortex in the young participants, the senior participants also showed higher gamma activity in the sensorimotor and parietal than the young participants.

In summary, Del *et al.* (2007) reported that the alpha activity increased during postural balance under the somatosensory influence in the parietal-occipital regions along with positive correlation to postural balance. In another study reported by Pirini, Mancini, Farella, & Chiari (2011) the alpha activity decreased in the eyes open condition in the inferior parietal lobe, while the gamma frequency increased in the left temporoparietal area of the cortex under the somatosensory influence. Tse *et al.* (2013) reported higher beta and sigma bands during the somatosensory, visual and vestibular influence to balance the posture. Ouchi, Okada, Yoshikawa, Nobezawa, & Futatsubashi (1999) reported the cerebellar vermis efferent system is an essential component of postural balance. Further, in the absence of visual feedback, the prefrontal cortex is highly active and helpful in compensating for the absence of visual information to balance posture. According to Chang, Yang, Yang, & Chern (2016), high levels of cortical activity were required for stabilising the posture in the senior participants, and the prefrontal lobe, visual cortex, and parietal lobe showed higher activity with visual tasks to balance the posture. With regards to frequency, both the gamma and beta activities showed sensorimotor integration in the parietal-occipital region. Ozdemir, Contreras-Vidal, & Paloski (2018) reported higher delta and gamma activities under the somatosensory and vestibular influences; besides, the seniors showed higher gamma activity in the sensorimotor and parietal lobe compared to the young participants.

3.7 *Rationale of the study*

3.7.1 Effect of aging on postural balance

Postural balance abilities diminish with the aging process (Barbieri & Vitório, 2017; Bradley, 2011; Era *et al.*, 2006). However, the decline in postural balance can be counteracted with physical activities and exercise (Giangregorio & El-Kotob, 2017; Kujawski *et al.*, 2018; Low, Walsh, & Arkesteijn, 2017; Marques, Figueiredo, Harris, Wanderley, & Carvalho, 2017; Melanson, 2017; Mikó, Szerb, Szerb, & Poor, 2017). No study thus far has reported the effect of aging on the postural balance in the physically active or senior individuals who are involved in regular sports activities, which is one of the considerations of the present study.

To balance the posture, the ankle and hip strategies are available; when the ankle alone cannot control the sway during postural balance then the hip muscles get activated to support the postural balance (Nashner, 1977) and the strategies to balance the posture are also dependent on the base of support (Gatev *et al.*, 1999; Horak & Nashner, 1986). The hip and ankle strategies together support the posture to be in balance and do not react alone (Hwang *et al.*, 2009; Runge *et al.*, 1999). Healthy people use 90 % ankle strategy to balance the posture (Blenkinsop *et al.*, 2017) and a relationship is evident in the strategy to balance the posture. As the balance abilities get worse, the individuals tend to depend more on the hip than the ankle strategy (Day *et al.*, 1993). Aging thus affects these strategies to balance the posture and seniors receive a greater contribution from the hip muscles and are dependent on hip strategy (Amiridis *et al.*, 2003). In the study by Day, Steiger, Thompson, & Marsden (1993) a positive relationship has been shown to exist between the strategies to balance the posture and enhance the postural balance abilities. Besides the postural balance abilities, exercise also helps to improve ankle dependent strategy (Ashton-Miller, Wojtys, Huston, & Fry-Welch, 2001). In the previous studies, no effect was reported of the balance strategies in light of the aging process in healthy physically active individuals, which is also one of the objectives of the present study.

3.7.2 Effect of aging on sensory integration to balance posture

As postural balance is a complex skill, it is attained by receiving the sensory information from the somatosensory, visual and vestibular systems which are processed by the cortex to generate a motoric response to stabilise the posture (Horak, 2006; Pollock *et al.*, 2000). Chow *et al.* (2016) and Pletcher *et al.* (2017) found that even in the young subjects the influence of sensory integration depends upon the lifestyle, job requirements and physical demands in the daily life routines of the individual. Besides, the sensory integration while balancing the posture also affects the strategies (Horak *et al.*, 1989). Horak, Nashner, & Diener (1989) reported that somatosensory impaired individuals use more hip strategies compared to those with vestibular loss and the strategies in young subjects under sensory integration are also dependent on the type of physical activity and the requirement of specific tasks (Chow *et al.*, 2016b). The findings of Chow *et al.* (2016b) are questionable because the manufacturer of the Balance Master (NeuroCom® International, Inc., USA) did not recommended it as a tool to compute strategies in relation to sensory integration, due to possible artifacts in conditions 4, 5 and 6 because the force plate had moved under these conditions (NeuroCom International, 1991). Manchester *et al.* (1989) demonstrated that young individuals could balance their posture better than the seniors under the visual and somatosensory influence. Peterka & Black (1990) reported that postural balance abilities decreased under visual and somatosensory information after 50 years of age. The composite sensory integration score too decreases with aging, and it was proposed to use normative data to report the results (Cohen, *et al.*, 1996). The young individuals included in the exercise group showed better SOT than the non-active group. In non-active individuals, the visual information was dominant while in the active group the somatosensory information was dominant in postural balance (Grace Gaerlan *et al.*, 2012). The positive effect on the sensory integration in postural balance was reported by Rehfeld *et al.* (2017). The sensory integration abilities between the young active and senior active individuals have been considered for the first time in the current study.

3.7.3 Cortical modulation to balance the posture

The SMA plays a fundamental role in posture balance and its recovery (Fujimoto *et al.*, 2014; Yoshida *et al.*, 2008). It is even more intensely activated during balancing the posture (Mihara *et al.*, 2008b; Yoshida *et al.*, 2008).

Many studies reported that event-related cortical activities like N1 decrease during unpredictable conditions compared to the predictable ones to balance the posture (Adkin *et al.*, 2006). Besides, there is less amplitude when evoking a negative potential (N1) and the delta, theta and gamma activities increase in the frontocentral regions in relation to the difficulty of the task under perturbation (Varghese *et al.*, 2014; Varghese, Beyer, Williams, Miyasike-daSilva, & McIlroy (2015b). Prior to the voluntary perturbation, the readiness potential and negative potential are similar (Saitou *et al.*, 1996). Slobounov, Hallett, Stanhope, & Shibasaki (2005) reported higher gamma activity in frontocentral and parietal lobes corresponding to the difficulty of the tasks to balance the posture. Semyon Slobounov, Hallett, Cao, & Newell (2008) showed a decline in the alpha and beta activities in the frontal lobe before perturbation while the gamma activity was higher prior to instability in the central lobe of the cortex. In terms of falling down, Semyon Slobounov, Cao, Jaiswal, & Newell (2009) reported that the alpha activity declined in the occipital lobe prior to the individual falling down while the theta and gamma activities increased in the frontocentral region.

In relation to a continuous postural balance task, Hülsdünker, Mierau, Neeb, Kleinöder, & Strüder (2015) reported greater theta activity in the frontal, central, and parietal lobes, which increased as the task became more difficult. In another study, Thorben Hülsdünker, Mierau, & Strüder (2016) reported higher alpha and theta activities in the centroparietal cortex compared to the frontal and frontocentral cortex in response to task difficulty. Del *et al.* (2009) also reported higher alpha 1 activity and lower alpha 2 activity in the young non-players in the left centre, right central, middle parietal and right parietal cortex compared to that of the active young players.

As aging progressed, the involvement of the higher order cortical network increased in the seniors to balance the posture (Ozdemir, Contreras-Vidal, Lee, & Paloski, 2016a). Zwergal *et al.* (2012a) also reported the sensory area in seniors to get more active then young people in imagery MRI study, However, there is no detailed study which reported the effect of aging on the cortical modulation to balance static posture in active senior people. Due to the importance of the problem of postural balance, the effect of aging on the cortical modulation is one of the objectives of the current study.

3.7.1 Cortical modulation to balance the posture under sensory influence

Del *et al.* (2007) reported that the alpha activity increased during postural balance under the somatosensory influence in the parietal-occipital regions along with positive correlation with postural balance. In the study of Pirini, Mancini, Farella, & Chiari (2011) the alpha activity was observed to decline in the eyes open condition in the inferior parietal lobe, while the gamma frequency increased in the left temporoparietal area of the cortex under the somatosensory influence. Tse *et al.* (2013) reported higher beta and sigma bands during somatosensory, visual and vestibular influence to balance the posture. Ouchi, Okada, Yoshikawa, Nobezawa, & Futatsubashi (1999) reported the cerebellar vermis efferent system is an essential component of postural balance. Further, in the absence of visual feedback, the prefrontal cortex is highly active and helpful in compensating for the absence of visual information to balance posture. According to Chang, Yang, Yang, & Chern (2016), high levels of cortical activity were required for stabilising the posture in the senior participants, and the prefrontal lobe, visual cortex, and parietal lobe showed higher activity with visual tasks to balance the posture. With regards to frequency, both the gamma and beta activities showed sensorimotor integration in the parietal-occipital region. Ozdemir, Contreras-Vidal, & Paloski (2018) reported that the delta and gamma activities were higher under somatosensory and vestibular influences; besides, the seniors revealed higher gamma activity in the sensorimotor and parietal lobes compared to the young participants.

Only limited research has been done to gain some understanding of the cortical modulation under different sensory influences to balance the posture in the studies mentioned above. Ozdemir, Contreras-Vidal, & Paloski (2018) reported the cortical modulation under the somatosensory and vestibular sensory influence to balance the posture between the young and senior individuals, with a limited number of participants and a limited number of EEG channels. Aging did not affect any specific cognitive function, although it did influence executive functioning, visuospatial abilities, language, memory, attention, processing speed, and crystallised and fluid intelligence (Harada, Natelson Love, & Triebel, 2013). In their work, Ozdemir, Contreras-Vidal, & Paloski (2018) simply give an overview of the effect of aging on the cortical activity to balance the posture under somatosensory and vestibular influences, they used the baseline of sitting position; however, during the sitting position the participants needed to control and balance the posture (Nichols, Miller, Colby, & Pease, 1996), therefore, the baseline does not isolate the function of postural balance. In the current study, the focus is trained on the specific regions of the cortex, which play a well-defined role in the balance of posture and accurate information can be provided.

Generally, postural balance is dependent on sensory integration, and with the aging process, the sensory information systems decline, which affect the abilities of postural balance (Barbieri & Vitório, 2017). To overcome the structure degeneration, compensation response is generated by the neuromotor system to stabilise the functional abilities (Mattay *et al.*, 2002). The degeneration effect influences the functional changes causing a decline in function (Nardone, Siliotto, Grasso, & Schieppati, 1995) and the compensation response recovers the functional abilities (Mattay *et al.*, 2002). The same phenomenon works in relation to postural balance (Papegaaij, Taube, Baudry, Otten, & Hortobágyi, 2014). In this regards it is important to identify the cortical modulation during postural balance under sensory integration to balance the posture, to know the effect of aging on the cortical activity under sensory integration to balance the posture and the way the cortex compensates for the decline in the sensory information, which are the principal goals of the study.

This study was done as a means to offer support to the aging society as well as handle the upcoming challenges of postural balance, which will only be on the increase with the number of senior individuals steadily rising. The results of the current study will be help in understanding the changes occurring in the cortical modulation with the aging process. Besides, this outcome will be helpful in the physical and cognitive training of senior individuals, as well as for rehabilitation and neurorehabilitation.

3.8 *Scientific questions and hypothesis*

This section includes the scientific questions and hypotheses of the study based on the scientific gap and aim of the study.

Research questions and hypothesis regarding postural balance

Q1. What is the effect of aging on the postural balance in active senior individuals?

Hypothesis

1H0: The postural balance abilities of active seniors are the same as that of the active young participants in the study.
1H1: The postural balance abilities of active seniors are different from that of the active young participants in the study.

Q2. Does aging affect the postural balance strategies of active seniors?

Hypothesis

2H0: The postural balance strategies of active seniors are same as the postural balance strategies of the active young participants in the study.
2H1: The postural balance strategies of active seniors are different from the postural balance strategies of the active young participants in the study.

Research questions and hypothesis regarding sensory integration to balance the posture

Postural balance depends on the integration of the somatosensory, visual and vestibular systems. The research questions in relation to sensory integration to balance the posture are listed below.

Q3. What is the effect of aging on sensory integration to balance posture?

Hypothesis

3H0: The sensory integration abilities of seniors to balance the posture are similar to those of the active young participants in the study.
3H1: The sensory integration abilities of seniors to balance the posture are different from those of the active young participants in the study.

Q4. Which sensory system dominates in the balance of posture in the young and senior individuals?

Hypothesis

4H1a: The somatosensory is the dominant system in the young participants to balance the posture.
4H1b: The visual is the dominant system in the young participants to balance the posture.
5H1a: The somatosensory is the dominant system in the seniors to balance the posture.
5H1b: The visual is the dominant system in the seniors to balance the posture.

Research questions and hypothesis regarding cortical modulation to balance the posture

The cortical regions play a vital role in stabilising the posture. In relation to the cortical response to balance the posture, the research questions and hypotheses are stated below:

Q5. To what extent does aging affect the cortical and subcortical activity while balancing the posture?

6H0: Senior participants use the same cortical sources as do the young participants in the study to balance the posture.
6H1: Senior participants use different cortical sources from those of the young participants in the study to balance the posture.

Q6. Does aging affect the cortical modulation while balancing the posture under the somatosensory influence?

7H0: The aging process does not affect the cortical modulation sources to balance the posture under the somatosensory influence.
7H1: The aging process does affect the cortical modulation sources to balance the posture under the somatosensory influence.

Q7. What is the effect of aging on the cortical activity while balancing the posture under the visual influence?

8H0: Seniors use the same cortical sources as do the young participants in order to balance the posture under the visual influence.
8H1: Seniors use different cortical sources from those of the young participants in order to balance the posture under the visual influence.

Q8. How does aging influence the cortical activity while balancing the posture under the vestibular influence?

9H0: Seniors use the same cortical sources as do the young participants to balance the posture under the vestibular influence.
9H1: Seniors use different cortical sources from those of the young participants to balance the posture under the vestibular influence.

4 Methods

4.1 *Study design*

This is a cross-sectional experimental study to identify the effect of aging on postural balance and neural processing during sensory feedback to maintain postural balance. In this study, the postural balance in seniors and young individuals were measured together with an electroencephalogram (EEG). The defined inclusion and exclusion criteria were adopted for screening the participants in the study. Next, they were prepared for the EEG recording. The participants underwent a sensory organisation test (SOT) for postural balance together with the acquisition of the EEG data. The data collected were analysed offline to study the hypothesis (Fig.17).

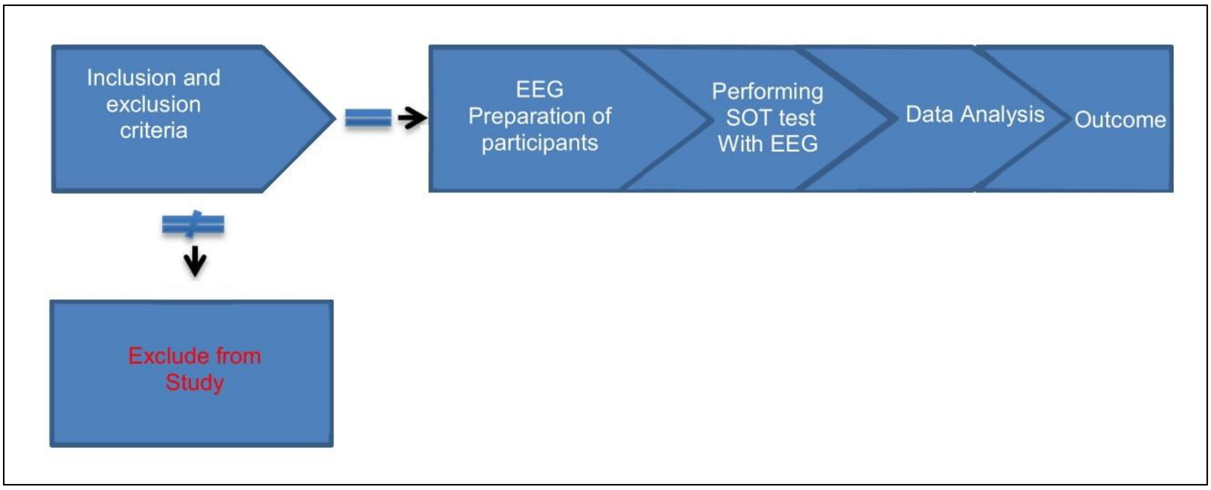


Fig. 17. Study Design

4.2 *Experiment setup*

4.2.1 Postural balance

A wide variety of methods are available to measure the postural balance abilities. Some of these are clinical postural balance tests; however, the measurement of COP is the recommended parameter, which can provide precise information regarding the change in the postural balance system (Palmieri-Smith, Ingersoll, Stone, & Krause, 2002). The technological advancements in medical science have led to the development of force platform systems which facilitate quantitative assessment of both the static and dynamic balance of an individual, termed the Computer Dynamic Posturography (CDP) system. This system is simple and practical and even cost-effective method of assessing functional balance through the analysis of the postural sway. It helps to determine and isolate the different sensory systems which are affected (Guskiewicz & Perrin, 1996). The CDP assess the changes in position and movement control of an individual when maintaining static or dynamic postural stability by eliminating or compromising the visual field, or conflicting the somatosensory system by sway-referencing the BOS to measure the postural balance (Liaw, Chen, Pei, Leong, & Lau, 2009).

Many tools are available in CDP to evaluate the postural balance such as the force plate, Balance Master and Equitest system. The Balance Master and Equitest systems can assess the sensory integration to balance the posture and measure the key parameter, COP (Chaudhry, Bukiet, Ji, & Findley, 2011). In light of the focus of this research, we used the Balance Master system (NeuroCom® International, Inc., USA) to estimate the abilities of postural balance and the sensory integration to balance the posture.

The Smart Balance Master (NeuroCom® International, Inc., USA) instrumented platform system was used to measure postural balance.It computes the Equilibrium score (ES) utilising the centre of pressure movement on the force plates. The force plates provide 2000 data samples in 20 seconds, during each test, from which the equilibrium score is calculated according to the theoretical limit of posture stability. The theoretical limit is 12.5° (6.5° interior and 6.5° posterior) sway (Fig. 18), and the equilibrium score is calculated using equation 1 (Nashner, Shupert, Horak, & Black, 1989; Ottaviani & Girolamo, 2001; Peterka, 1990). These results can be in the range of 0 to 100 %.

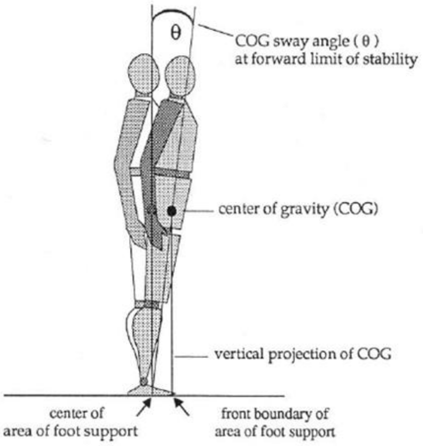


Fig. 18. Sway on Balance Master (NeuroCom International, 1991, p.2)

$$ES = \frac{12.5-[\theta_{max}(ant)-\theta_{max}(post)]}{12.5} \qquad (1)$$

where ES signifies the equilibrium score, ant is anterior, and post is posterior.

The Smart Balance Master (NeuroCom® International, Inc., USA) includes an anterior-posterior (AP) moveable dual force plate of 100 Hz, to record the centre of pressure (COP) during postural balance tasks for the left and right foot and three-sided covered AP directions for moveable surroundings. It is also equipped with a harness to prevent falls. This system is used to determine the displacement of the COP as well as the sways of the centre of mass (COM) of the body.

The force plate and surroundings of the system move according to participant sway to minimise the degree of change. If the participants move in the forward direction, the surroundings also move in the forward direction, which helps to reduce the information about the visual environment of how far the participant is from the vertical surroundings. This phenomenon is referred to as the "sway-referenced motion" (Fig. 19).

Fig. 19. Smart Balance Master (NeuroCom® International, Inc., USA)

4.2.2 Strategy analysis

Strategy analysis is the second parameter which can be obtained from the Smart Balance Master, NeuroCom®. The strategies to maintain postural balance are calculated with equation 2.

$$Movement\ Strategy = \left[1 - \frac{SH_{max} - SH_{min}}{25}\right] * 100 \qquad (2)$$

where SH_{max} is the highest shear force and SH_{min} is the minimum shear force, and 25 lbs is the deference and multiplied by 100 to obtain the percentage.

If the value of the equation is about 100 %, it implies that the participant is using the ankle strategy to balance the posture. Whereas if the value is moving towards 0%, it signifies that the participant is dependent on hip strategy. (Ottaviani & Girolamo, 2001).

An example of the further analysis of the strategies is presented in Fig. 20. It is evident that the test is 20 seconds long and the shear forces are presented, and the range from ankle to hip is also cited to understand the interpretation of the results. The system computes the strategies from the peak to peak of the oscillation in the horizontal direction during each trial.

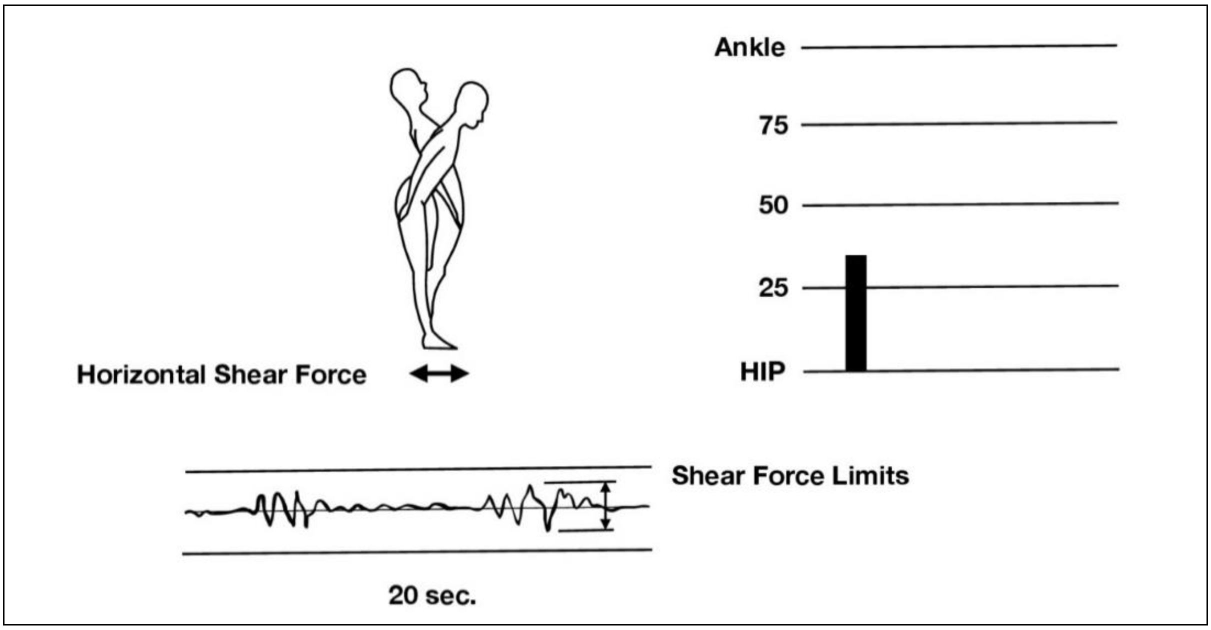


Fig. 20. Analysis of the strategies during the postural balance (NeuroCom International, 1991, p.12)

4.2.3 Sensory organisation test (SOT)

The Sensory Organisation Test (SOT) of the Smart Balance Master, NeuroCom® was employed to identify the sensory input influence during postural balance. The postural balance abilities and strategies to balance the posture are measured in different environments, which cause a suppression of the inputs from the inaccurate sensory system, and the participants generate appropriate motor and postural response strategies. This test has six conditions as follows:

1. Condition 1: Eyes open, and stand on the firm surface (*Normal vision and fixed support*).
2. Condition 2: Eyes closed, and stand on a firm surface (*Absent vision and fixed support).*
3. Condition 3: Eyes open with sway referenced visual surround (*Sway reference vision and fixed support*).
4. Condition 4: Eyes open on the sway reference support surface (*Normal vision and sway reference*).
5. Condition 5: Eyes closed and stand on the sway reference support surface (*Absent vision and sway reference support*).
6. Condition 6: Eyes open and stand on the sway reference support surface and surrounding (*Sway reference vision and sway reference support*).

Each condition in the SOT involved three trials, each of which lasted 20 seconds. During this duration, the equilibrium percentage and strategies to balance posture were assessed. The average of three trials in each condition was considered as the average ability to balance the posture in a specific environment as shown in Fig. 21.

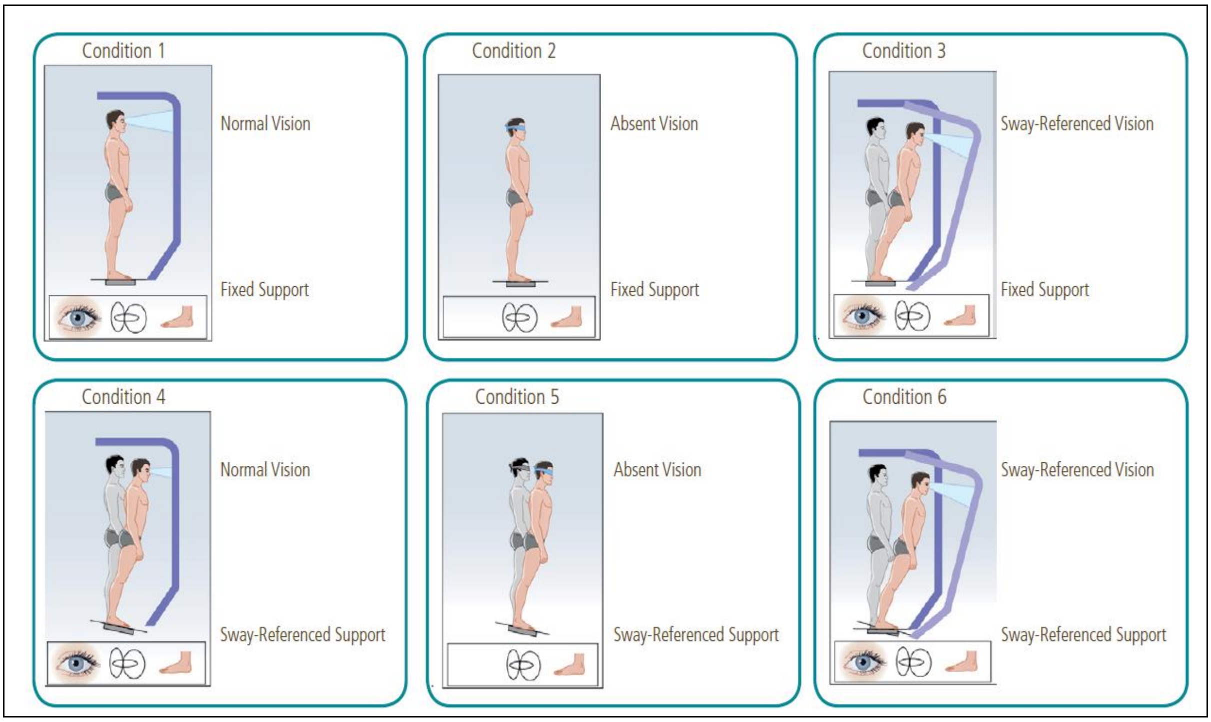


Fig. 21. Six different conditions of the Sensory Organisation Test (SOT) (Chaudhry, Bukiet, Ji, & Findley, 2011)

Condition 1 provided the information regarding the static postural balance abilities, also considered as the baseline of the sensory organisation test, to identify the influence of sensory information on the postural balance ability.

The influence of each dominant sensory information on postural balance was calculated as stated in Tab 1.

Tab. 1. *Each sensory influence calculation on postural balance*

Sensory Analysis		
Ratio Name	**Ratio Pair**	**Function relevance**
(SOM) Somatosensory	$\frac{\text{Condition 2}}{\text{Condition 1}}$	Postural balance ability dominance of the Somatosensory system
(VIS) Visual	$\frac{\text{Condition 4}}{\text{Condition 1}}$	Postural balance ability dominance of the Visual system
(VEST) Vestibular	$\frac{\text{Condition 5}}{\text{Condition 1}}$	Postural balance ability dominance of the Vestibular system

Besides the influence of individual sensory information to maintain postural balance, the Smart Balance Master, NeuroCom® also computed the total status of the sensory integration to postural balance with the formula mentioned in Tab 2.

Tab. 2. *Formula to calculate sensory influence on postural balance*

Sensory integration
((Average (SOT-1)+ Average (SOT-2)+Trial_1(SOT-3)+Trial_2(SOT-3)+Trial_3(SOT-3)+Trial_1(SOT-4)+Trial_2(SOT-4)+rial_3(SOT-4)+Trial_1(SOT-5)+Trial_2(SOT-5)+Trial_3(SOT-)+Trial_1(SOT-6)+ Trial_2(SOT-6)+Trial_3(SOT-6))/(3 trials(SOT-3) + 3 trials(SOT-4) + 3 trials (SOT-5) + 3 trials (SOT-6) + 2 trials(SOT-1 and SOT-2))

*SOT= Sensory organization test conditions.

4.2.4 Cortical activity measurements

Several brain imaging techniques are available for studying the structure or cortical modulation like functional magnetic resonance imaging (fMRI), positron emission tomography (PET), electroencephalography (EEG), magnetoencephalography (MEG), near-infrared spectroscopy (NIRS), and transcranial magnetic stimulation (TMS). Related diffusion-weighted magnetic resonance imaging techniques (DWI), including diffusion tensor imaging (DTI) and high angular resolution diffusion imaging (HARDI) (for review, please refer, Crosson *et al.* 2010) due to high temporal resolution and wireless uses EEG wireless system was used to assess the cortical modulation during the study.

The Brain Vision wireless MOVE electroencephalography system was used to record the cortical activity during sensory integration to balance the posture. It includes the components listed:

I. Unipolar Ag/AgCl 32 active electrodes with EEG cap > record signal from the cortex.

II. ACTiCAP control BOX > receives a signal from EEG and transmits it to the wireless transmitter.
III. Wireless transmitters > transmit a signal to a receiver within a 6m range.
IV. Receiver > receives EEG signals from the wireless transmitter.
V. Power pack > provides power to the amplifier.
VI. Brain AmDC 32 channel AC/DC amplifier > amplifies the signal and sends it to the laptop.
VII. Trigger box > synchronises the Balance Master and EEG inputs by providing markers to EEG data.
VIII. Laptop > to use the EEG Brain vision recorder, analyser and ACTiCAP software.

The complete EEG system is shown in Fig. 22.

Fig. 22. EEG Brain products system ("Brain Products GmbH / Products & amp; Applications / MOVE")

4.2.4.1 EEG cap

The EEG cap with a 34-electrode holder was used in this study. A total number of 32 active electrodes with one reference and one ground electrode were fixed on the cap to record the EEG data. The electrode was placed based on the international 10-20 system of electrode placement (H. Klem, Otto Lüders, Jasper, & Elger, 1958). The 32 electrodes used in this study are named Fp1, Fp2, F7, F3, Fz, F4, F8, FC5, FC1, FCz, FC2, FC6, T7, C3, Cz, C4, T8,TP9, CP5, CP1, CP2, CP6,TP10 P7, P3, Pz, P4, P8, PO9, O1, Oz, O2, PO10. The electrodes were placed to facilitate working on the centre reference montage, in which the reference electrode FCz was situated between the Cz and Fz electrodes and the ground electrode was placed between Fp1, Fp2, and Fz as shown in Fig. 23. To obtain the required impedance SuperVisc high-viscosity electrode gel was used, which helped to bridge the connection between the electrode and the scalp.

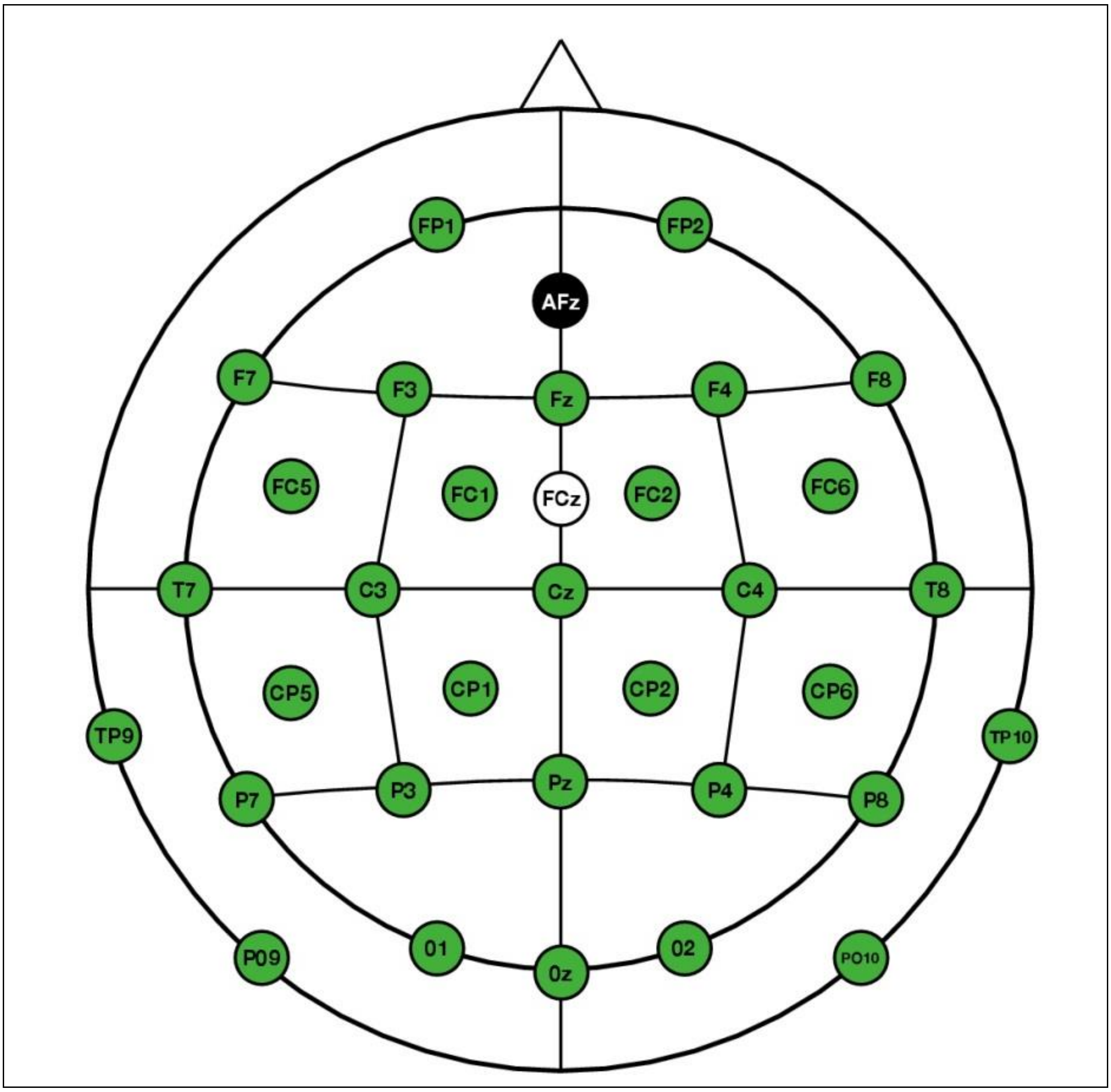


Fig. 23. EEG standard montage using 32 electrodes referring to the international 10–20 system(“Brain Products GmbH / Products & amp; Applications / MOVE”)

4.2.4.2 EEG recording workspace

The Brain Vision Recorder Version 1.21.0102 software was used to record the EEG data. Specific workplaces were developed to record the data based on the requirements of the SOT (Sensory organisation test).

The workspace was developed to record the data for 32 channels. A sampling rate of 1000 Hz with 0.1µv resolution and 3.28 [±/-mV] range Low Cut-off 10s, high cut-off 1000 Hz criteria were used to record the data, and no filter was applied during the recording. Further, six segments for the SOT test were defined for each condition including three subsegments for each trial with a duration of 26 seconds, 3 seconds before the trial and 3 seconds after trial, which enables the EEG data to be separated in different trials and conditions according to the SOT (Fig. 24).

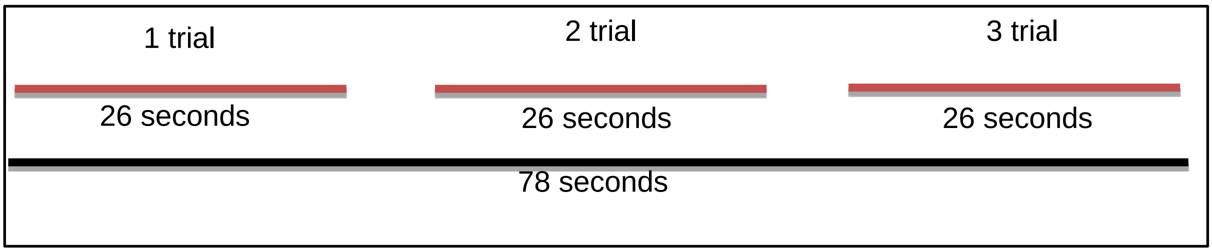


Fig. 24. EEG segmentation in the recording workspace

4.2.4.3 EEG coupling system

To record the EEG and postural balance data, the Balance Master (NeuroCom® International, Inc., USA) and EEG system need to work together. In this sense, the coupling system has been used to synchronize the Balance Master (NeuroCom® International, Inc., USA) and EEG system. The system includes a wireless mouse and NI USB 6501 - National Instruments device (Fig. 25). This system and software for the system have been produced by the sport and technology branch of the Sports Sciences Department of the Otto-von-Guericke University Magdeburg, Germany.

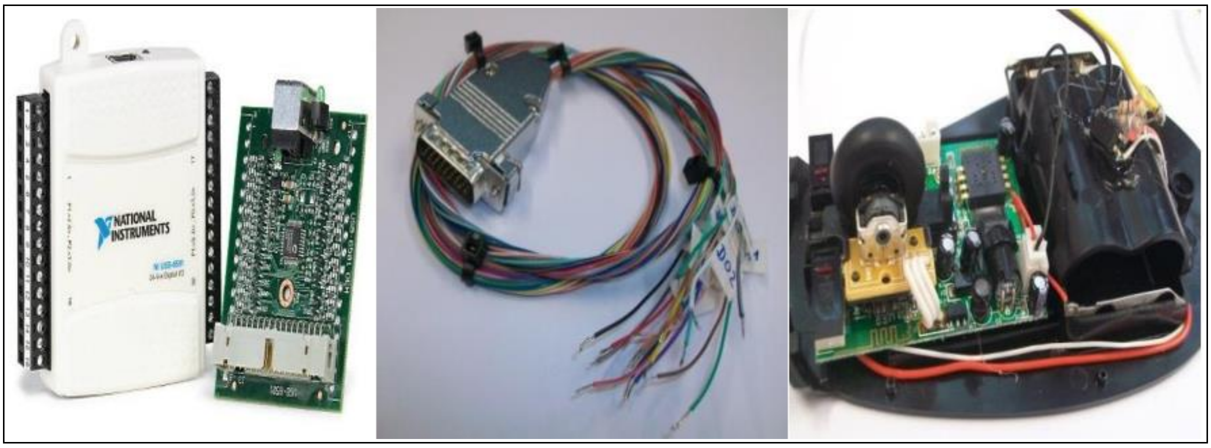
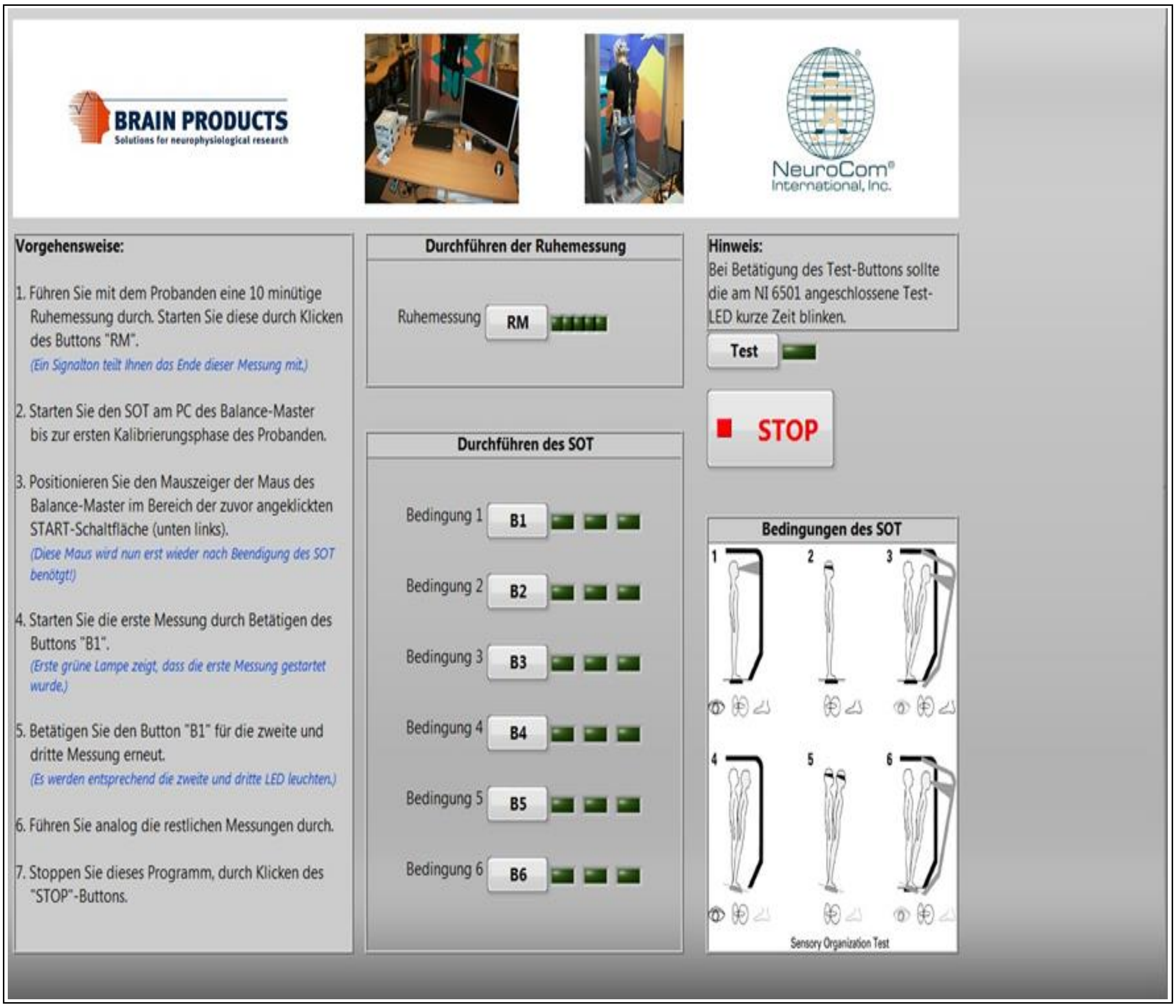


Fig. 25. EEG Coupling system components

This coupling system received a signal from the systems operator through the mouse, and together they triggered the signal to the EEG system and Balance Master (NeuroCom® International, Inc., USA) with a wireless mouse. The signal thus triggered was received by the Balance Master (NeuroCom® International, Inc., USA), which started the SOT test. In the meantime, the same signal goes to the EEG workspace and places a marker 3 seconds before the Balance Master signal, so that the EEG data can be monitored before and after the Sensory Organisation Test. The coupling software system is shown in Fig. 26.



Vorgehensweise:

1. Führen Sie mit dem Probanden eine 10 minütige Ruhemessung durch. Starten Sie diese durch Klicken des Buttons "RM".
   (Ein Signalton teilt Ihnen das Ende dieser Messung mit.)
2. Starten Sie den SOT am PC des Balance-Master bis zur ersten Kalibrierungsphase des Probanden.
3. Positionieren Sie den Mauszeiger der Maus des Balance-Master im Bereich der zuvor angeklickten START-Schaltfläche (unten links).
   (Diese Maus wird nun erst wieder nach Beendigung des SOT benötgt!)
4. Starten Sie die erste Messung durch Betätigen des Buttons "B1".
   (Erste grüne Lampe zeigt, dass die erste Messung gestartet wurde.)
5. Betätigen Sie den Button "B1" für die zweite und dritte Messung erneut.
   (Es werden entsprechend die zweite und dritte LED leuchten.)
6. Führen Sie analog die restlichen Messungen durch.
7. Stoppen Sie dieses Programm, durch Klicken des "STOP"-Buttons.

Hinweis:
Bei Betätigung des Test-Buttons sollte die am NI 6501 angeschlossene Test-LED kurze Zeit blinken.

Fig. 26. The EEG coupling software

The complete experimental setup consists of the Electroencephalography (EEG) system of Brain Products GmbH, Munich, Germany, the EEG coupling system together with the software developed at the Otto-von-Guericke University Magdeburg, Germany, and the Smart Balance Master (NeuroCom® International, Inc., USA). This complete experimental setup was used to acquire the data on postural balance during the sensory organisation test (SOT) and the cortical electrophysiological activity (Fig. 27).

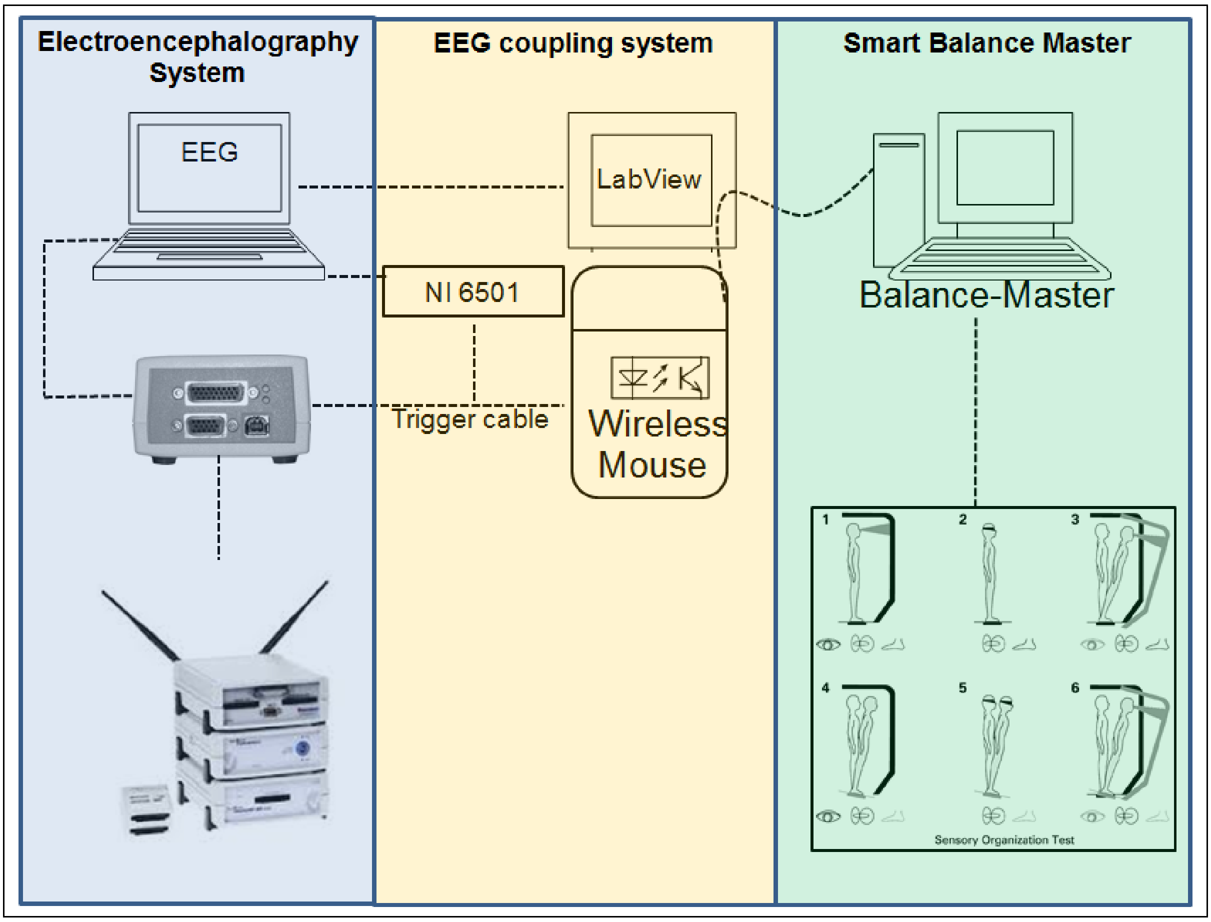


Fig. 27. Complete experimental setup

4.3 *Experiment protocol*

The experimental protocol included participant selection, inclusion, exclusion of the subject in this study, participant preparation and the experimental procedure.

4.3.1 Sampling for study

4.3.1.1 Inclusion and exclusion criteria

The recruitment and selection criteria for this study were similar for both the young and senior participants. The advertisement was displayed in the Otto-von-Guericke-University, Magdeburg and the senior health clubs of Magdeburg. A total of 38 seniors and 40 interested young individuals reported participating in the study. In the first stage, the participants those younger than 60 years old were excluded, in consideration of the study performed by P. Era *et al.* (2006). Further, the young and senior individuals who were not involved regularly in any physical activity or sport were excluded, along with the other inclusion and exclusion criteria (Tab 3). The participants were informed about the preparation for the day of the experiment. They could wash but not apply any oil or gel on their hair; apart from this, they could wear regular comfortable clothes to feel at ease on the day of the study. The objectives and methodologies were explained to them, and they signed a consent form, according to the guidelines of the Helsinki declaration of the World Health Organization WHO (Appendix A). Participants also underwent a Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975) after signing the consent form to participate in the experiment (Appendix B).

The inclusion and exclusion criteria included age limits, diseases, infections and cognitive impairments, which were considered prior to the selection of the participants, which is stated in Table 3.

Tab. 3. *Inclusion and exclusion criteria*

Inclusion criteria

S. No	Young	Senior
1	Age 20 to 30	Age > 60
02	Non-alcoholic	Non-alcoholic
03	No chronic diseases	No chronic diseases
04	No current infection	No current infection
05	*No cognitive impairment	*No cognitive impairment

Exclusion criteria

S. No	Young	Senior
01	Age <20 and >30	Age < 60
02	Alcoholic	Alcoholic
03	Have chronic diseases	Have chronic diseases
04	Have current infection	Have current infection
05	*Cognitive impairment	*Cognitive impairment
06	Acute or chronic inflammation of the skeletal, muscular, cardiovascular, metabolic or nervous systems	Acute or chronic inflammation of the skeletal, muscular, cardiovascular, metabolic or nervous systems
07	History of deep vein thrombosis	History of deep vein thrombosis

*Cognitive impairment was tested with the Mini-Mental State Examination (Appendix B)

4.3.1.2 Participants

A total number of 50 active, healthy subjects participated in this study. Due to some artifacts present in the electroencephalogram (EEG), the data of 5 senior and 5 young participants were not considered. The data of n = 20 young students aged 24.64 ± 2.47 years and n = 20 seniors aged 68.45 ± 5.37 years has been included in the study. A significant difference in the mean age of both groups was found to be p = 001 with effect size r = 85.72.

4.3.2 Participant preparation

The participants were prepared for the experiment and screened. Each participant was made to sit in the “relaxed condition” on a comfortable chair in preparation for the EEG recording. The head of each participant was measured around the head, from the Nasion to the Inion to select a suitable EEG cap. Based on the measurement, a suitable cap was prepared using 34 electrodes, including one reference and one ground electrode. The EEG cap was fixed on the head in keeping with the 10-20 system. The first measurement taken was of the size, while the second measurement was done from the Nasion to the Inion to locate the correct site to fix the EEG cap with reference to the 10 % distance from the Nasion to the Fp1 electrode, as shown in Fig. 28. Further, from the left and right pre-auricular point via the vertex the cap position was verified with reference to the Cz electrode.

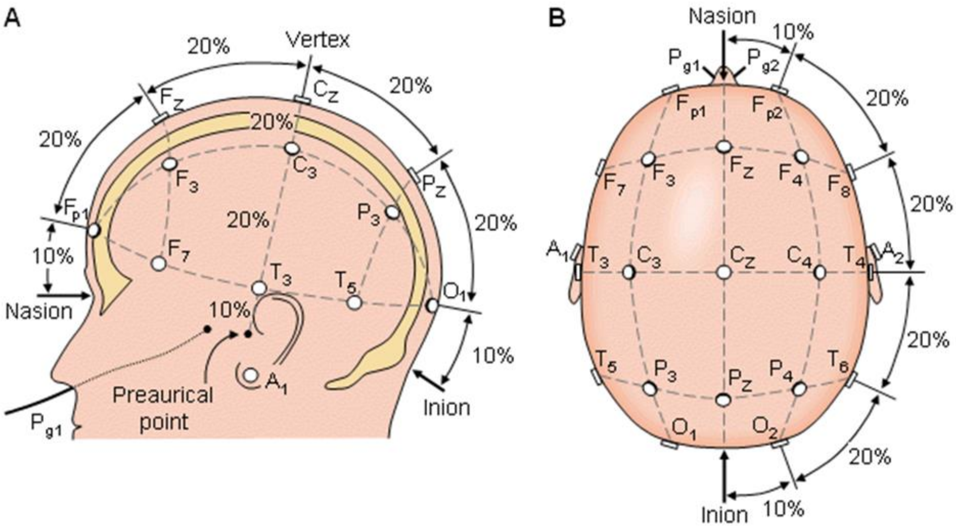


Fig. 28. Measurements to fix the EEG cap. A = Nasion to Inion via Vertex, B = Nasion to Inion around the head (Khuwaja, Haghighi, & Hatzinakos, 2015, p. 3)

The splitter box was connected after the cap was placed, and the impedance level was checked on the computer using the ACTiCAp software. To ensure good connectivity between the scalp and electrodes, high viscosity electrode gel was placed between the scalp and the electrodes using a syringe until the ACTiCAP software did not show impedance below 5 kΩ (Fig. 29).

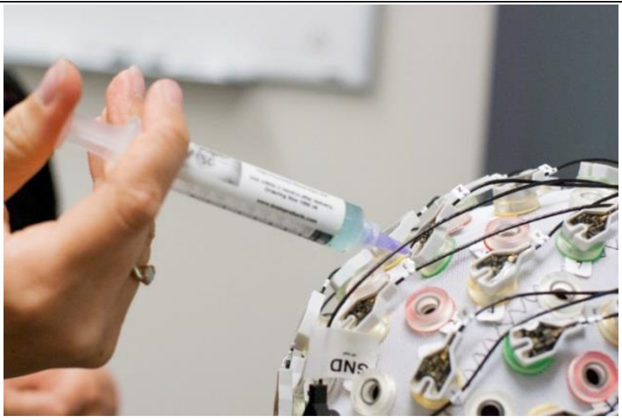


Fig. 29. Placing gel to ensure good impedance

4.3.3 Sensory organisation test with EEG

The participants needed to get onto the Balance Master (NeuroCom® International, Inc., USA) after the EEG cap was prepared, wearing a harness for safety. Before the sensory organisation test was started, the impedance of the EEG electrodes was rechecked. The sensory organisation test and EEG recording were done in parallel, while the Balance Master (NeuroCom® International, Inc., USA) and EEG system were operated through the coupling software. The experimental setup and subject are shown in Fig. 30. After completion of the sensory organisation test, the electrodes were washed with cold water and kept ready for the next experiment.

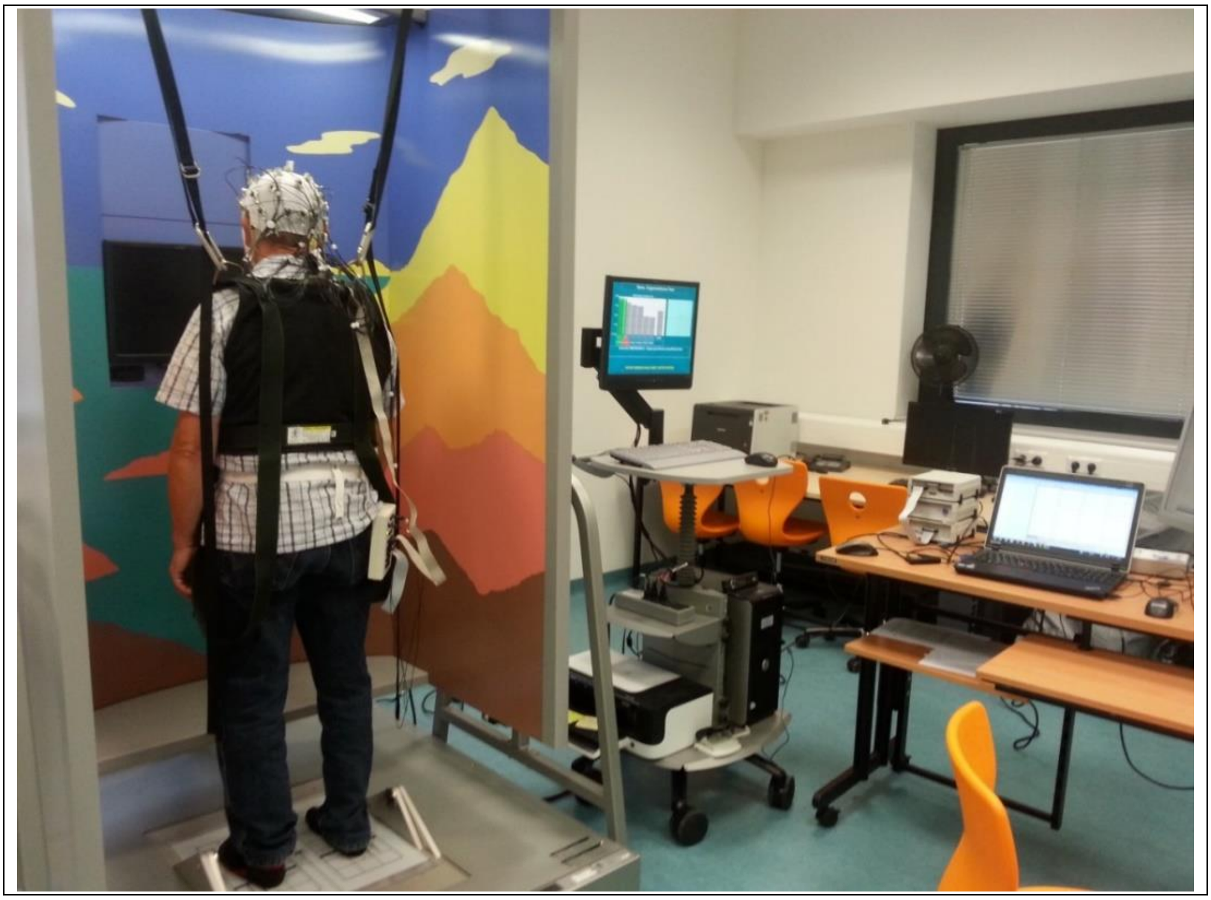


Fig. 30. A participant in the sensory organisation test

4.4 Data analysis

4.4.1 Postural balance

The data of postural balance and postural balance strategies obtained from the Balance Master (NeuroCom® International, Inc., USA) were exported as screenshots and manually inserted in an excel sheet. The sensory influence on the postural balance was calculated with Microsoft Excel 2010 according to the sensory influence on the postural balance, as mentioned in Tab 1.

4.4.2 Electrophysiological cortical activity

The cortical electrophysiological activity was analysed from the cortex for the power spectrum, subcortex and linear lagged connectivity during the postural balance tasks in different environments using electroencephalography (EEG). The Brain Vision analyser version 2.1.2.327 was used to analyse the cortical activity power spectrum, and low-resolution brain electromagnetic tomography (LORETA) 2008-11-04 was used for the functional localisation of the cerebral cortex and functional connectivity in the subcortex as shown in Fig. 31.

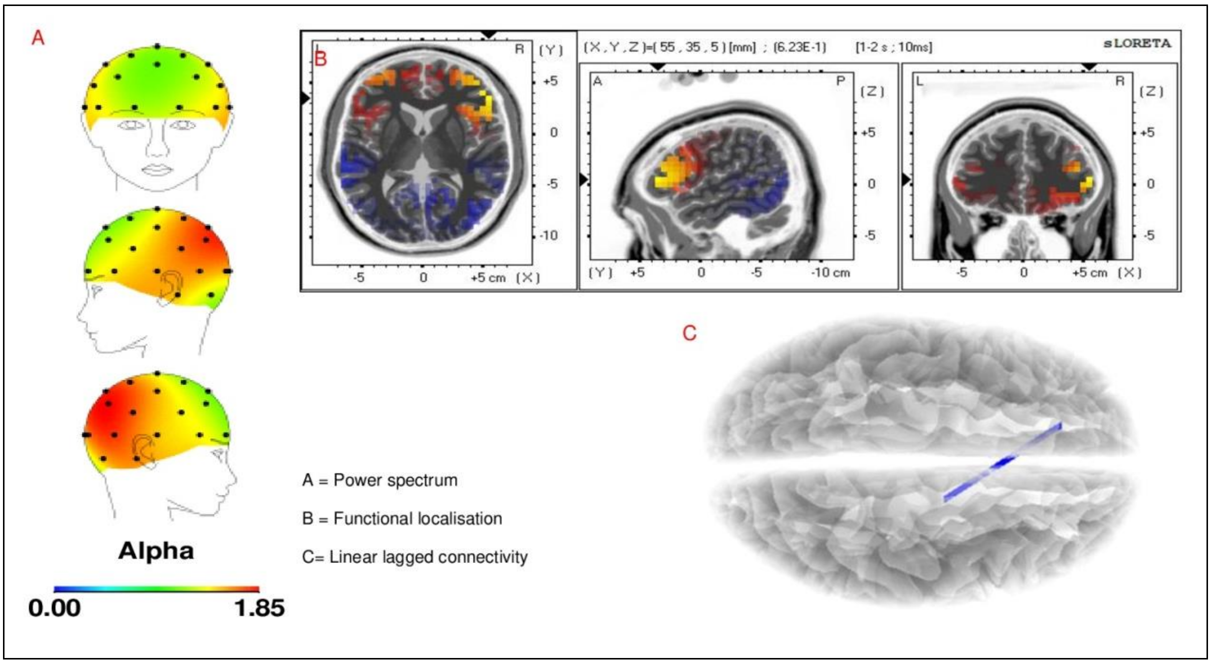


Fig. 31. The scheme of Electrophysiological cortical activity analysis for the study

4.4.2.1 Electroencephalography (EEG) data analysis

The electroencephalography (EEG) recorded data with the Brain Vision recorder was analysed with the Brain Vision analyser in the steps mentioned below.

4.4.2.2 Segmentation (Epochs)

The EEG recorded data during the SOT test includes six conditions, each of which entailed three trials with a duration of 78 seconds. Each trial has three predefined segments of 26 seconds each. The 26 seconds of each trial segment was offline segmented in 20 seconds without overlay because the removed section of the EEG data was not recorded during the SOT test, which is the length and the data of 3 seconds before and after each SOT test trial was removed. The segmentation structure is shown in Fig. 32.

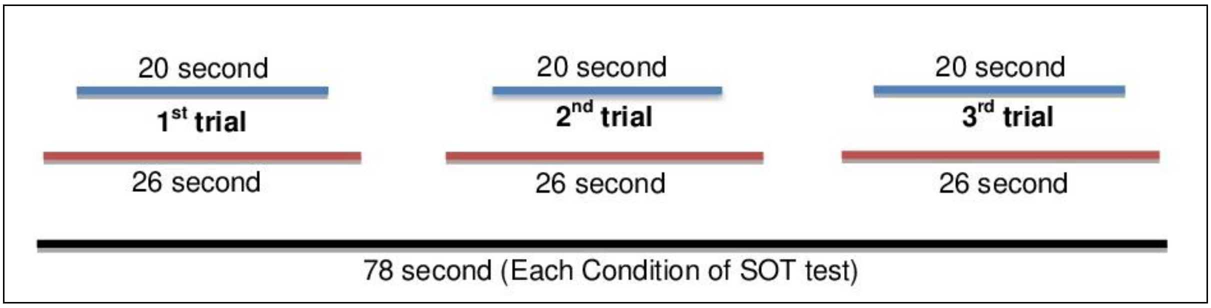


Fig. 32. Electroencephalography (EEG) segmentation scheme

4.4.2.3 Filter

The filtering process was followed to extract the EEG signals. The infinite impulse response (IIR) filter was applied to the segmented data of the 20 second duration of each trial. Low cutoff 0.5 Hz, High cutoff 120 Hz, Slope 48dB/octave and Notch filter applied on 50 Hz to remove the noise of the electricity according to the European standards (Boecker, Hillman, Scheef, & Struder, 2012; Kropotov, 2009; Teplan, 2002).

4.4.2.4 Segmentation (Epochs)

Each trial data lasted for 20 seconds, which was a long segment to go for artifact rejection and compute the average activity for the power spectrum; therefore, the data for each trial from 20 seconds to 10 segments of duration 2 seconds each was divided (Levy, 1987). The segmented data was recorded during a postural balance task, which was the reason for selecting an overlay of 50% of the data which was one second to maintain the continuity of the underlying sources in the EEG data (Sanei & Chambers, 2007).

4.4.2.5 Baseline correction

The baseline was not corrected while recording the EEG data. Therefore, the baseline of each 2-second segment was corrected from 0 to 2000 milliseconds (Sanei & Chambers, 2007).

4.4.2.6 Artifact rejection

The EEG data contained artifacts originating from cardiac, electrode, an external device, muscle and ocular sources. Different signal processing techniques were used to remove the artifacts and get clean cortical signals. Independent component analysis (ICA) is considered an optimum technique for artifact extraction from the EEG data. It is a statistical computing method that separates a signal into maximum statistically independent components (sources). (Jung *et al.*, 1998; Jung, Makeig, Lee, Sejnowski, & Diego 1998.; Vigârio, Särelä, Jousmäki, Hämäläinen, & Oja, 2000). The ICA is sensitive to the EEG data, and some non-stereotype artifacts can result in creating bad ICA for the analysis (McMenamin, Maxwell, & Davidson, 2011; Onton, Westerfield, Townsend, & Makeig, 2006).

The non-stereotype artifacts were removed from the EEG data using semiautomatic artifact rejection, which was used with a gradient of 50µV/ms, with the maximum allowed activity of 200 µV, and lowest allowed the activity of 0.5 µV. All the data from each segment were visually inspected, and only the segments containing the non-stereotype artifacts were removed, which was rare in the EEG data. The examples of non-stereotype artifacts are shown in Fig. 33.

The ICA Ocular Correction method was used in this study, which includes one more advanced algorithm to remove the eye-related artifact from the EEG data (Vigário, 1997) followed by a semiautomatic artifact rejection to remove all the artifacts from the EEG data. The ICA Ocular Correction application criteria was selected in consideration of the central reference EEG recording while no additional VEOG channel was available. The ICA Ocular Correction algorithm was used with Blink Trigger Value 97 (%) and Correlation Trigger 70 (%), VEOG Channel = Fp1, Convergence Bound 1E-07, Number of ICA steps 512, VEOG, Manual ICA and blinks.

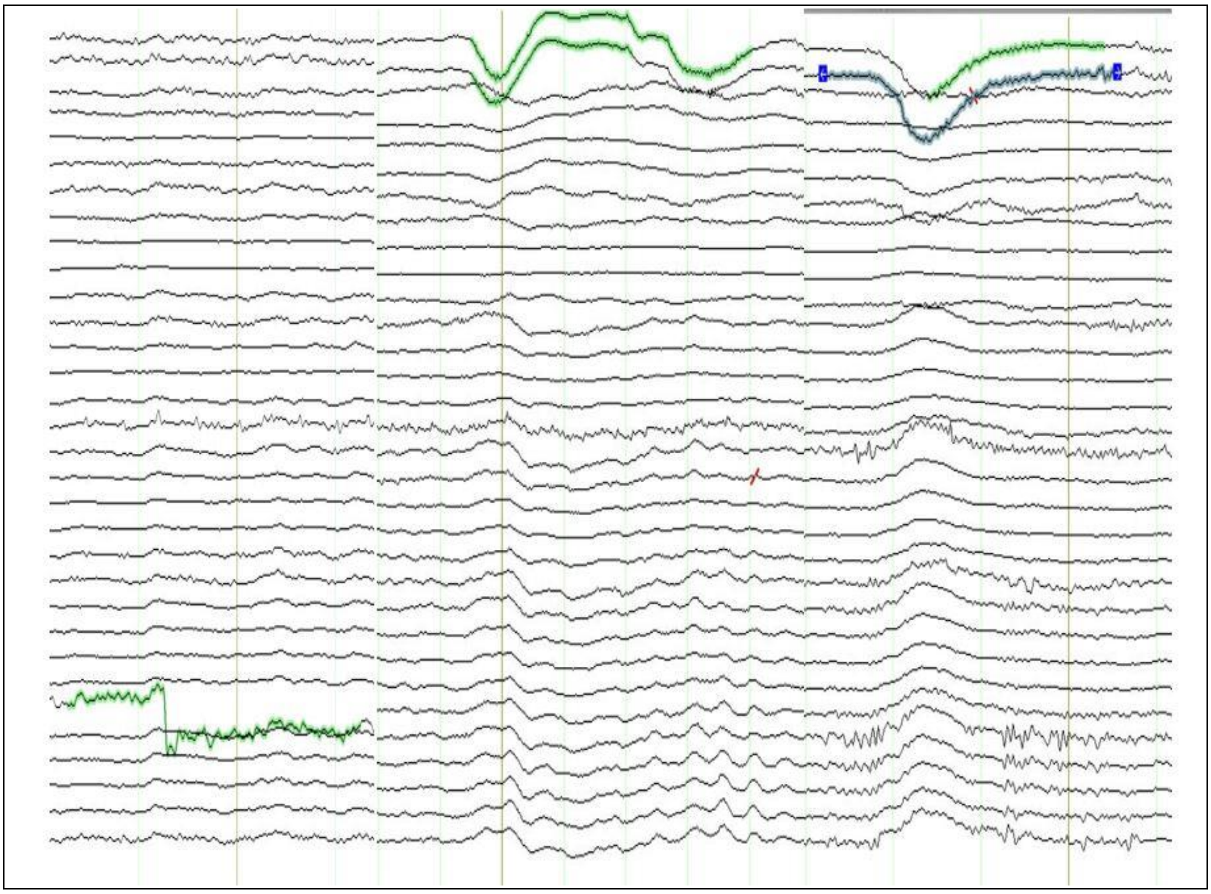


Fig. 33. Non-stereotyped artifacts

4.4.2.7 Fast Fourier Transform

The processed data was converted from the time domain to the frequency domain with Fast Fourier Transform (FFT) using the criteria of Maximum Resolution (0.488 Hz), Power (µV^2/ HZ), full spectrum with normalization of the segment from 0.5 to 100 Hz and Henning windows of 20 % length with variance correction (Akin & Kiymik, 2000). These compute the power spectrum.

4.4.2.8 Averaging

Two different averages were computed from the data processed. One before applying the Fast Fourier Transform, the clean segments with time domain data were averaged and a data set of 2 seconds was exported from each trial of the four conditions for functional localization and functional connectivity like the LORETA export, which also included electrode coordinates file. The second average was computed after applying the Fast Fourier Transform (FFT) and the average segment of 2 seconds was used for the frequency analysis.

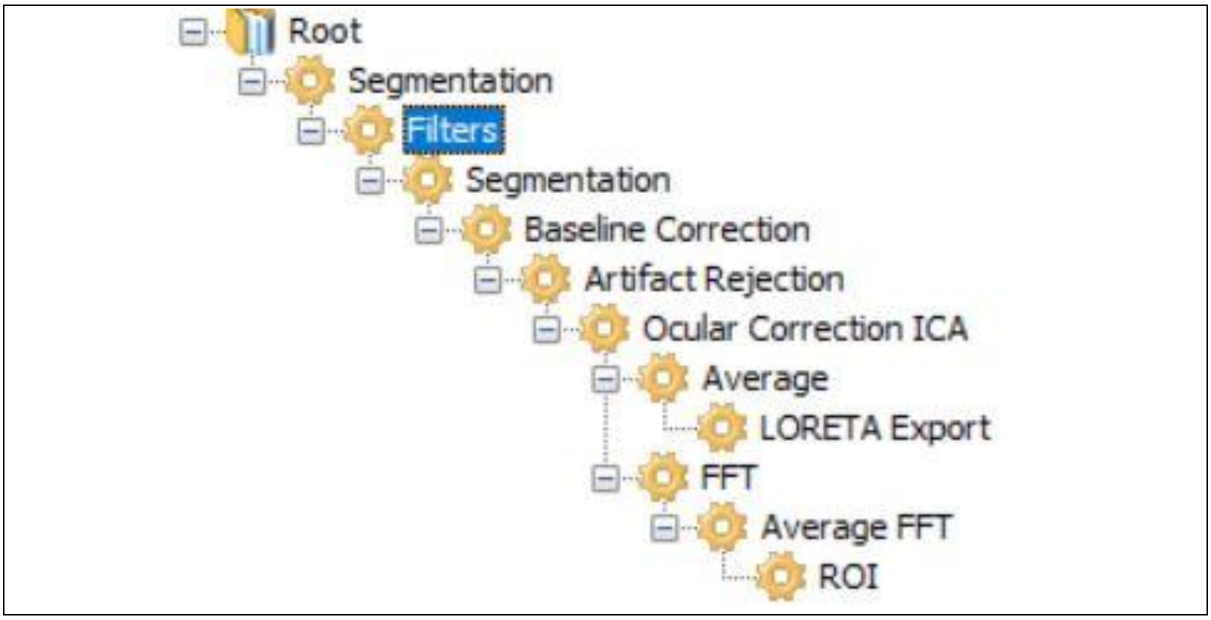
4.4.2.9 Region of interest for power spectral analysis

The regions of interest were selected according to the position of the electrodes on the EEG cap (Oken & Chiappa, 1986; Semyon Slobounov, Sebastianelli, & Hallett, 2012a). The electrode groups were pooled in the Brain Vision analyser according to frontal, temporal, central, parietal and occipital lobes of the cortex as stated in Tab 4, which was recommended to retain the statistical power (Semyon Slobounov, Sebastianelli, & Hallett, 2012b). The average power spectrum was computed with the electrodes involved in each region of interest, accordingly.

Tab. 4. *Electrodes involved in the region of interest*

S. No	Region of interest	Electrodes
01	Frontal	Fp1, Fp2, F7, F3, Fz, F4, F8
02	Temporal	T7, T8
03	Central	C4, C3, Cz
04	Parietal	P7, P3, Pz, P4, P8
05	Occipital	O1, Oz, O2

Five frequency bands like delta (δ) 0.5 to 3.5 Hz, theta (θ) 3.5 to 7.5 Hz, alpha (α) 7.5 to 12.5 Hz, beta (β) 12.5 to 35 Hz, and gamma (γ) 35-100 Hz (Boecker *et al.*, 2012) from above the ROI were exported in Microsoft Excel 2010 for further analysis. The working template of the software is shown in Fig. 34.



- Root
  - Segmentation
    - Filters
      - Segmentation
        - Baseline Correction
          - Artifact Rejection
            - Ocular Correction ICA
              - Average
                - LORETA Export
              - FFT
                - Average FFT
                  - ROI

Fig. 34. Working template of Brain Vision analyser software

The pre-processing of the power spectrum was computed with the Brain Vision analyser version 2.1.2.327 as the above mentioned criteria and process. The flow chart of the processing of the data is shown in Fig. 35.

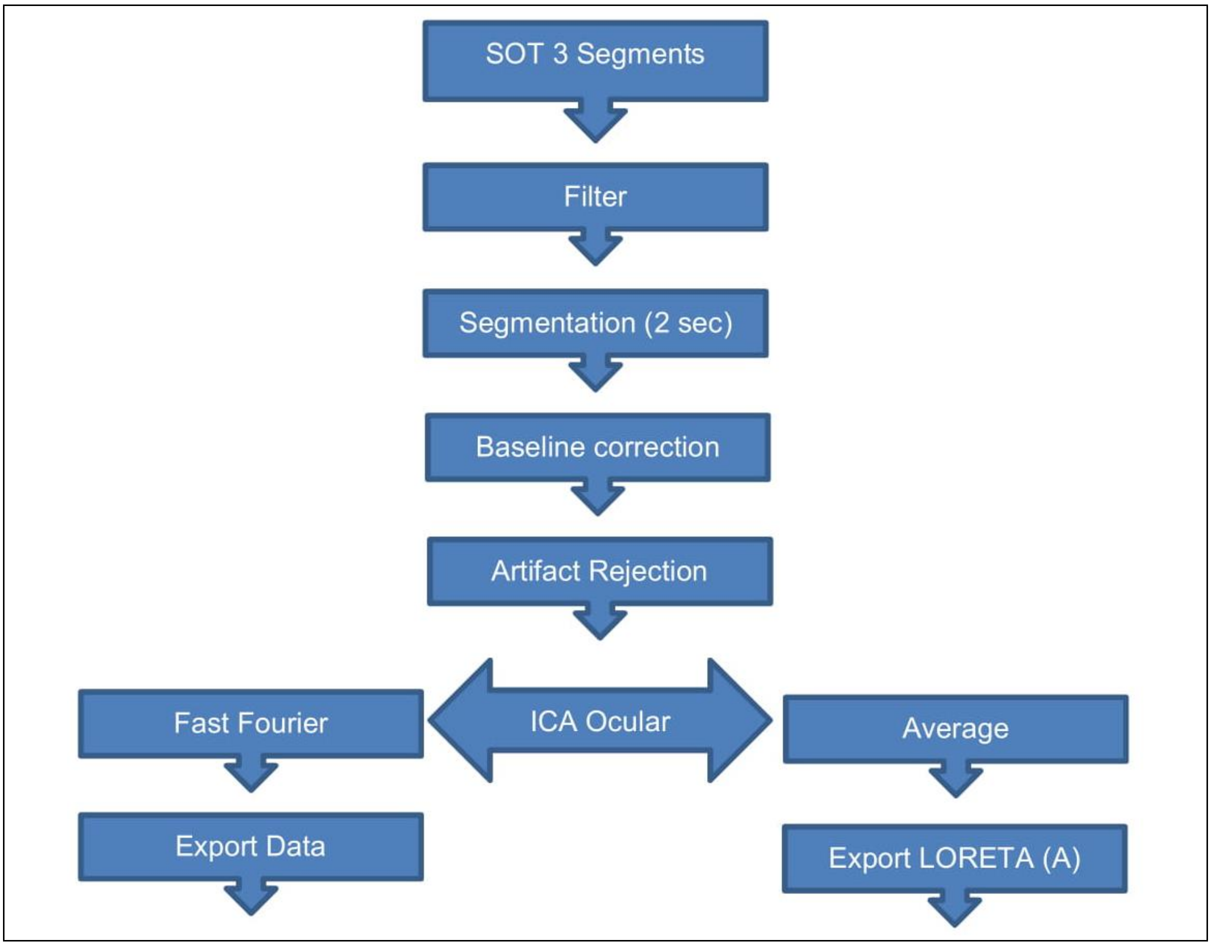


Fig. 35. Flow chart of the EEG data analysis

The exported data were used for the analysis of the power spectrum while the sensory influence was computed according to Tab 1. Another export of data was used for the functional localisation of the cerebral cortex and functional connectivity.

4.4.2.10 Functional localization

The EEG data recorded were used to estimate the electric neuronal activity distribution for the functional localization of the cerebral cortex using the LORETA method. There are standardized LORETA (*s*LORETA) and exact LORETA (*e*LORETA) methods which are commonly used for the electrical neural activity in the cortex. The *e*LORETA software is more accurate compared to the *s*LORETA software to estimate the functional localization in the cortex (Herrmann & Fallgatter, 2004).

The *e*LORETA software computes the source localization in three dimensions cortical grey matter and the hippocampus, which is defined by the Talairach Atlas (Lancaster *et al.*, 2000) using the MNI152 template in a realistic head model (Fuchs, Kastner, Wagner, Hawes, & Ebersole, 2002; Mazziotta *et al.*, 2001). It represents the cortical activity in each voxel out of the 6239 voxels at a 5 x 5 x 5 mm spatial resolution of the neuroanatomic Montreal Neurological Institute (MNI) space. Besides the voxels, it also provides the current source density in the Brodmann area representing the Talairach space(Brett, Johnsrude, & Owen, 2002).

The eLORETA method was used in this study to find source localisation during the sensory organisation test (SOT). Low resolution brain electromagnetic tomography (LORETA) data and electrode coordinates from the Brain Vision analyser software were utilised in the eLORETA software. The transformation from the electrode coordinates were created in the eLORETA software to define the electrode position in the cortex. In the next step, the LORETA data of the Brain Vision analyser converted in cross spectrum with the defined frequency bands i.e. five frequency bands such as the delta (δ) 0.5 to 3.5 Hz, theta (θ) 3.5 to 7.5 Hz, alpha (α) 7.5 to 12.5 Hz, (β) 12.5 to 35 Hz, and gamma (γ) 35-100 Hz (Boecker *et al.*, 2012). The frequency defined cross spectrum was used to convert the data in eLORETA for each participant. The pipeline for the *e*LORETA data processing is shown in Fig. 36.

Fig. 36. .The pipeline for *e*LORETA data analysis

4.4.2.11 Functional connectivity

The functional connectivity was analysed during the postural balance task, which depends on the statistically significant dependence on the correlation between the activity of the different brain regions (Fingelkurts, & Kähkönen, 2005). Two types of brain connectivity are present, linear and nonlinear. The nonlinear connectivity method is based on assumptions under certain disorders (Lorenz, 1963) (35). In our study, as the participants were free from any cognitive disorder, the linear connectivity method was chosen. The linear connectivity method is resistant to non-physiological artifacts, and besides any signal pair in the cortex can obtain as a physiological index of ‘‘lagged connectivity’’ (Nolte *et al.*, 2004; Stam, Nolte, & Daffertshofer, 2007).

In this study, we considered whole brain region for functional connectivity, which included 84 Brodmann areas (BAs) in consideration of a single voxel centre approach while the *e*LORETA has a low spatial resolution, and cannot separate two close sources of cortical activity. Each Brodmann area considers one region of interest (ROI). The detailed location of the region of interest for functional connectivity can be seen in Appendix C. The functional connectivity between any pair of defined 84 ROIs is measured via phase synchronisation (Mulert, Kirsch, Pascual-Marqui, Mccarley & Spencer, 2011; Pascual-Marqui *et al.*, 2011).

The pre-processed electrode transformation matrix to *e*LORETA during brain source localisation was used to define the ROIs in the *e*LORETA software with the ROI maker 2 option. All the regions of the brain including 84 ROI were defined as individual ROI. The *e*LORETA transform matrix was used in the connectivity option 1, and liner connectivity was estimated by using the cross spectrum which was computed during the brain source localisation. Statistics was applied on the linear lagged connectivity, and the results were viewed through the connectivity viewer from the *e*LORETA software. The complete flowchart of liner connectivity is shown in Fig. 37.

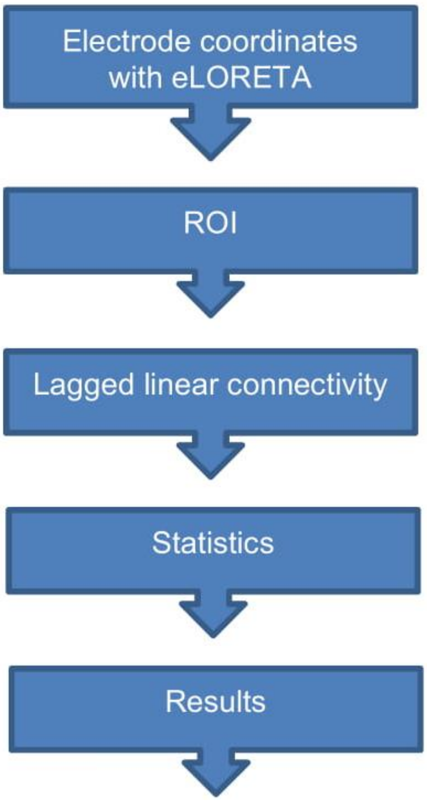


Fig. 37. Flowchart of linear connectivity data analysis

4.5 *Statistics*

4.5.1 Power spectrum statistics

Statistical analysis was done using the statistical package for the social sciences (SPSS). The statistical analysis included correlation, regression, t-tests, and analysis of variance, namely parametric tests such as normal distribution or Gaussian distribution. Normal distribution or Gaussian distribution was first used by Johann Karl Gauss (177–1855) (Joaquim P.

Marques de Sá, 2008). The normal distribution of postural balance, balance strategies, sensory organisation test variable and cortical activity, were assessed utilising SPSS. The normality Shapiro-Wilk test was used to check the normality distribution, based on the correlation between the data and the normal corresponding score. (Elliott, 2007; Thode, 2002). Further skewness and kurtosis were checked, which measured the asymmetry and peakedness of the distribution, respectively. Descriptive statistics mentioned in appendix C. The z score was computed from the skewness and kurtosis scores to reject or accept the normality of data with the formula given below (D’agostino, Belanger, & D’Agostino, 1990; Kim, 2013).

Z = Skew value/ SE skewness and Z = Excess kurtosis/ SE excess kurtosis

Where SE indicates standard error.

In this study as the sample size was $n < 50$ the alpha was 0.05 considered at Z-score 1.96 for skewness or kurtosis. When the Z score for skewness or kurtosis was above 1.96, the data was considered as not normally distributed (Kim, 2013). Besides the Shapiro-Wilk normality test and Z score, the further normality of the data was checked with the histogram stem-and-leaf plot, box plot, P-P plot (probability-probability plot), and Q-Q plot (quantile-quantile plot) to verify the normality visually (Field, 2009).

The t-test and Mann-Whitney U Test were used according to the normality of the data of two variables like postural balance, postural balance strategies, age, height and complete sensory organisation score. If the data followed the criteria of normality mentioned above, then the t-test was used; but. If the data did not follow the criteria mentioned above, the Mann-Whitney U Test was used for the comparison (McKnight & Najab, 2010). More than two variables like the cortical activity between the groups and within the groups were tested with One-Way ANOVA if the variable followed the normality criteria (Heiberger & Neuwirth, 2009). The follow up a test to identify the difference between the ANOVA results included the post hoc test or Scheffe test (Keppel & Wickens, 2004). The effect size was computed with an independent t-test to follow up the post hoc test. If the variables failed to meet the criteria of normality required by the One-way ANOVA such as the sensory organisation test conditions, strategies to maintain postural balance during the sensory organisation test, then the Kruskal-Wallis Test was employed (McKight & Najab, 2010); between the groups the pairwise analysis was done based on the Mann–Whitney U test, a non-parametric test. If by the pairwise analysis significance was noted in two normal distributed variables then the t-test was used to compute the effect size. Statistics are stated in Appendix C along with exact p values.

4.5.1.1 Effect size

The parametric or non-parametric test provides information only regarding the presence or absence of a significant difference. The question to be answered is which information is not complete? In this regards the effect size is worthy of mention, as it can indicate to what degree the parameters are different from each other (Sullivan & Feinn, 2012) The effect size was calculated with the SPSS output.

The effect size of two independent normally distributed samples was calculated with the equation (3)

$$\omega^2 = \frac{t^2 - 1}{t^2 + n_1 + n_2 - 1} \tag{3}$$

where ω^2 refers to effect size, t^2 is the square root of the t value and n is the number of subjects (Berg & Latin, 2008).

The effect size of the variable not normally distributed was computed with the output of the Mann–Whitney U test using the equation (4)

$$r = \frac{|z|}{\sqrt{N}} \cdot 100 \tag{4}$$

where r is defined as the effect size, Z is the output Z value of the test and N represents the number of subjects *$r = 0.1$ small, 0.3 medium and 0.5 large effect size* (Fritz, Morris, & Richler, 2012).

When more than two variables show normal distribution,

The effect size of more than two normal distributed variables was computed with the output of the One Way ANOVA with equation 5.

$$\eta^2 = \frac{SS_{ef}}{SS_t} \tag{5}$$

where Eta square (η^2) indicates effect size, SS_{ef} is the sum of the squares for effect, and SS_t is the total sum of the squares. The index assumed values from 0 to 1 and multiplied by 100, which indicates the percentage of variance in the dependent variable (Fritz *et al.*, 2012).

The effect size of more than two not normally distributed variables was computed from the output of the Kruskal-Wallis test using equation 6 (Tomczak & Tomczak, 2014).

$$E_R^2 = \frac{H}{(n^2-1)/(n+1)} \qquad (6)$$

Where E_R^2 is defined as the effect size, H is the value obtained in the Kruskal-Wallis test (the Kruskal-Wallis H-test statistic) and n is the total number of observations.

4.5.1.2 Correlation

The same procedure has been adopted for the correlation analysis where the variables showed the normal distribution in postural balance. For postural balance strategies, sensory organisation and the power spectrum of the EEG data product the moment correlation by Pearson coefficient single tail product - was used; and if the values of both the variables were not normal, the one tail rank- correlation by Spearman was used (Fritz *et al.*, 2012).

4.5.2 eLORETA and connectivity statistics

The statistics package including the *e*LORETA software was used to compare the data of the participants between the conditions and between the groups during the sensory organisation test (SOT). Generally, the EEG data did not show normal distribution. In this case, the *e*LORETA statistics software non-parametric mapping (SnPM) approach can work without any normal distribution requirements. The *e*LORETA computes the current source density from unknown vectors, and maximum statistics decreases the number of vectors from three to one, in each voxel. This approach, termed maximum statistics bypasses the requirement of normality in the data (Pascual-Marqui, 2002). Along with SNPM, the parametric test is recommended for the *e*LORETA statistics (North, Biver, Words, & Statistics, 2015). The t-test with randomisation method was used to evaluate the results of linear connectivity, and in the *e*LORETA, the voxel-to-voxel approach was used for the statistics (Anderer, Saletu, & Pascual-Marqui, 2000; Park *et al.*, 2002; Thatcher, North, & Biver, 2007). There are limitations in the *e*LORETA statistics, the optimum method to compute the statistics in the software package is to compare the two data sets. In this regard, the influence of each sensory information was computed separately for the young and senior participants.

4.5.2.1 Region of interests of eLORETA

The *e*LORETA has a low spatial resolution and voxel-to-voxel approach report all significant activities in the structure, and maximum significant activity in each structure is reported in the result section, in this approach we can skip the significant activity in the areas, which are already defined in the functional neuroanatomy of postural balance. In consideration of previous models of cortical involvement, the significant activities in the specific areas are also reported as the region of eLORETA region of interest (EROI). EROI are considered according to the functional neuroanatomy of postural balance (Loram, 2015; Takakusaki, 2017b) (see Tab 5).The statistics results of EROI are stated in the Appendix A.

Tab. 5. *Region of interests of eLORETA (EROI).*

ROI	BAs	Region
01	17 (Orhan E. Arslan, 2015)	Primary visual cortex
02	5 and 7 (Flemming, 2006)	Posterior parietal cortex
03	1, 2 and 3 (Orhan E. Arslan, 2015)	Primary sensory cortex
04	6 (Orhan E. Arslan, 2015)	Supplementary motor area / Premotor area
05	4 (Orhan E. Arslan, 2015)	Primary motor cortex
Vestibular cortex is not included because it shares a part of the primary sensory cortex, which is next to Brodmann area 2 (Orhan E. Arslan, 2015) , further The junction of superior temporal gyrus, posterior insula, inferior parietal lobule is defined as parieto-insular vestibular cortex (PIVC) but not fixed structure can define PIVC (Besnard, Lopez, Brandt, Denise, & Smith, 2015).		

5 Results

5.1 *Static postural balance*

The young participants demonstrated significantly high static postural balance abilities (*p* < 0.001, $\omega^2 = 0.32$) when compared with the senior participants in the study. Static postural balance is also the baseline and condition 1 (C1) of the sensory organisation test (SOT). Further, the young participants showed significantly high postural balance strategy (*p* < 0.05, $\omega^2 = 0.11$) when compared with the senior participants in the study. Both groups underwent the sensory organisation test, and young participants showed significantly high (*p* < 0.001, $\omega^2 = 0.61$) sensory integration percentage when compared with that of the seniors (Tab 6).

Tab. 6. *Postural balance and strategies percentage during static condition (C1)*

Conditions	Young M (SD)	Senior M (SD)
Static postural balance (C1) %	96.43 ± 0.76	94.30 ± 1.97
Static postural balance strategies (C1) %	98.88 ± 0.66	98.30 ± 0.80
Sensory organization test score %	89.45 ± 1.80	79.85 ± 4.50

The difference in the static postural balance and sensory organisation test percentages was highly significant, more than the significant difference seen between the young and senior participants in the study in the results of the strategies to maintain postural balance (Fig. 38).

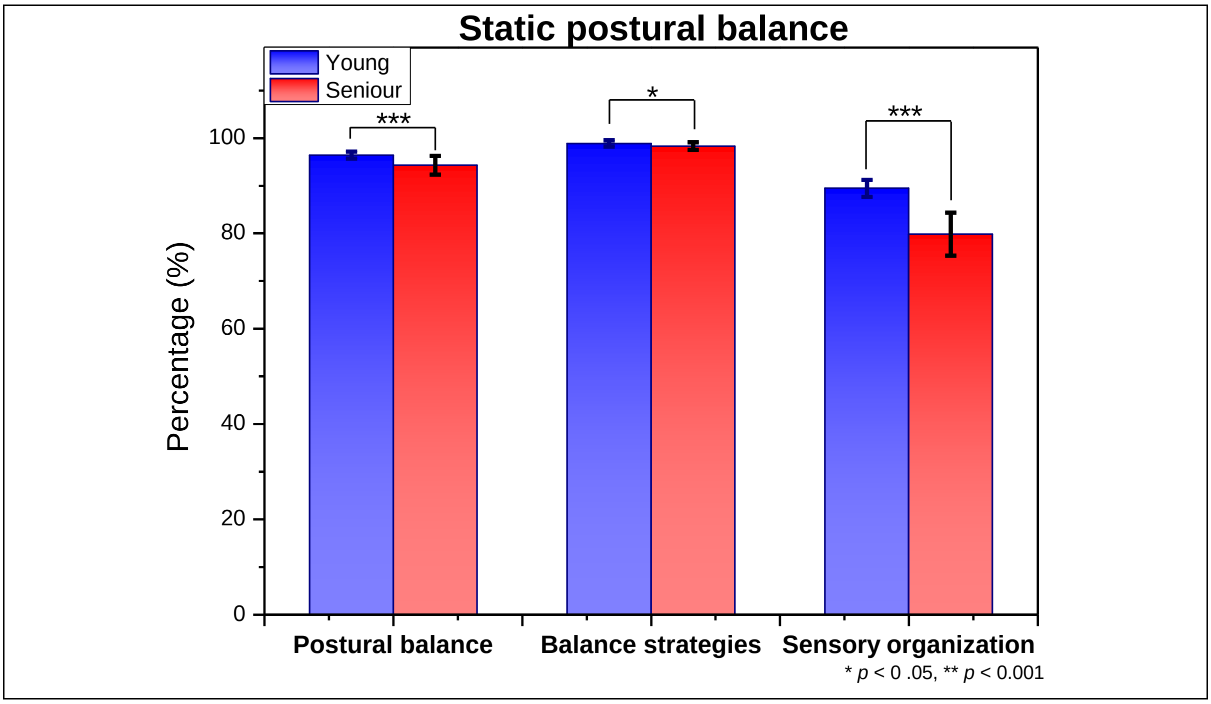


Fig. 38. Static postural balance, strategies and the sensory organisation test

5.1.1 Correlation of static postural balance

The static postural balance of the young and senior participants showed high positive correlation with the postural balance strategies ($p < 0.01$, r = 0.49, $R^2 = 24.10$) and sensory organisation test ($p < 0.001$, r = 0.66, $R^2 = 44.22$) (Fig. 39).

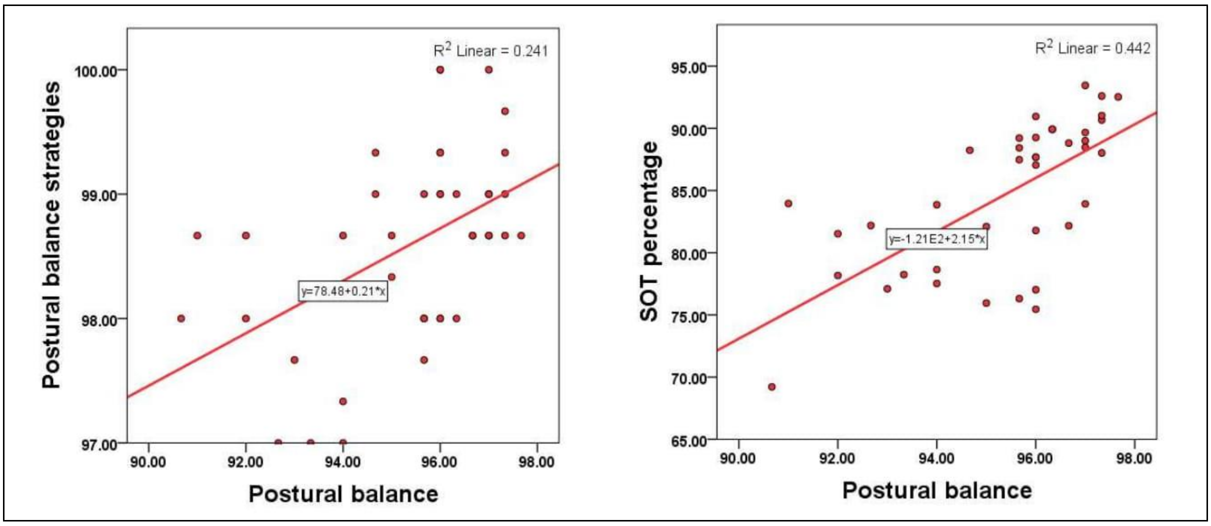


Fig. 39. Correlation of static postural balance with the strategies and SOT

5.1.2 Power spectrum during the postural balance

The power spectrum (μV^2) between the senior and young participants in the study was compared during the static postural balance test, to identify the impact of aging on the cortical activity during static postural balance.

The **delta** activity revealed no significant difference in the frontal and central lobes between the young and senior participants; however, the young participants showed high delta activity in the temporal ($p < 0.01$, r = 50.46), parietal ($p < 0.01$, r = 52.17) and occipital ($p < 0.01$, r = 52.17) lobes than did the senior participants. The median and interquartile range of delta activity are shown in Tab. 7.

Tab. 7. *Delta activity during static postural control*

Lobs	Young Delta (β) [μV^2] Mdn (IQR)	Senior Delta (β) [μV^2] Mdn (IQR)
Temporal	5.97 (4.72 – 6.47)	3.85 (2.85 – 5.12)
Parietal	6.38 (5.00 – 6.83)	4.17 (3.36 – 5.20)
Occipital	6.54 (4.45 – 6.96)	4.12 (2.68 – 4.80)

The ***theta*** activity in the young participants is significantly higher in the frontal lobe ($p < 0.001$, $\omega^2 = 0.39$), temporal lobe ($p < 0.001$, $\omega^2 = 0.53$), central lobe ($p < 0.001$, $\omega^2 = 0.40$), parietal lobe ($p < 0.001$, $\omega^2 = 0.46$) and occipital lobe, Mdn = 2.28, IQR = 2.04 – 2.47 (μV^2) ($p < 0.001$, r = 52.17) than that of the senior participants. Mdn = 1.53, IQR = 1.17 – 1.79 (μV^2).

The **alpha** activity showed no significant difference in any of the ROIs or lobes between the young and senior participants.

The ***beta*** activity in the senior participants is significantly higher in the central lobe ($p < 0.01$, $r = 50.46$), parietal lobe ($p < 0.001$, $r = 54.31$) and occipital lobe ($p < 0.05$, $r = 38.05$) than that in the young participants in the study. The median and interquartile range of delta activity are shown in Tab.8.

Tab. 8. *Beta activity during static postural control.*

Lobs	Young Beta (β) [μV^2] Mdn (IQR)	Senior Beta (β) [μV^2] Mdn (IQR)
Central	0.47 (0.37 – 0.57)	0.60 (0.52 – 0.78)
Parietal	0.46 (0.37 – 0.56)	0.60 (0.49 – 0.67)
Occipital	0.46 (0.38 – 0.56)	0.54 (0.46 – 0.65)

The ***gamma*** activity was significantly higher in the seniors in the temporal ($p < 0.01$, $\omega^2 = 0.16$) and occipital ($p < 0.05$, $\omega^2 = 0.098$) lobes than that of the young participants. However, no significant difference was found in the frontal, central and central lobe in the gamma activity between young and senior participants in the study. The mean power spectrum during the postural balance is stated in Tab. 9.

The delta and theta activities were significantly higher in the cortex of the young participants compared with that of the senior participants in the study, and the senior participants showed significantly higher beta and gamma activity during static posture balance when compared with the young participants (Fig. 40).

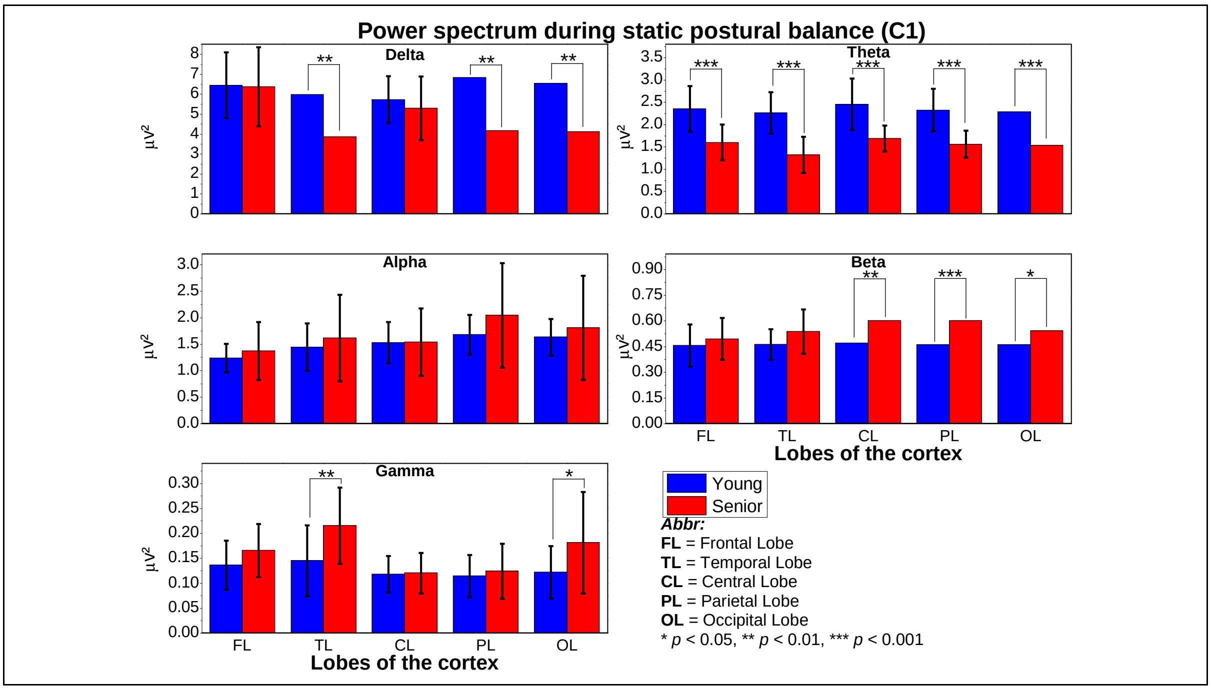
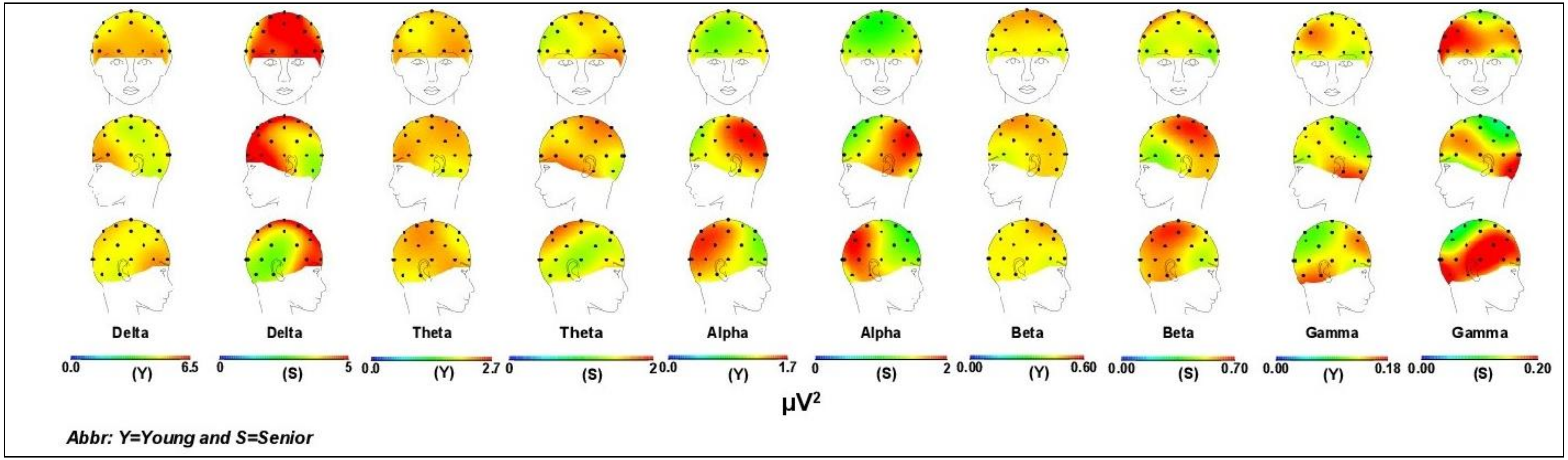


Fig. 40. Power spectrum during static postural balance (The means are stated with an error bar, while the medians are stated without the error bar)

Tab. 9. *Power spectrum mean activity during static postural balance*

ROI	Delta(δ) [μV²] M (SD)		Theta (θ) [μV²] M (SD)		Alpha (α) [μV²] M (SD)		Beta (β) [μV²] M (SD)		Gamma (γ) [μV²] M (SD)	
	Young	**Senior**	**Young**	**Senior**	**Young**	**Senior**	**Young**	**Senior**	**Young**	**Senior**
FL*	6.44 ± 1.64	6.37 ± 1.98	2.35 ± 0.51	1.60 ± 0.40	1.23 ± 0.27	1.37 ± 0.55	0.46 ± 0.12	0.49 ± 0.12	0.14 ± 0.05	0.17 ± 0.05
TL*	5.68 ± 1.39	4.14 ± 1.64	2.26 ± 0.47	1.32 ± 0.40	1.44 ± 0.45	1.61 ± 0.82	0.46 ± 0.09	0.54 ± 0.13	0.14 ± 0.07	0.22 ± 0.08
CL*	5.72 ± 1.17	5.28 ± 1.60	2.45 ± 0.57	1.69 ± 0.29	1.53 ± 0.39	1.54 ± 0.64	0.48 ± 0.13	0.64 ± 0.15	0.12 ± 0.04	0.12 ± 0.04
PL*	5.86 ± 1.23	4.38 ± 1.17	2.32 ± 0.48	1.56 ± 0.30	1.68 ± 0.37	2.04 ± 0.99	0.47 ± 0.10	0.62 ± 0.15	0.11 ± 0.04	0.12 ± 0.06
OL*	5.90 ± 1.38	4.03 ± 1.59	2.27 ± 0.43	1.46 ± 0.44	1.63 ± 0.34	1.80 ± 0.98	0.46 ± 0.10	0.57 ± 0.13	0.12 ± 0.05	0.18 ± 0.10

Abbr: FL = Frontal Lobe, TL = Temporal Lobe, CL = Central Lobe, PL= Parietal Lobe and OL = Occipital Lobe



Abbr: Y=Young and S=Senior

Fig. 41. Topographic maps during static postural balance

Further, the topographic maps of the cortical activity during the static postural balance performed by the young and senior participants are presented in Fig. 41 for a better understanding of the power spectrum changes, which occur due to aging and postural balance.

5.1.2.1 Correlation between postural control and the power spectrum

The correlation coefficients (r) between static postural balance and the cortical activity power spectrum in the individual groups of the young and senior participants showed different trends, as reported below.

5.1.2.2 Correlation of the power spectrum in the young participants

The young participants showed significant correlation coefficients (r) between static postural balance and the power spectrum in different lobes and frequencies. A negative correlation was observed in the theta activity in the frontal and central lobes ($p < 0.01$, r = -0.58, $R^2 = 33.41$), ($p < 0.05$, r = -0.40, $R^2 = 35.60$), respectively. Positive correlation was present for the beta activity in the frontal ($p < 0.01$, r = 0.60, $R^2 = 36$), temporal ($p < 0.05$, r = 43, $R^2 = 18.75$), central ($p < 0.05$, r = 0.40), parietal ($p < 0.05$, r = 0.42, $R^2 = 17.50$) and occipital ($p < 0.05$, r = 0.48, $R^2 = 23.04$) lobes. Further gamma activity also showed a positive correlation in the frontal lobe with static postural balance ($p < 0.05$, r = 0.40, $R^2 = 17.14$) (Fig. 42).

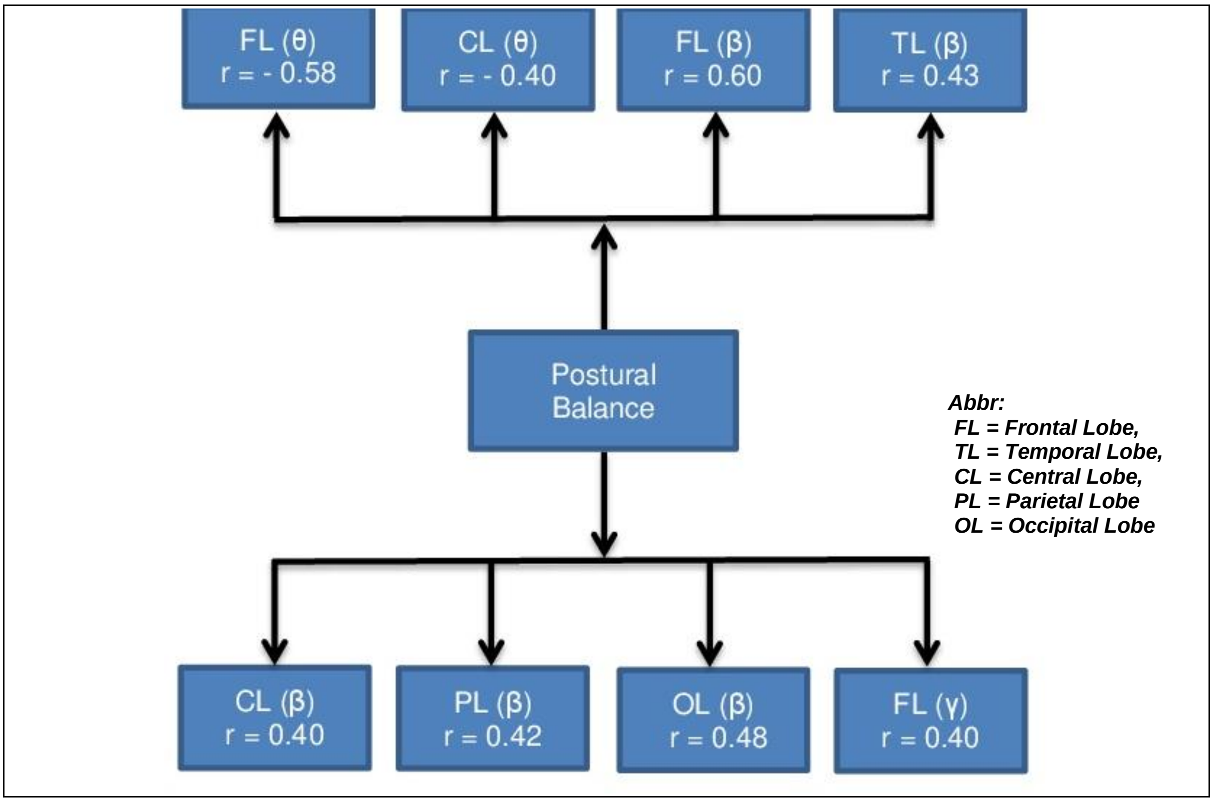


Fig. 42. Correlation of static postural balance with the power frequency spectrum in the young participants

5.1.2.3 Correlation of power spectrum in the senior participants

Besides the different trends present in the power frequency spectrum in the cortex of the senior participants, a significant negative correlation of the coefficients (r) was noted ($p < 0.05$, r = -0.40, $R^2 = -15.21$) between static postural balance and the gamma power spectrum in the central lobe of the cortex in the seniors (Fig. 43).

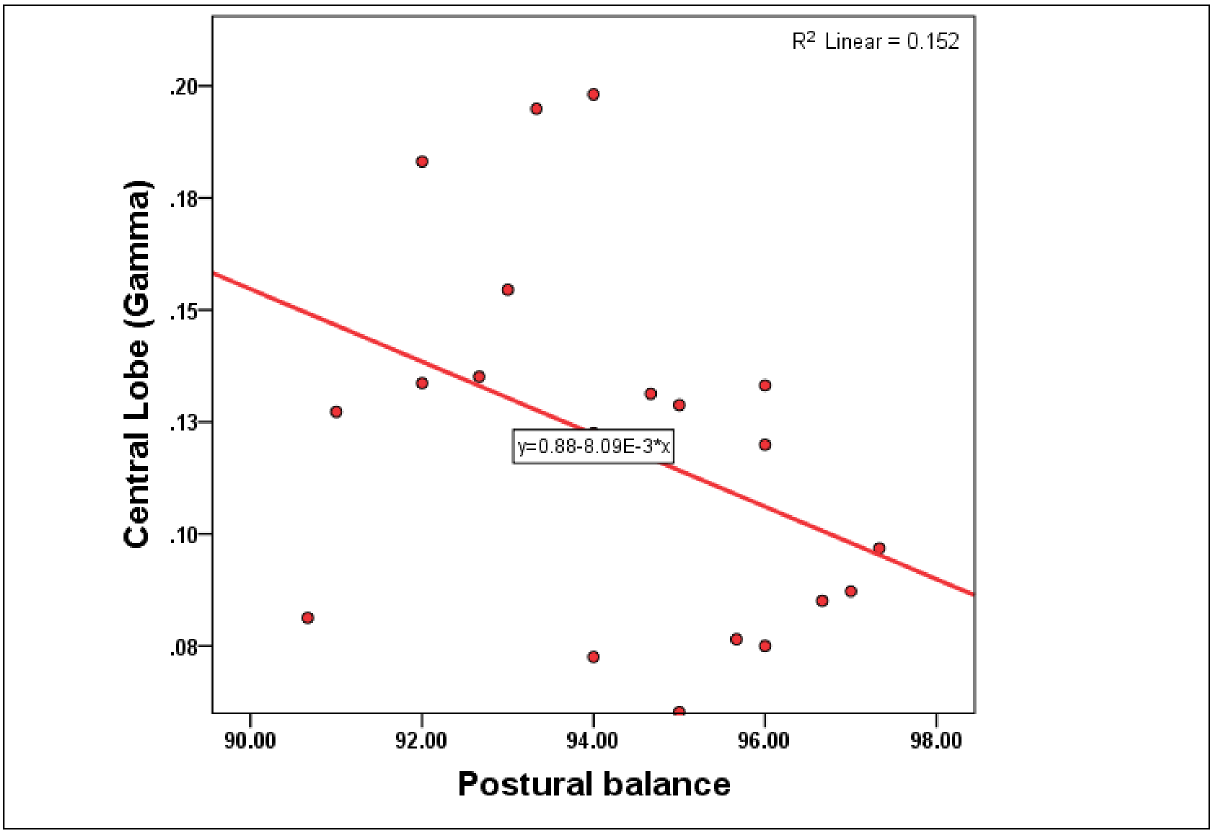


Fig. 43. Correlation of static postural balance with the power frequency spectrum in the senior participants

5.1.2.4 Correlation between postural control and the power spectrum of both groups

Correlation coefficients (r) were computed to identify the relationship between static postural balance and the cortical activity power spectrum with the combined data of the young and senior participants, which also revealed trends quite different from the individual correlation coefficients of the young and senior groups.

A positive correlation was observed in the delta activity in the temporal lobe ($p < 0.05$, r = 0.29), parietal lobe ($p < 0.05$, r = 0.29) and occipital lobe ($p < 0.05$, r = 0.34). The theta activity showed positive correlation in the frontal, ($p < 0.05$, r = 0.29, $R^2 = 8.52$), temporal ($p < 0.01$, r = 0.41, $R^2 = 16.81$), central ($p < 0.05$, r = 0.31, $R^2 = 9.54$), parietal ($p < 0.05$, r = 0.33, $R^2 = 10.62$) and occipital lobes ($p < 0.01$, r = 0.37). Further gamma activity in the temporal lobe showed a negative correlation ($p < 0.05$, r = 0.36, $R^2 = 12.96$) with static postural balance (Fig. 44).

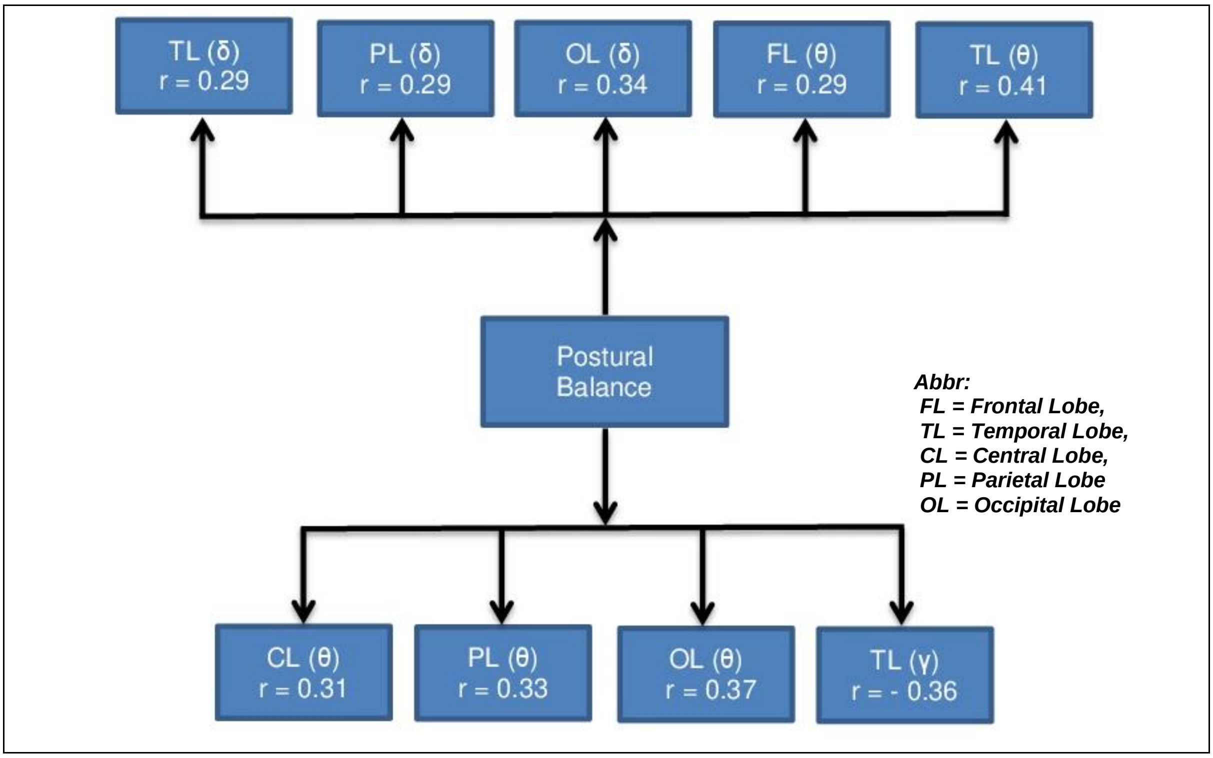


Fig. 44. Correlation of the static postural balance and power frequency spectrum in the young participants and senior group

5.1.3 Functional localisation during static postural balance

The EEG data was used to discern the functional localisation of the cortical activity using *e*LORETA. The same frequency band was used to study the functional localisation of the cortical activity that was used for the power spectrum analysis. The comparative results of all the frequency bands during the postural balance tasks, which is also a baseline for the sensory organisation test (SOT) or condition one of SOT are presented, one by one.

The statistical threshold of the functional localisation of the cortical activity during postural balance was defined according to the one-tailed statistical results, where the seniors were compared with the young participants (senior < young) $p < 0.01$ = t - 4.94, $p < 0.05$ = t - 4.22 and (senior > young) $p < 0.01$ = t 4.97, $p < 0.05$ = t 4.26.

Delta activity is significantly low $p < 0.01$ was found in Insula in **sub-lobar**, superior temporal gyrus and transverse temporal gyrus in the **temporal lobe** and significantly $p < 0.05$ low was found in posterior cingulate and parahippocampal gyrus in the **limbic lobe** and lingual gyrus in the **occipital lobe** of senior participants as compared to young participants of the study. The MRI coordinates and exact t-values are mentioned in Tab. 10.

Tab. 10. *Functional localization delta activity seniors compared to young participants*

Structure	X(MNI)	Y(MNI)	Z(MNI)	T-Value	BAs	Lobe
Superior Temporal Gyrus	35	-35	15	-5.99**	41	Temporal
Insula	30	-30	15	-5.97**	13	Sub-lobar
Transverse Temporal Gyrus	40	-35	10	-5.34**	41	Temporal
Posterior Cingulate	20	-55	5	-4.69*	30	Limbic
Lingual Gyrus	20	-55	0	-4.62*	18	Occipital
Parahippocampal Gyrus	25	-55	0	-4.59*	30	Limbic

*** = p < 0.01, * p < 0.05*

The maximum low delta activity existed in the superior temporal gyrus at 35 X(MNI), -35 Y(MNI) and 15 Z(MNI) in Brodmann area 41 of the cortex of seniors participants as compared with young participants(Fig 45).

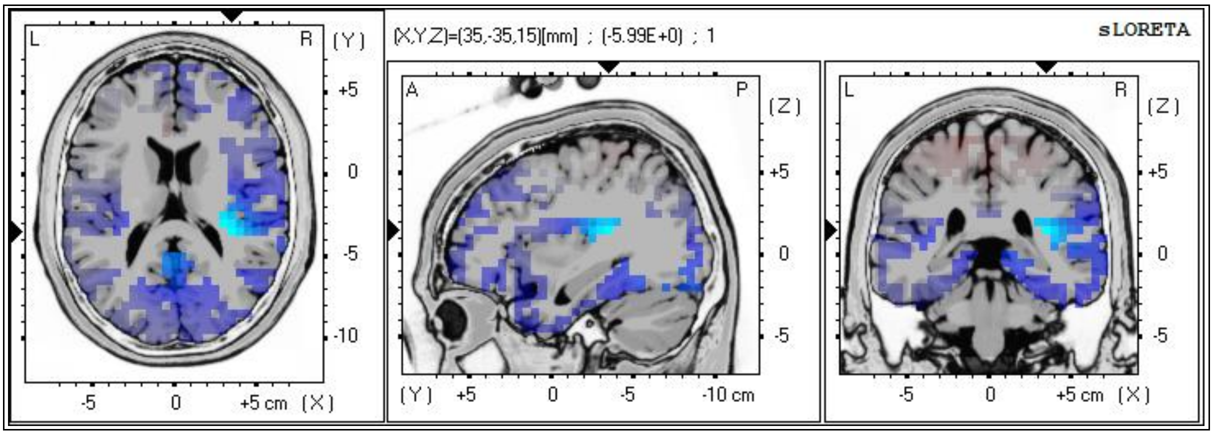


Fig. 45. Functional localisation of the delta activity during postural balance in the seniors compared with that of the young participants in the study

The ***theta*** activity was significantly low *p* < 0.01 in the medial frontal gyrus and precentral gyrus in **frontal lobe**, anterior cingulate, posterior cingulate and cingulate gyrus in **limbic lobe**, middle occipital gyrus, lingual gyrus, inferior temporal gyrus and inferior occipital gyrus in **occipital lobe**, inferior parietal lobule, postcentral gyrus and precuneus in **parietal lobe**, insula in sub-lobar, superior temporal gyrus, transverse temporal gyrus, middle temporal gyrus and supramarginal gyrus in **temporal lobe.** Further, significantly low activity *p* < 0.05 was found in the superior frontal gyrus, paracentral lobule, middle frontal gyrus, inferior frontal gyrus, orbital gyrus, rectal gyrus and subcallosal gyrus in **frontal lobe**, parahippocampal gyrus and uncus in **limbic lobe**, cuneus in **occipital lobe**, angular gyrus and superior parietal lobule in **parietal lobe**, extra-nuclear in **sub-lobar** and sub-gyral and fusiform gyrus in **temporal lobe** of senior participants as compared to young participants of the study. The MRI coordinates and exact T-values are listed in Tab. 11.

Tab. 11. *Functional localisation of the theta activity in seniors compared with that of the young participants*

Structure	X(MNI)	Y(MNI)	Z(MNI)	T-Value	BAs	Lobe
Insula	35	-35	20	-7.44**	13	Sub-lobar
Superior Temporal Gyrus	35	-35	15	-7.42**	41	Temporal
Transverse Temporal Gyrus	40	-35	10	-6.81**	41	Temporal
Middle Temporal Gyrus	55	-45	5	-6.10**	21	Temporal
Inferior Parietal Lobule	55	-35	25	-5.85**	40	Parietal
Supramarginal Gyrus	50	-50	20	-5.75**	40	Temporal
Middle Occipital Gyrus	40	-65	0	-5.74**	37	Occipital
Anterior Cingulate	0	45	0	-5.74**	32	Limbic
Posterior Cingulate	20	-60	10	-5.73**	30	Limbic
Lingual Gyrus	25	-65	0	-5.72**	19	Occipital
Cingulate Gyrus	20	-45	25	-5.71**	31	Limbic
Postcentral Gyrus	55	-30	20	-5.67**	40	Parietal
Precuneus	20	-45	30	-5.65**	31	Parietal
Medial Frontal Gyrus	5	50	-5	-5.62**	10	Frontal
Inferior Temporal Gyrus	45	-70	-5	-5.58**	37	Occipital
Precentral Gyrus	45	0	10	-5.54**	44	Frontal
Inferior Occipital Gyrus	40	-75	-10	-5.53**	19	Occipital
Superior Frontal Gyrus	5	60	-5	-5.49*	10	Frontal
Sub-Gyral	50	-45	-10	-5.46*	37	Temporal
Paracentral Lobule	10	-45	55	-5.44*	5	Frontal
Parahippocampal Gyrus	25	-55	0	-5.40*	30	Limbic
Fusiform Gyrus	50	-40	-15	-5.34*	37	Temporal
Middle Frontal Gyrus	25	-5	45	-5.32*	6	Frontal
Inferior Frontal Gyrus	50	0	20	-5.30*	44	Frontal
Orbital Gyrus	10	55	-20	-5.26*	11	Frontal
Rectal Gyrus	5	55	-25	-5.15*	11	Frontal
Cuneus	10	-65	5	-5.07*	30	Occipital
Extra-Nuclear	40	5	-10	-4.97*	13	Sub-lobar
Angular Gyrus	50	-65	30	-4.88*	39	Parietal
Superior Parietal Lobule	20	-45	65	-4.57*	5	Parietal
Uncus	35	-5	-40	-4.31*	20	Limbic
Subcallosal Gyrus	25	5	-15	-4.29*	34	Frontal

** = $p < 0.01$, * $p < 0.05$

The maximum low ***theta*** activity in the cortex of the senior participants was found in the insula sub-lobe at 35 X(MNI), -35 Y(MNI) and 20 Z(MNI) in Brodmann area 13 when compared with the young participants in the study (Fig. 46).

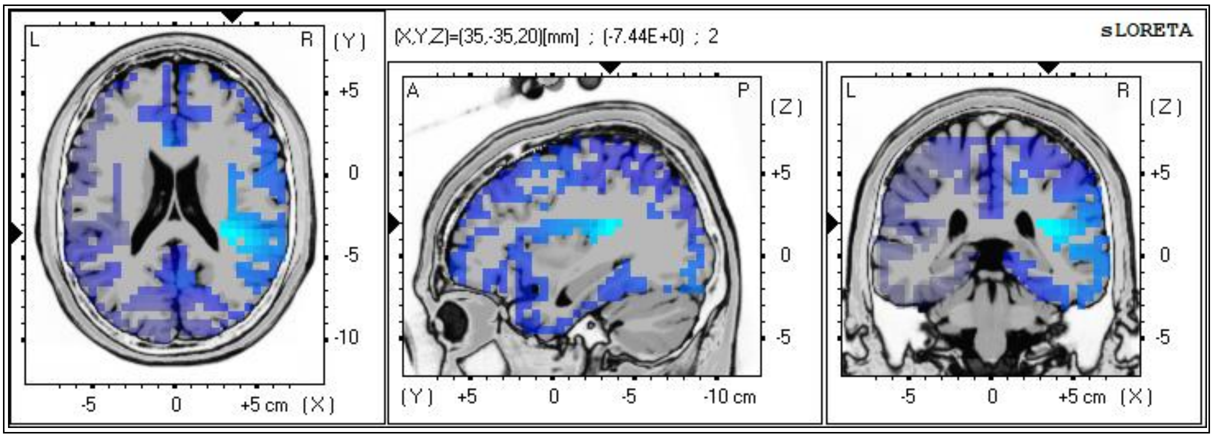


Fig. 46. Functional localisation of the theta activity during postural balance in the seniors compared with that of the young participants in the study

The ***alpha*** frequency was also found to be significantly low in the cortex of the seniors when compared with that of the young participants $p < 0.01$ in the superior frontal gyrus, medial frontal gyrus, middle frontal gyrus, precentral gyrus and inferior frontal gyrus in **frontal lobe** and anterior cingulate in **limbic lobe**. Besides, the alpha activity was significantly $p < 0.05$ low in the rectal gyrus, and orbital gyrus in **frontal lobe**, postcentral gyrus and inferior parietal lobule in **parietal lobe**, insula in **sub-lobar** and superior temporal gyrus in **temporal lobe**. The MRI coordinates and exact T-values of the alpha activity are given in Tab. 12.

Tab. 12. *Functional localisation of the alpha activity in the seniors compared with that of the young participants*

Structure	X(MNI)	Y(MNI)	Z(MNI)	T-Value	BAs	Lobe
Superior Frontal Gyrus	20	65	10	-6.02**	10	Frontal
Medial Frontal Gyrus	15	60	5	-5.92**	10	Frontal
Middle Frontal Gyrus	45	0	55	-5.45**	6	Frontal
Anterior Cingulate	5	55	0	-5.33**	10	Limbic
Precentral Gyrus	45	-5	55	-5.30**	6	Frontal
Inferior Frontal Gyrus	40	55	5	-5.03**	10	Frontal
Insula	35	20	10	-4.43*	13	Sub-lobar
Postcentral Gyrus	55	-15	50	-4.41*	3	Parietal
Rectal Gyrus	5	55	-25	-4.35*	11	Frontal
Superior Temporal Gyrus	55	15	-5	-4.33*	22	Temporal
Orbital Gyrus	5	50	-20	-4.31*	11	Frontal
Inferior Parietal Lobule	60	-35	50	-4.26*	40	Parietal

*** = p < 0.01, * p <0.05*

The alpha activity in the cortex of the seniors was at the maximum low point than in the young participants, as observed in the superior frontal gyrus of the frontal lobe at the MRI coordinates 20 X (MNI), 65 Y(MNI) and 10 Z(MNI) in Brodmann area 10 (Fig. 47).

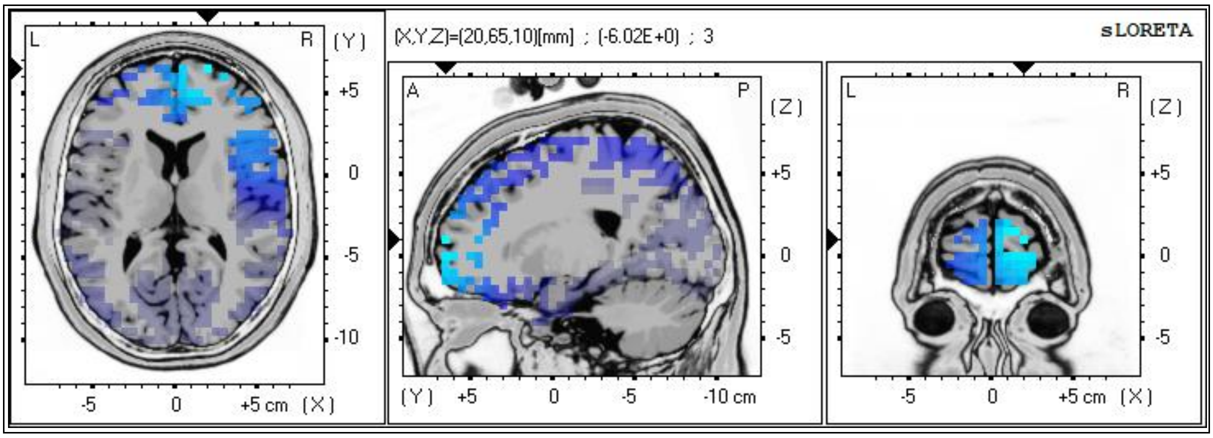


Fig. 47. Functional localisation of the alpha activity during postural balance in the seniors compared with the young participants in the study

The ***beta*** activity was found to be significantly higher in the senior participants $p < 0.05$ in the posterior cingulate of the **limbic lobe** at 5 X(MNI), -50 Y(MNI) and at the 10 Z(MNI) MRI coordinates in Brodmann area 29 with T-value 4.32 when compared with that of the young participants (Fig. 48).

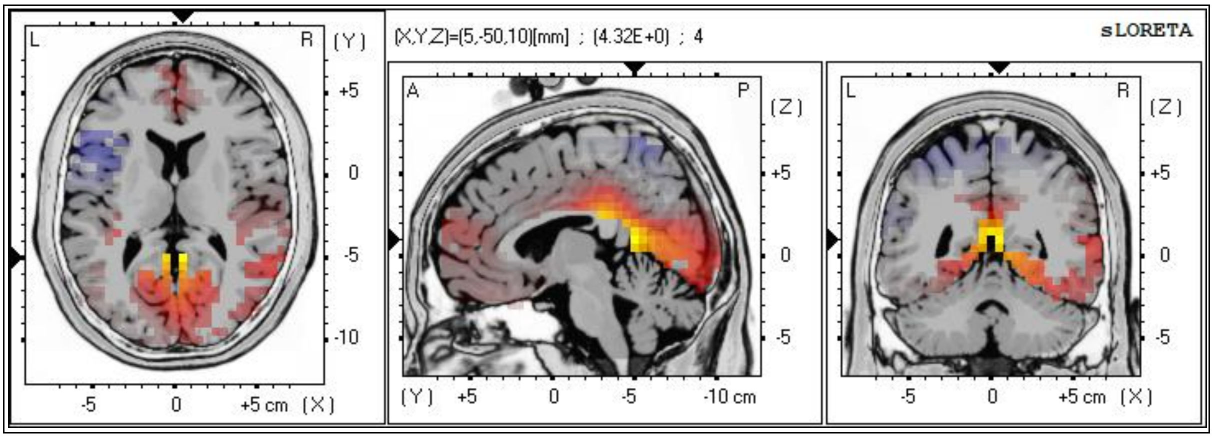


Fig. 48. Functional localisation of the beta activity during postural balance in the seniors compared with that of the young participants in the study

The ***gamma*** activity was significantly high in the cortex of the senior participants in the study p < 0.05 in the inferior frontal gyrus, middle frontal gyrus and superior frontal gyrus in the ***frontal lobe*** when compared with the young participants. The MRI coordinates and exact T-values are mentioned in Tab. 13.

Tab. 13. *Functional localisation of the gamma activity in the seniors compared with the young participants in the study*

Structure	X(MNI)	Y(MNI)	Z(MNI)	T-Value	BAs	Lobe
Middle Frontal Gyrus	40	45	30	4.68	10	Frontal
Superior Frontal Gyrus	40	50	25	4.52	10	Frontal
Inferior Frontal Gyrus	35	35	15	4.35	46	Frontal

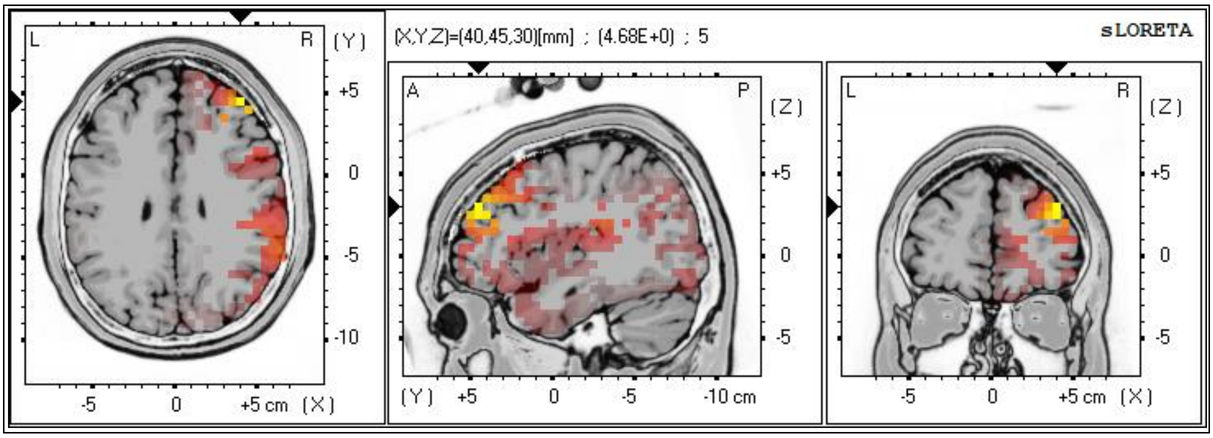


Fig. 49. Functional localisation of the gamma activity during postural balance in the seniors compared with the young participants in the study

The highest gamma activity in the cortex of the seniors was found in the middle frontal gyrus of the frontal lobe at 40 X(MNI), 45Y(MNI), 30Z(MNI) with T-value 4.65 in Brodmann area 10 when compared with the young participants in the study (Fig. 49).

5.2 *Postural balance during the SOT*

The postural balance ability was measured during the static postural balance tasks in different environments and reported as a percentage (%) of the postural control abilities, which were used to analyse the sensory integration or sensory organisation during postural balance. The young participants showed significantly high ability of postural balance in the baseline condition of the sensory organisation test when compared with the senior participants in the study, which is also the static postural balance ability ($p < 0.001$, ω2 = 0.32). Similar trends observed in all the other five conditions or environments of the sensory organisation test in the young participants demonstrated significantly higher abilities of postural balance in condition 2 ($p < 0.05$, $r = 37.07$), condition 3, ($p < 0.01$, $\omega^2 = 0.14$), condition 4 ($p < 0.001$, $r = 75.8$, condition 5 ($p <0.001$, $\omega^2 = 0.50$) and condition 6, ($p <0.001$, $\omega^2 = 0.51$, respectively, than in the senior participants in the study (Tab. 14).

Tab. 14. *Equilibrium percentage during balance posture in the different environments of the sensory organisation test*

Conditions	**Young [EQ* %] M (SD)/ Mdn (IQR)**	**Senior [EQ* %] M (SD)/ Mdn (IQR)**
Normal vision and fixed support (C1)	96.43 ± 0.76	94.30 ± 1.97
Absent vision and fixed support (C2)	93.83 (92.83 – 95.00)	92.00 (90.00 – 94.25)

Sway reference vision and fixed support (C3)	93.41 ± 2.17	91.08 ± 3.02
Normal vision and sway reference (C4)	93.67 (92.58 – 94.67)	87.00(84.50 – 88.41)
Absent vision and sway reference support (C5)	80.26 ± 3.17	66.60 ± 8.80
Sway reference vision and sway reference support (C6)	86.78 ± 5.03	66.76 ± 11.57

The ability of the seniors in maintaining postural balance significantly declined from condition 1, though to condition 6. The decline in the postural abilities is highly significant under static postural balance, normal vision and sway reference, which was condition 1, normal vision and sway reference (C4), absent vision and sway reference support (C5) and sway reference vision and sway reference support (C6) when compared with the conditions of absent vision and fixed support (C2) and sway reference vision and fixed support with (C3). The differences in the significance levels between the young and senior groups are stated in Fig. 50.

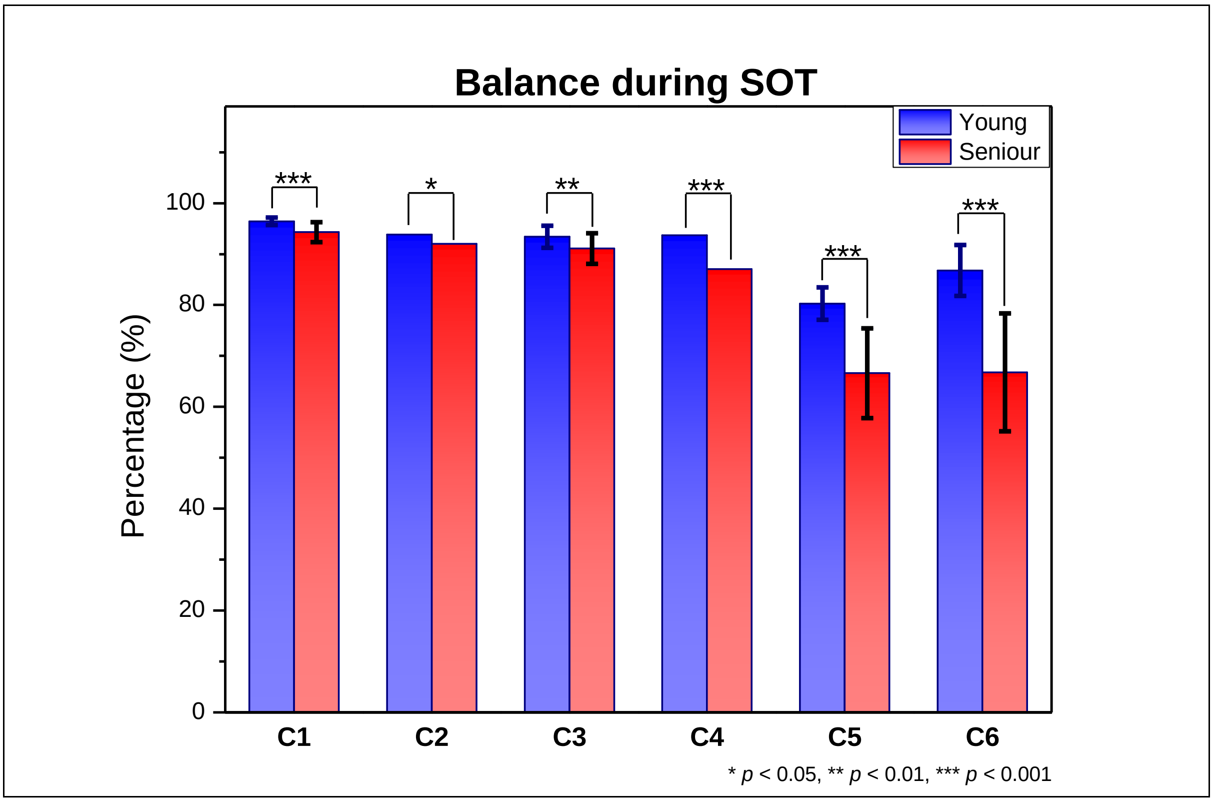


Fig. 50. Postural balance abilities during the sensory organisation test (SOT) conditions. (C) represents the condition in the figure. (Means are stated with the error bar, while the medians are stated without the error bar)

5.3 *Cortical activity during the SOT*

The power spectrum functional localisation and linear connectivity were computed for six (6) conditions of the SOT to identify the impact of each specific environment. The results of condition one (1) have already been presented above as static postural balance which is also condition one (1) of the sensory organisation test (SOT). The result of the power spectrum functional localisation and linear connectivity of the other 5 conditions of the sensory organisation test are presented below. In these results, compression of the cortical activity was performed in the seniors and young individuals to discern the impact of aging on postural balance in the different environments.

5.3.1 Power spectrum of condition two (2) of SOT

The power frequency spectrum between the senior and young participants in the study was compared during the static postural balance test under the conditions of absent vision and fixed support, with the eyes closed and stable surface and surrounding, which provides information regarding the cortical activity in the absence of visual information and the participants' relay of the somatosensory information to balance the posture.

The ***delta*** activity was found to be significantly higher in the frontal lobe in the young participants ($p < 0.05$, $\omega^2 = 0.07$). The temporal lobe activity of the young participants Mdn = 5.87 IQR = 4.16 – 6.99 (μV^2) ($p < 0.01$, r = 51.75) was significantly higher than in that of the senior participants Mdn = 3.53, IQR = 2.88 – 4.46. (μV^2); a similar trend was found in the parietal ($p < 0.01$, $\omega^2 = 0.19$) and occipital lobes, where the activity in the occipital lobe of the young participants was Mdn = 4.07, IQR = 2.86 – 5.89 (μV^2) ($p < 0.01$, r = 48.33) and seniors Mdn 2.35 = IQR = 1.78 – 3.56. (μV^2). However, no significant difference was found in the central lobe.

The ***theta*** activity of the young participants was significantly higher in all the five lobes of the cortex than in that of the senior participants viz., the frontal ($p < 0.001$, $\omega^2 = 0.48$), temporal ($p < 0.001$, $\omega^2 = 0.51$), central $p < 0.001$, $\omega^2 = 0.44$) parietal $p < 0.01$, $\omega^2 = 0.0.25$) and occipital ($p < 0.01$, $\omega^2 = 0.20$) lobes.

The ***alpha*** activity showed no significant difference between the frontal, temporal, central, parietal and occipital lobes of the young and senior participants.

The ***beta*** activity was significantly higher in the temporal ($p < 0.01$, $\omega^2 = 0.14$), central, ($p < 0.01$, $\omega^2 = 0.24$) and parietal ($p < 0.05$, $\omega^2 = 0.13$) lobes of the seniors than in that of the young participants. Further, no significant difference was observed in the frontal and occipital lobes of the young and senior participants in the study.

The ***gamma*** activity was significantly higher in the frontal lobe ($p < 0.01$, $\omega^2 = 0.23$) of the seniors than in the young participants. The temporal lobe of the senior participants Mdn = 0.14, IQR = 0.09 – 0.20 (μV^2) showed significantly higher activity ($p < 0.01$, r = 42.76) than that of the young participants Mdn = 0.07, IQR = 0.05 – 0.12 (μV^2). The same trend was found where the seniors Mdn = 0.11, IQR = 0.07 – 0.21 (μV^2) showed higher activity in the occipital lobe ($p < 0.01$, r = 45.33) than did the young participants in the study Mdn = 0.05, IQR = 0.39 – 0.08 (μV^2). Furthermore, no significant difference was found in the central and parietal lobes in both groups (Tab.15).

The power spectrum frequency showed higher delta and theta activities in the young participants, as well as higher beta and gamma activities in the senior participants, although no significant difference was present in the alpha activity, when they balanced the posture under conditions of eyes closed, firm surface and surrounding environment or absence of visual information (Fig 51).

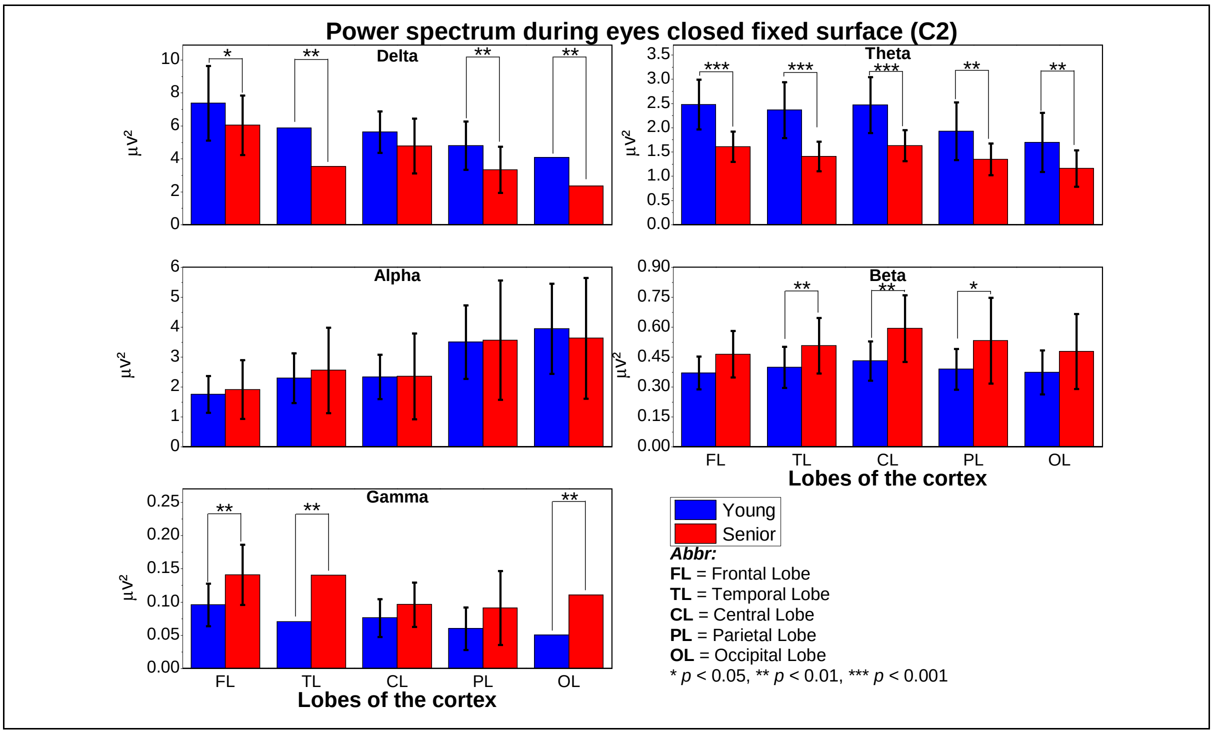


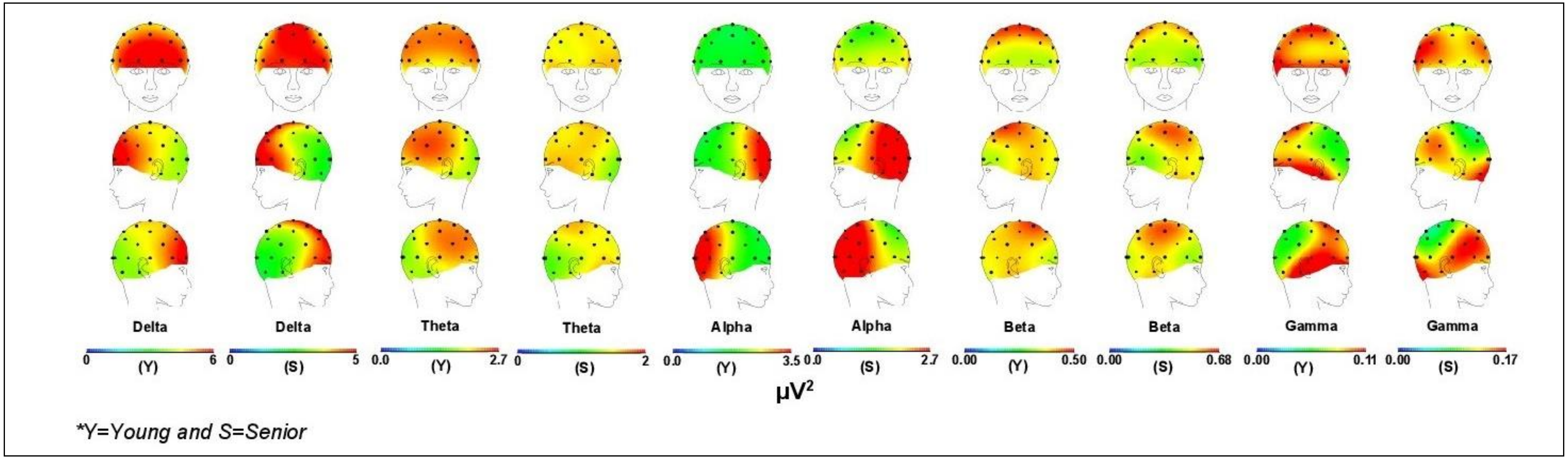
Fig. 51. Power spectrum during static postural balance under conditions of absent vision and fixed support. (Means are stated with the error bar while medians are stated without the error bar)

The overview of the power spectrum is shown as topographic maps during the static postural balance cortical activity of the young and senior participants in the study under the absence of visual feedback or condition two (2) of the sensory organisation test in Fig. 52.

Tab. 15. *Power spectrum mean activity during static postural balance under the condition of absent vision and fixed support*

ROI	**Delta(δ) [μV^2] M (SD)**		**Theta (θ) [μV^2] M (SD)**		**Alpha (α) [μV^2] M (SD)**		**Beta (β) [μV^2] M (SD)**		**Gamma (γ) [μV^2] M (SD)**	
	Young	**Senior**	**Young**	**Senior**	**Young**	**Senior**	**Young**	**Senior**	**Young**	**Senior**
FL	7.36 ± 2.26	6.04 ± 1.80	2.47 ± 0.51	1.60 ± 0.31	1.75 ± 0.61	1.91 ± 0.98	0.37 ± 0.08	0.46 ± 0.12	0.10 ± 0.03	0.14 ± 0.05
TL	5.62 ± 1.70	3.88 ± 1.62	2.36 ± 0.58	1.40 ± 0.31	2.29 ± 0.83	2.55 ± 1.43	0.40 ± 0.10	0.51 ± 0.14	0.10 ± 0.08	0.15 ± 0.06
CL	5.62 ± 1.26	4.77 ± 1.65	2.46 ± 0.57	1.63 ± 0.32	2.33 ± 0.74	2.36 ± 1.43	0.43 ± 0.10	0.59 ± 0.17	0.08 ± 0.03	0.10 ± 0.03
PL	4.79 ± 1.46	3.32 ± 1.40	1.92 ± 0.59	1.34 ± 0.33	3.50 ± 1.23	3.56 ± 1.99	0.39 ± 0.10	0.53 ± 0.21	0.06 ± 0.03	0.09 ± 0.06
OL	4.35 ± 1.60	2.77 ± 1.43	1.70 ± 0.61	1.16 ± 0.38	3.93 ± 1.51	3.62 ± 2.02	0.37± 0.11	0.48 ± 0.19	0.06 ± 0.03	0.14 ± 0.10

Abbr: FL = Frontal Lobe, TL = Temporal Lobe, CL = Central Lobe, PL= Parietal Lobe and OL = Occipital Lobe



**Y=Young and S=Senior*

Fig. 52. Topographic maps during static postural balance under the condition of absent vision and fixed support

5.3.2 *Functional localisation condition two (2) of the SOT*

Functional localisation of the cortical activity during postural balance under the absence of visual feedback was computed in the delta, theta, alpha, beta and gamma frequencies. The statistical threshold of functional localisation in the cortical activity during postural balance under the condition of eyes closed, firm surface and surrounding environment were defined according to the one-tailed statistical results, when comparing the senior with the young participants (senior < young). The $p < 0.01$ = t - 4.99, $p < 0.05$ = t - 4.31 and (senior > young) $p < 0.01$ = t 4.88 P < 0.05 = t 4.24.

The **delta** activity in the senior participants was significantly low $p < 0.01$ as when compared with the young participants in the posterior cingulate of the **limbic lobe** and rectal gyrus in the **frontal lobe**. $p < 0.05$ in anterior cingulate of **limbic lobe**, inferior frontal gyrus, medial frontal gyrus, middle frontal gyrus, orbital gyrus, subcallosal gyrus, superior frontal gyrus of the **frontal lobe**. The exact t-value are mentioned in Tab. 15.

Tab. 16. *Functional localisation delta activity in seniors compared with that of the young participants under condition two (2) of the SOT*

Structure	X(MNI)	Y(MNI)	Z(MNI)	T-Value	BAs	Lobe
Posterior Cingulate	0	-50	15	-5.04**	30	Limbic
Rectal Gyrus	-10	45	-25	-4.34**	11	Frontal
Orbital Gyrus	-20	35	-25	-4.27*	47	Frontal
Inferior Frontal Gyrus	-10	40	-20	-4.27*	11	Frontal
Middle Frontal Gyrus	-15	45	-20	-4.24*	11	Frontal
Superior Frontal Gyrus	-15	50	-20	-4.19*	11	Frontal
Anterior Cingulate	0	10	-5	-4.15*	25	Limbic
Medial Frontal Gyrus	-5	40	-15	-4.14*	11	Frontal
Subcallosal Gyrus	-10	25	-15	-4.10*	11	Frontal

*** = p < 0.01, * p <0.05*

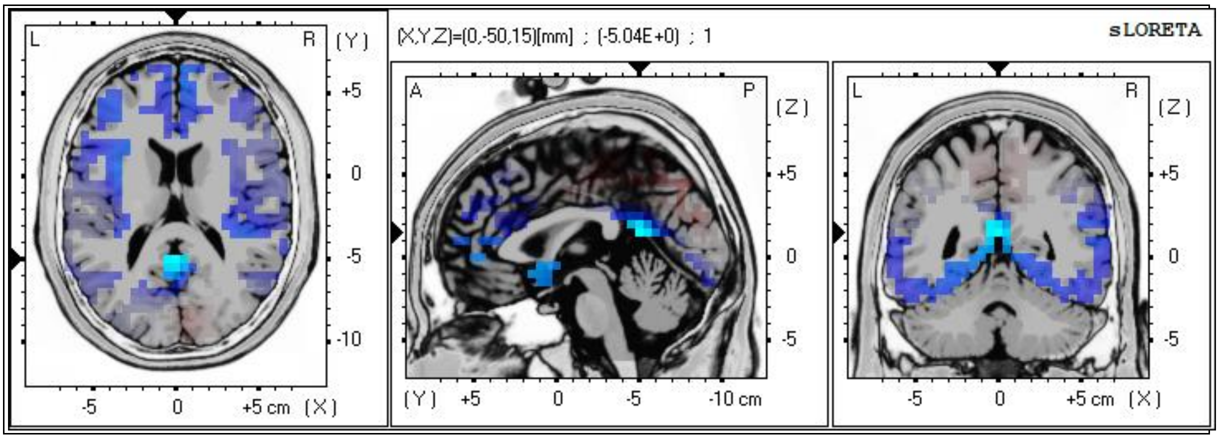


Fig. 53. Functional localisation delta activity during postural balance under the condition of absent vision and fixed support in the seniors, when compared with the young participants in the study.

The maximum low delta activity was observed in the posterior cingulate cortex of the limbic lobe, located at the 0 X(MNI), -50 Y(MNI) and 15 Z(MNI) of the MRI coordinates, in Brodmann area 30 (Fig. 53).

The **theta** activity was also significantly low in the cortex of the seniors when compared with that of the young participants in the study with $p < 0.01$ activity in the inferior frontal gyrus, medial frontal gyrus, middle frontal gyrus, paracentral lobule, postcentral gyrus, precentral gyrus, sub-gyral, superior frontal gyrus in **frontal lobe**, cingulate gyrus in **limbic lobe**, inferior parietal lobule and precuneus in **parietal lobe**, insula in s**ub-lobar**, supramarginal gyrus, superior temporal gyrus in **temporal lobe**. Further, significantly low $p <$ 0.05 was found in the orbital gyrus. and rectal gyrus in **frontal lobe**, anterior cingulate in **limbic lobe**, angular gyrus in **parietal lobe**, middle occipital gyrus in **occipital lobe** and middle temporal gyrus in **temporal lobe** of seniors as compared to young participants. The exact T-values of the structure with the MRI coordinates are mentioned in Tab. 17.

Tab. 17. *Functional localisation of the theta activity in the seniors when compared with the young participants under condition two (2) of the SOT*

Structure	X(MNI)	Y(MNI)	Z(MNI)	T-Value	BAs	Lobe
Cingulate Gyrus	-20	-20	40	-8.26**	24	Limbic
Precentral Gyrus	-25	-15	50	-8.25**	6	Frontal
Middle Frontal Gyrus	-30	-10	65	-8.22**	6	Frontal
Superior Frontal Gyrus	-25	-10	70	-7.16**	6	Frontal
Sub-Gyral	-25	-5	60	-6.88**	6	Frontal
Postcentral Gyrus	-30	-25	45	-6.57**	3	Parietal
Medial Frontal Gyrus	-15	-15	50	-6.49**	6	Frontal
Paracentral Lobule	-5	-25	45	-6.41**	31	Frontal
Precuneus	-5	-35	45	-5.80**	7	Parietal
Inferior Parietal Lobule	-60	-45	20	-5.71**	40	Parietal
Superior Temporal Gyrus	-65	-45	20	-5.69**	22	Temporal
Supramarginal Gyrus	-65	-50	25	-5.49**	40	Temporal
Insula	-55	-40	20	-5.24**	13	Sub-lobar
Inferior Frontal Gyrus	50	45	-10	-5.06**	47	Frontal
Anterior Cingulate	-15	45	10	-4.96*	32	Limbic
Angular Gyrus	-55	-60	35	-4.69*	39	Parietal
Orbital Gyrus	-15	45	-25	-4.58*	11	Frontal
Middle Occipital Gyrus	-50	-70	5	-4.55*	19	Occipital
Middle Temporal Gyrus	-55	-70	10	-4.54*	39	Temporal
Rectal Gyrus	-10	45	-25	-4.53*	11	Frontal
Inferior Temporal Gyrus	-50	-75	-5	-4.38*	19	Temporal

** = $p < 0.01$, * $p < 0.05$

The senior participants showed the lowest theta activity in the cingulate gyrus of the limbic lobe at the -20 X (MNI), -20 Y (MNI) and 40 Z (MNI) of the MRI coordinates in Brodmann area 24 when compared with the young participants in study Fig. 54.

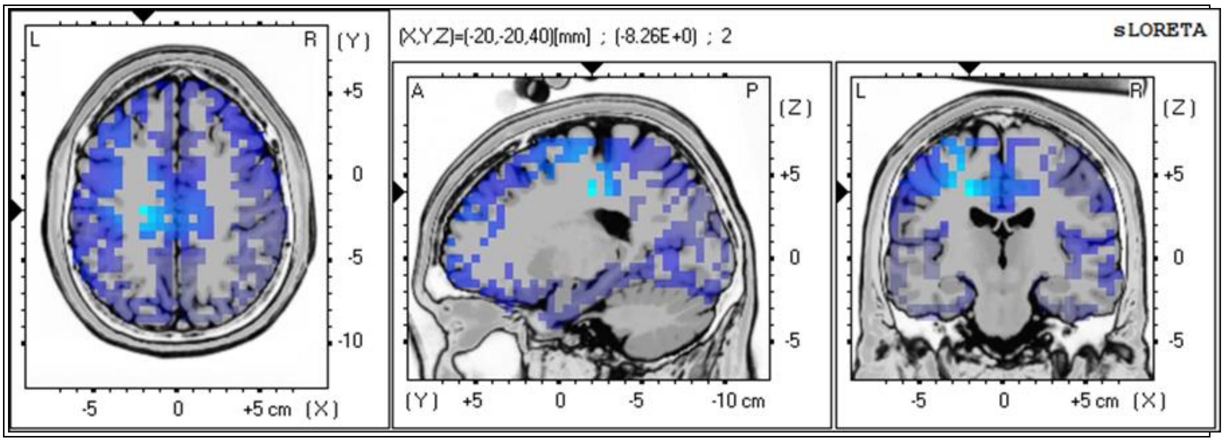


Fig. 54. Functional localisation of the theta activity during postural balance in the seniors under the condition of absent vision and fixed support when compared with the young participants in the study

The **alpha** and **beta** activities showed no significant difference between the young and senior participants in the study during postural balance under the condition of absent visual feedback.

The **gamma** activity in the cortex of the seniors is significantly $p < 0.01$ higher in the inferior frontal gyrus, medial frontal gyrus in **frontal lobe**, posterior cingulate and anterior cingulate in **limbic lobe**, cuneus and lingual gyrus in **occipital lobe,** extra-nuclear and insula in **sub-lobar**. $p < 0.05$ middle frontal gyrus, superior frontal gyrus, orbital gyrus, precentral gyrus, rectal gyrus, subcallosal gyrus and sub-gyral in **frontal lobe**, precuneus, middle occipital gyrus, inferior occipital gyrus and fusiform gyrus in **occipital lobe,** inferior parietal lobule in **parietal lobe**, middle temporal gyrus and superior temporal gyrus in **temporal lobe.** The exact T-value and MRI coordinates of the gamma activity are stated in Tab. 18.

Tab. 18. *Functional localisation of the gamma activity in the seniors compared with the young participants under condition two (2) of the SOT*

Structure	X(MNI)	Y(MNI)	Z(MNI)	T-Value	BAs	Lobe
Posterior Cingulate	25	-70	5	5.32**	30	Limbic
Lingual Gyrus	20	-70	0	5.21**	19	Occipital
Cuneus	25	-75	10	5.17**	30	Occipital
Extra-Nuclear	-35	20	0	5.15**	47	Sub-lobar
Insula	-35	15	0	5.10**	13	Sub-lobar
Inferior Frontal Gyrus	-35	25	0	5.02**	47	Frontal
Anterior Cingulate	-10	35	-5	5.01**	32	Limbic

Medial Frontal Gyrus	-10	40	-5	4.96**	10	Frontal
Precuneus	25	-75	15	4.87*	31	Occipital
Middle Occipital Gyrus	30	-85	-5	4.87*	18	Occipital
Middle Frontal Gyrus	-20	40	-15	4.80*	11	Frontal
Superior Frontal Gyrus	-15	50	-15	4.78*	11	Frontal
Inferior Occipital Gyrus	35	-85	-10	4.71*	18	Occipital
Orbital Gyrus	-10	55	-20	4.66*	11	Frontal
Precentral Gyrus	-35	0	30	4.64*	6	Frontal
Middle Temporal Gyrus	45	-75	10	4.62*	39	Temporal
Superior Temporal Gyrus	65	-45	15	4.59*	22	Temporal
Rectal Gyrus	-10	45	-25	4.56*	11	Frontal
Subcallosal Gyrus	-10	25	-10	4.56*	11	Frontal
Inferior Parietal Lobule	60	-45	20	4.46*	40	Parietal
Fusiform Gyrus	25	-85	-20	4.37*	19	Occipital
Sub-Gyral	-40	45	0	4.25*	10	Frontal

*** = p < 0.01, * p <0.05*

The maximum high gamma activity in the senior cortex was found in the anterior cingulate of the limbic lobe at the -10 X (MNI) 35 Y (MNI) -5 Z (MNI) of the MRI coordinates when compared with that of the young participants in the study, as shown in Fig. 55.

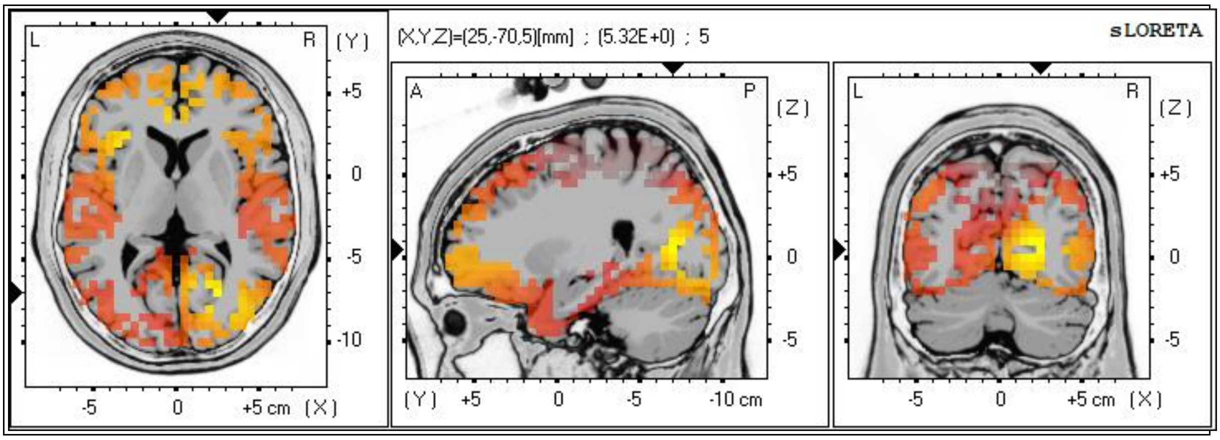


Fig. 55. Functional localisation of the gamma activity during postural balance under the condition of absent vision and fixed support in the seniors when compared with that of the young participants in the study

5.3.3 Power spectrum of condition four (4) of the SOT

The power frequency spectrum of the young and senior participants in the study during postural balance under the condition of normal vision with sway reference or moving support is presented below in the delta, theta, alpha, beta and gamma frequencies.

The d**elta** activity was significantly low in the senior participants Mdn = 3.67, IQR = 2.92 – 4.48 (μV^2) in the temporal lobe ($p < 0.01$, r = 42.34) than in the young participants Mdn = 5.58, IQR = 4.20 – 6.42 (μV^2) and in the parietal lobe of the senior Mdn = 4.35, IQR = 3.63 – 5.39 (µV^2) ($p < 0.01$, r = 47.48) and young participants Mdn = 6.28, IQR =4.80 – 6.56 (µV^2). The seniors also showed significantly low activity in the occipital lobe ($p < 0.01$, $\omega^2 = 0.23$). However, no significant difference was found in the activity of the frontal and central lobes between the senior and young participants in the study.

The **theta** activity in the senior participants was significantly low in the frontal ($p < 0.001$, $\omega^{2\,=}$ 0.61), temporal ($p < 0.001$, size $\omega^2 = 0.49$), central ($p < 0.001$, $\omega^2 = 0.56$), parietal ($p < 0.001$, $\omega^{2\,=}$ 0.45) and occipital $p < 0.001$, $\omega^2 = 0.41$) lobes when compared with the young participants in the study.

The **alpha** activity showed no significant difference between the seniors and young subjects in the study, in the frontal, temporal, central, parietal and occipital lobes. The **beta** activity in the senior participants was significantly higher in the frontal ($p < 0.01$, $\omega^2 = 0.20$), temporal ($p < 0.01$, $\omega^2 = 0.17$), central ($p < 0.001$, $\omega^2 = 0.36$), parietal ($p < 0.001$, $\omega^2 = 0.34$) and occipital ($p < 0.001$, $\omega^2 = 0.27$) lobes, when compared with the young participants. The **gamma** activity was also significantly higher in the frontal lobe ($p < 0.001$, $\omega^2 = 0.37$) and occipital lobe ($p < 0.01$ $\omega^2 = 0.15$) of the seniors when compared with the young participants in the study. No significant difference was found in the gamma activity in the temporal, central and parietal lobes between both groups. The mean power spectra of the young and senior participants are stated in Tab. 19.

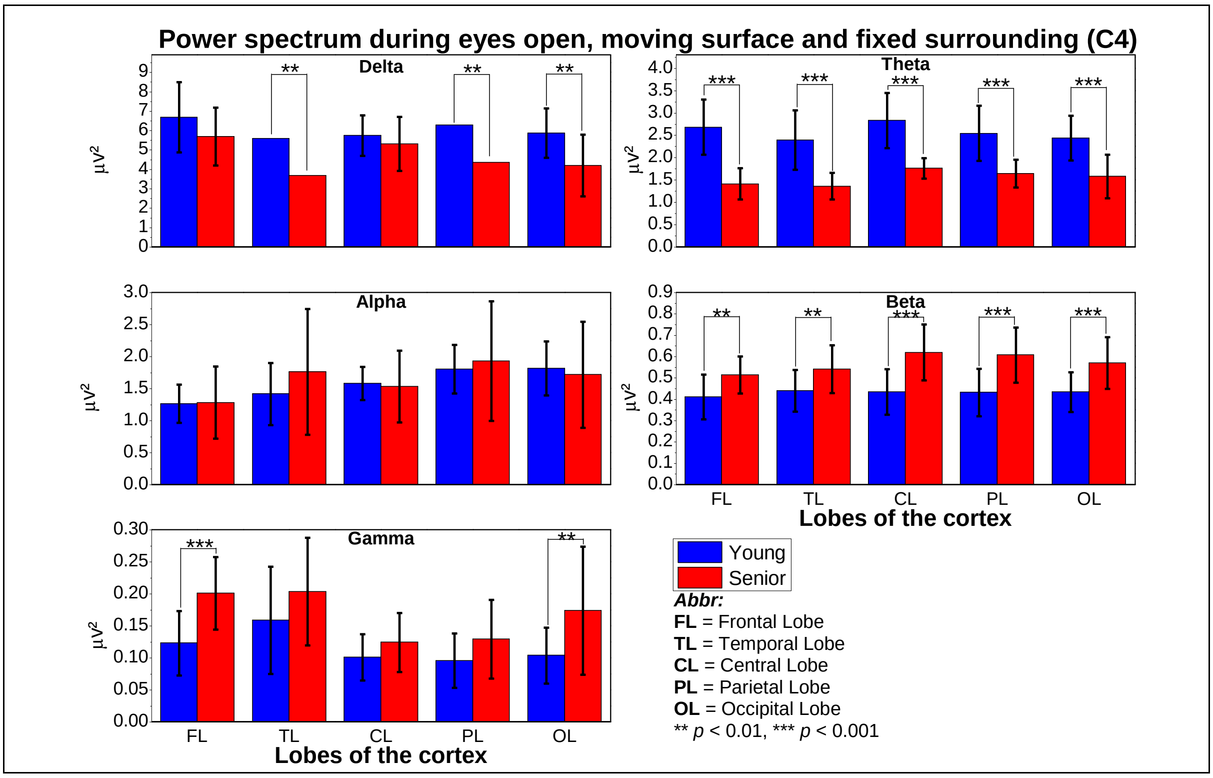
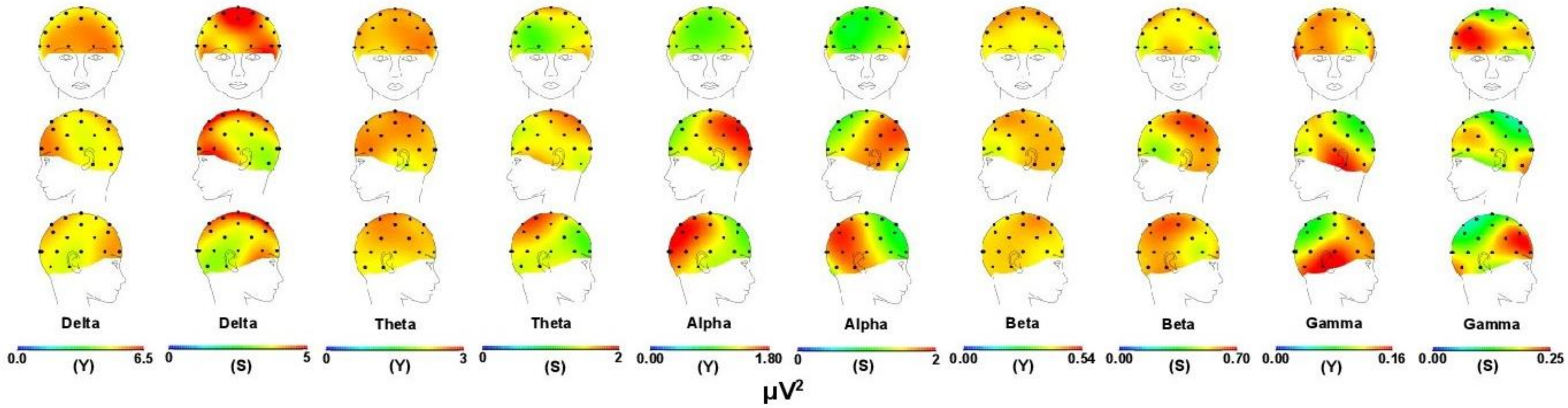


Fig. 56. Power spectrum during static postural balance under the condition of normal vision with sway reference. (Means are stated with the error bar while medians are stated without the error bar)

Tab. 19. *Power spectrum mean activity during static postural balance under the condition of normal vision with sway reference*

ROI	**Delta(δ) [μV^2] M (SD)**		**Theta (θ) [μV^2] M (SD)**		**Alpha (α) [μV^2] M (SD)**		**Beta (β) [μV^2] M (SD)**		**Gamma (γ) [μV^2] M (SD)**	
	Young	**Senior**	**Young**	**Senior**	**Young**	**Senior**	**Young**	**Senior**	**Young**	**Senior**
FL*	6.68 ± 1.80	5.68 ±1.49	2.68 ± 0.61	1.41 ± 0.35	1.26 ± 0.29	1.28 ± 0.56	0.41± 0.10	0.51 ± 0.09	0.12 ± 0.05	0.20 ± 0.06
TL*	5.25 ± 1.38	4.01 ± 1.39	2.39 ± 0.66	1.36 ± 0.30	1.41 ± 0.48	1.76 ± 0.98	0.44 ± 0.10	0.54 ± 0.11	0.16 ± 0.08	0.20 ± 0.08
CL*	5.74 ± 1.04	5.31 ± 1.39	2.83 ± 0.62	1.76 ± 0.23	1.58 ± 0.26	1.53 ± 0.56	0.43 ± 0.11	0.62 ± 0.13	0.10 ± 0.04	0.12 ± 0.05
PL*	5.92 ± 1.22	4.53 ± 1.16	2.54 ± 0.61	1.64 ± 0.31	1.80 ± 0.38	1.93 ± 0.93	0.43 ± 0.11	0.61 ± 0.13	0.10 ± 0.04	0.13 ± 0.06
OL*	5.87 ± 1.27	4.19 ± 1.59	2.43 ± 0.50	1.58 ± 0.49	0.81 ± 0.42	1.71 ± 0.83	0.43 ± 0.10	0.57 ± 0.12	0.10 ± 0.04	0.17 ± 0.10

Abbr: FL = Frontal Lobe, TL = Temporal Lobe, CL = Central Lobe, PL= Parietal Lobe and OL = Occipital Lobe



**Y=Young and S=Senior*

Fig. 57. Topographic maps during static postural balance under the condition of normal vision with sway reference

The senior participants showed low delta activity in the temporal, parietal and occipital lobes and less theta activity in all the lobes in the cortex when compared with the young participants in the study. However, they showed high beta activity in all the lobes and gamma activity only in the frontal and occipital lobes while balancing the posture under the influence of the visual sway. Further, no significant difference was noted in the alpha activity between the young and senior participants (Fig. 56).

The overview of the power spectrum is shown as topographic maps during the static postural balance cortical activity of the young and senior participants in the study under the condition of normal vision with sway reference or condition four (4) of the sensory organisation test in Fig. 57.

5.3.4 Functional localisation of condition four (4) of the SOT

The functional localisation during postural balance under normal vision with sway reference is reported in the delta, theta, alpha, beta and gamma frequencies.

The statistical threshold of functional localisation of the cortical activity during postural balance under the condition of eyes open, moving surface and fixed surrounding was defined according the one-tailed statistical results, where the seniors were compared with the young participants (senior < young). $p < 0.01$ = t 5.04, $p < 0.05$ = t 4.25 and (senior > young) $p < 0.01$ = t -4.89 $p < 0.05$ = t -4.22.

The **delta** activity was significantly low in the cortex of the senior participants when compared with that of the young participants in the study $p < 0.05$ in the posterior cingulate cortex of the **limbic lobe** at the 5 X (MNI) -50 Y (MNI) 20 Z (MNI) of the MRI coordinates with T-value - 4.46 at Brodmann area 30 (Fig. 58).

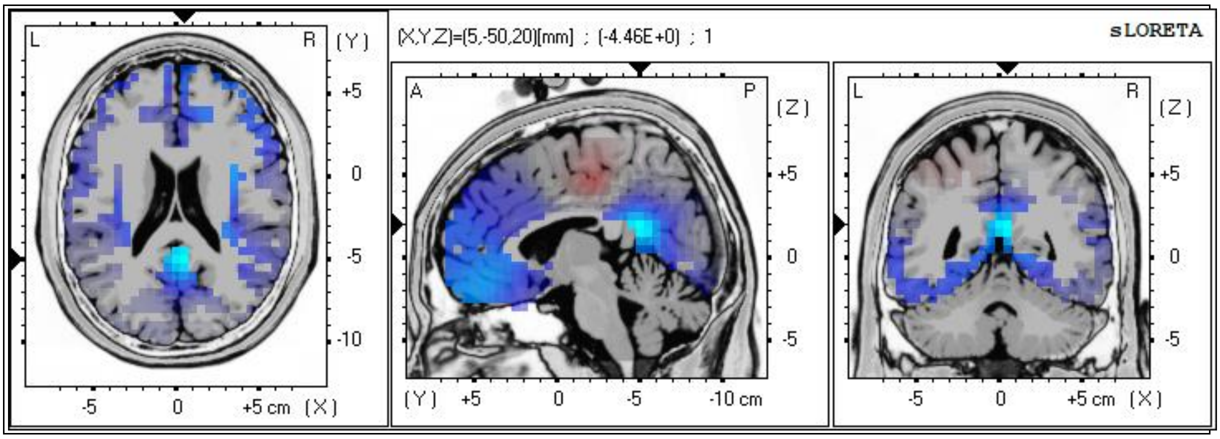


Fig. 58. Functional localisation delta activity during postural balance under the condition of normal vision with sway reference

The **theta** activity was significantly low in the cortex of the seniors *p* < 0.01 than in the young participants in the study. This significantly low activity was found in the inferior frontal gyrus, medial frontal gyrus, middle frontal gyrus, orbital gyrus, paracentral lobule, postcentral gyrus, precentral gyrus, rectal gyrus, sub-gyral and superior frontal gyrus, in **frontal lobe**, anterior cingulate, cingulate gyrus and posterior cingulate in **limbic lobe**, precuneus, in **partial lobe** and insula in **sub-lobar.**

While even more significantly low activity of *p* < 0.05 was observed in the middle temporal gyrus in the **occipital lobe**, superior parietal lobule in the **partial lobe**, extra-nuclear, insula in **sub-lober** and superior temporal gyrus and supramarginal gyrus, superior temporal gyrus in the **temporal lobe**. The location of the activity and the T-values are mentioned in Tab. 20.

Tab. 20. *Functional localisation of the theta activity in the seniors was compared with that of the young participants under condition four (4) of the SOT*

Structure	X(MNI)	Y(MNI)	Z(MNI)	T-Value	BAs	Lobe
Cingulate Gyrus	15	-30	40	-7.54**	31	Limbic
Precentral Gyrus	25	-20	55	-7.00**	6	Frontal
Paracentral Lobule	5	-30	45	-6.96**	31	Frontal
Precuneus	5	-35	45	-6.88**	7	Parietal
Middle Frontal Gyrus	25	-15	60	-6.87**	6	Frontal
Medial Frontal Gyrus	10	-25	50	-6.76**	6	Frontal
Superior Frontal Gyrus	30	-10	70	-6.56**	6	Frontal
Sub-Gyral	20	-10	60	-6.27**	6	Frontal
Postcentral Gyrus	10	-35	70	-6.19**	3	Frontal
Anterior Cingulate	5	40	10	-6.03**	32	Limbic
Posterior Cingulate	-5	-30	25	-5.89**	23	Limbic
Inferior Frontal Gyrus	35	5	30	-5.47**	9	Frontal
Insula	35	5	20	-5.22**	13	Sub-lobar
Orbital Gyrus	10	55	-20	-5.14**	11	Frontal
Rectal Gyrus	5	55	-25	-5.03**	11	Frontal
Superior Temporal Gyrus	-35	-55	20	-4.67*	22	Temporal
Middle Temporal Gyrus	-35	-60	15	-4.54*	19	Occipital
Superior Temporal Gyrus	-45	-45	20	-4.51*	13	Temporal
Superior Parietal Lobule	20	-45	65	-4.42*	5	Parietal
Supramarginal Gyrus	-50	-50	20	-4.31*	40	Temporal
Extra-Nuclear	35	20	0	-4.27*	47	Sub-lobar

*** = $p < 0.01$, * $p < 0.05$*

The senior participants revealed the lowest theta activity in the cingulate gyrus of the limbic lobe at the 15 X (MNI), -30 Y (MNI) and 40 Z (MNI) of the MRI coordinates, as shown in Fig. 59.

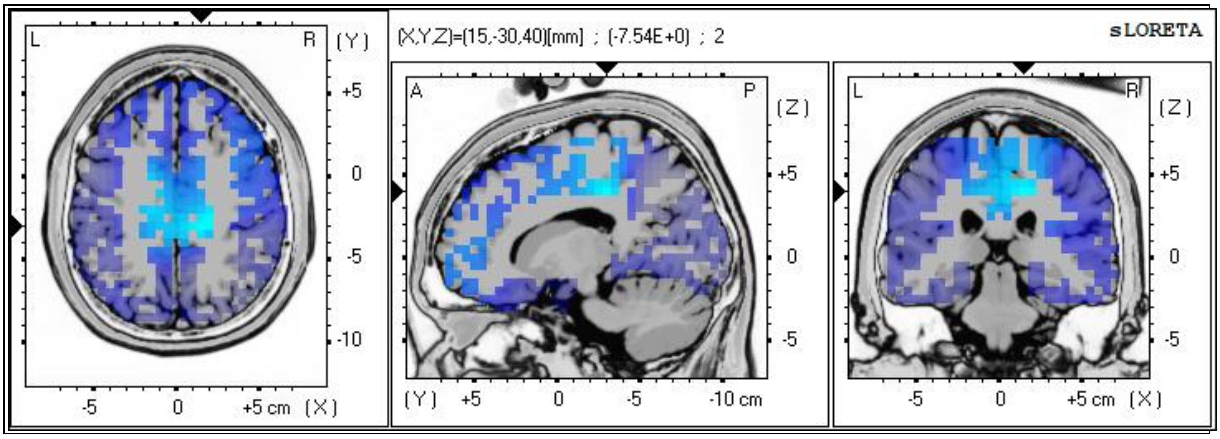


Fig. 59. Functional localisation of the theta activity during postural balance under the condition of normal vision with sway reference

The **alpha** activity was seen to be significantly low $p < 0.01$ in the cortex of the seniors when compared with that of the young participants in the study, in anterior cingulate of the **limbic lobe** and in the medial frontal gyrus, middle frontal gyrus, precentral gyrus and superior frontal gyrus in the **frontal lobe**. Significantly low $p < 0.05$ was found in the postcentral gyrus of the **parietal lobe** and the inferior frontal gyrus, orbital gyrus and rectal gyrus in the **frontal lobe**. The location of the activity and the T-values are mentioned in Tab. 21.

Tab. 21. *Functional localisation of the alpha activity in the seniors compared with that of the young participants under condition four (4) of the SOT*

Structure	X(MNI)	Y(MNI)	Z(MNI)	T-Value	BAs	Lobe
Superior Frontal Gyrus	-5	65	-5	-5.67**	10	Frontal
Medial Frontal Gyrus	-5	65	0	-5.65**	10	Frontal
Middle Frontal Gyrus	40	0	45	-5.52	6	Frontal
Precentral Gyrus	35	5	40	-5.34**	9	Frontal
Anterior Cingulate	-5	50	0	-5.2**	32	Limbic
Inferior Frontal Gyrus	35	5	30	-4.82*	9	Frontal
Orbital Gyrus	10	55	-20	-4.48*	11	Frontal
Postcentral Gyrus	55	-15	50	-4.32*	3	Parietal
Rectal Gyrus	5	55	-25	-4.24*	11	Frontal

*** = $p < 0.01$, * $p < 0.05$*

The senior participants showed the lowest alpha activity in the superior frontal gyrus in the frontal lobe at the -5 X (MNI), 65 Y (MNI) and -5 Z (MNI) MRI coordinates in Brodmann area 10, as depicted in Fig. 60.

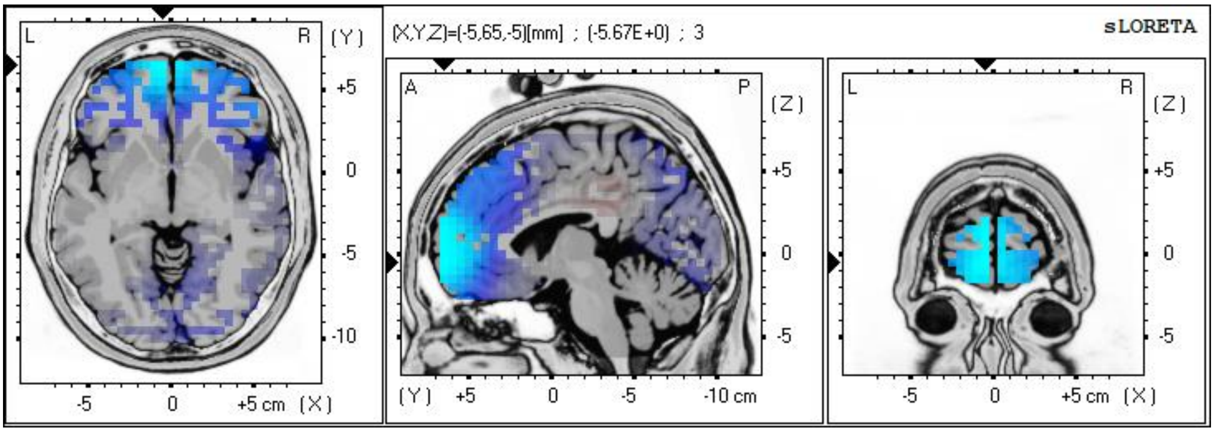


Fig. 60. Functional localisation of the alpha activity during postural balance under the condition of normal vision with sway reference

The **beta** activity revealed no significant difference between the young and senior participants in the study.

Gamma activity was found to be significantly higher $p < 0.01$ in the insula in the **sub-lobar** and anterior cingulate of the **limbic lobe** in the senior participants compared with that in the young participants. Significantly higher $p < 0.05$ activity was evident in the cingulate gyrus, inferior frontal gyrus, medial frontal gyrus, precentral gyrus, sub-gyral, superior frontal gyrus in the **frontal lobe**, cingulate gyrus in the **limbic lobe** and extra-nuclear in **sub-lobar** of the seniors than in that of the young participants in the study. The location of the activity and the T-values are mentioned in Tab. 22.

Tab. 22. *Functional localisation of the gamma activity in the seniors compared with the young participants under condition four (4) of the SOT*

Structure	X(MNI)	Y(MNI)	Z(MNI)	T-Value	BAs	Lobe
Insula	30	15	15	5.13**	13	Sub-lobar
Anterior Cingulate	10	20	25	5.06**	24	Limbic
Cingulate Gyrus	15	15	35	4.93*	32	Limbic
Medial Frontal Gyrus	20	35	20	4.86*	9	Frontal
Precentral Gyrus	35	-15	45	4.73*	6	Frontal
Inferior Frontal Gyrus	35	25	5	4.66*	45	Frontal
Superior Frontal Gyrus	25	50	5	4.44*	10	Frontal
Cingulate Gyrus	15	25	40	4.36*	6	Frontal
Sub-Gyral	20	25	45	4.35*	8	Frontal
Extra-Nuclear	35	20	0	4.31*	47	Sub-lobar

*** = $p < 0.01$, * $p < 0.05$*

The senior participants showed significantly high gamma activity in the insula in the sub-lobar region at the -30 X(MNI), 15 Y(MNI) and 15 Z(MNI) MRI coordinates in Brodmann area 13, as seen in Fig. 61.

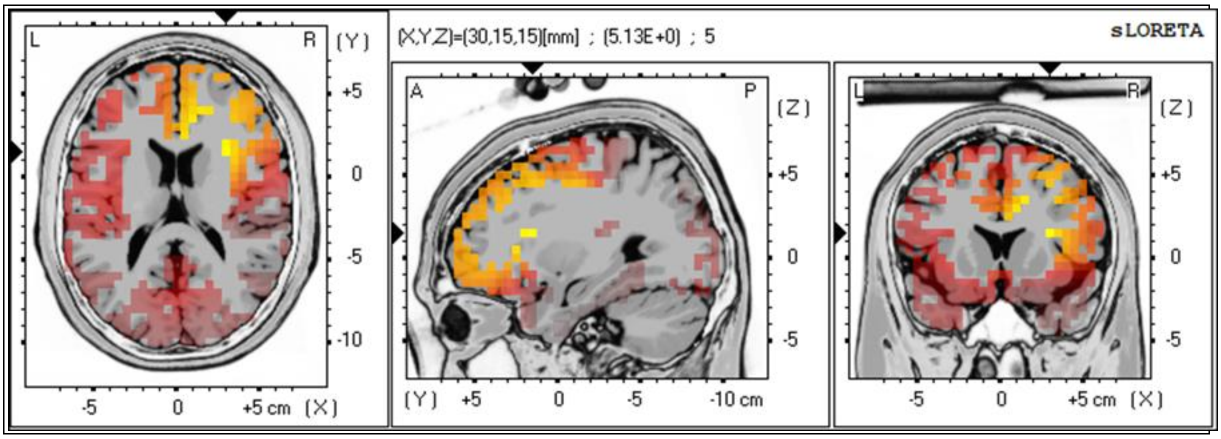


Fig. 61. Functional localisation of the gamma activity during postural balance under the condition of normal vision with sway reference

5.3.5 Power spectrum of condition five (5) of the SOT

The power frequency spectrum during postural balance in condition five (5). The absence of vision with sway reference support is presented below.

The **delta** activity was found to be significantly lower in the temporal lobe of the seniors Mdn = 3.64, IQR = 2.96 – 5.19 (μV^2) ($p < 0.01$, r = 49.17) when compared with that of the young participants. Mdn = 5.72, IQR = 4.62 – 6.74. (μV^2) and parietal lobe ($p < 0.05$, $\omega^2 = 0.10$). However, no significant difference was observed in the frontal, central and occipital lobes between the young and senior groups.

The **theta** activity was also seen to be significantly low in the senior participants than in the young participants in the frontal ($p < 0.001$, $\omega^2 = 0.57$), temporal ($p < 0.001$, $\omega^2 = 0.54$), central ($p < 0.001$, $\omega^2 = 0.53$), parietal ($p < 0.001$, $\omega^2 = 0.34$) and occipital ($p < 0.001$, $\omega^2 = 0.27$) lobes.

The **alpha** activity displayed no significant difference between the seniors and young participants in the frontal, temporal. central, parietal and occipital lobes.

The **beta** activity was found to be significantly higher in the senior participants in the study, in the frontal ($p < 0.01$, $\omega^2 = 0.17$), temporal ($p < 0.01$, $\omega^2 = 0.20$), central ($p < 0.001$, $\omega^2 = 0.38$), parietal ($p < 0.01$, $\omega^2 = 0.24$) and occipital lobes ($p < 0.01$, $\omega^2 = 0.15$) than in the young participants in the study.

The **gamma** activity was also found to be significantly higher in the frontal lobe in the seniors ($p < 0.001$, $\omega^2 = 0.36$). The temporal lobe of the seniors Mdn = 0.17, IQR 0.11 – 0.23 (μV^2) also showed significantly higher activity ($p < 0.001$, r = 61.03) than did the young participants, Mdn = 0.06, IQR 0.04 – 0.12 (μV^2). Further, the seniors showed higher activity in the central ($p < 0.001$, $\omega^2 = 0.29$), parietal ($p = 0.01$, $\omega^2 = 0.23$) and occipital lobes ($p = 0.01$, $\omega^2 = 0.25$) than did the young participants in the study, as shown in Tab. 23.

The **delta** activity was low in the temporal and parietal lobes, while the **theta** activity was low in all the lobes in the seniors when compared with those of the young participants in the study. On the other hand, the seniors demonstrated high **gamma** and **beta** activities in the cortex under the condition of absence of vision with sway reference support. (Fig. 62).

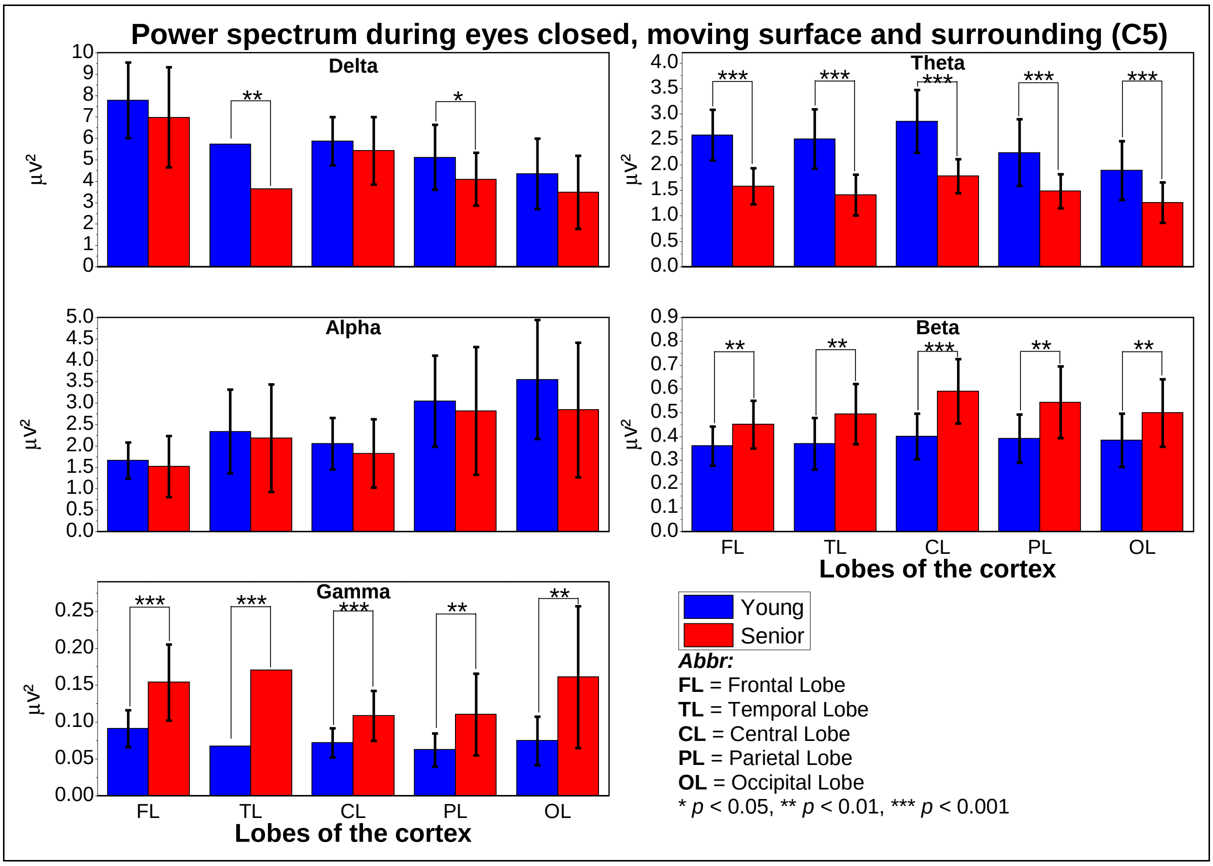


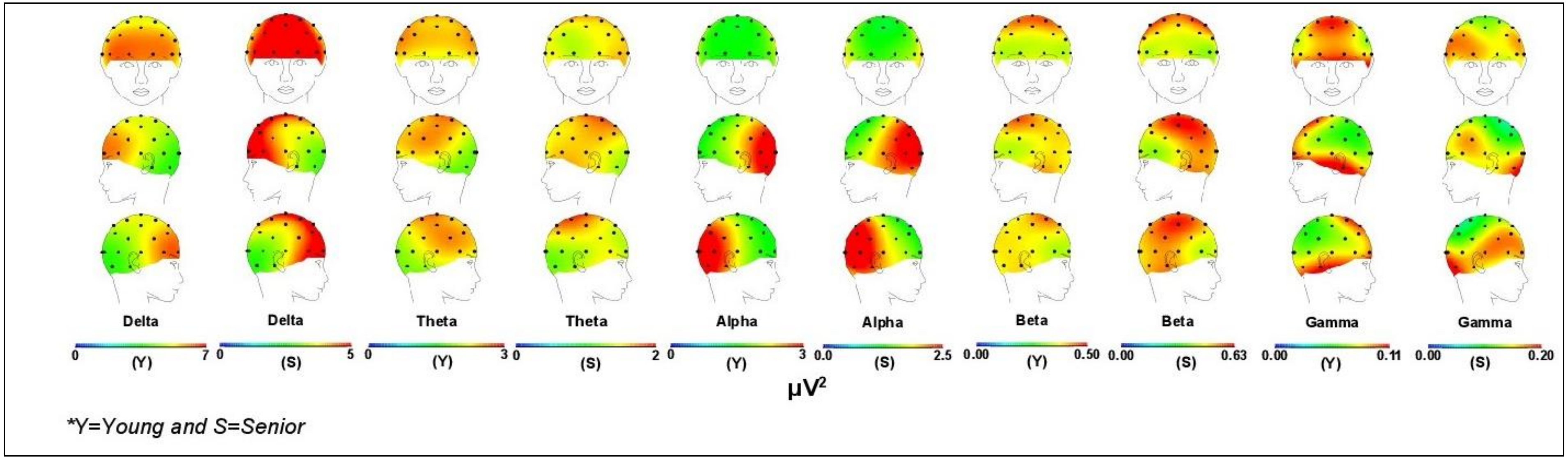
Fig. 62. Power spectrum during static postural balance under the condition of absence of vision with sway reference support. (Means are stated with the error bar, while the medians are stated without the error bar)

The overview of the power spectrum is displayed as topographic maps during the static postural balance cortical activity of both the young and senior participants in the study, under the condition of absence of vision with sway reference support or condition five (5) of the sensory organisation test, as evident in Fig. 63.

Tab. 23. *Power spectrum mean activity during static postural balance under the condition of absence of vision with sway reference support*

ROI	**Delta(δ) [µV²] M (SD)**		**Theta (θ) [µV²] M (SD)**		**Alpha (α) [µV²] M (SD)**		**Beta (β) [µV²] M (SD)**		**Gamma (γ) [µV²] M (SD)**	
	Young	**Senior**	**Young**	**Senior**	**Young**	**Senior**	**Young**	**Senior**	**Young**	**Senior**
FL*	7.77 ± 1.77	6.97 ± 2.34	2.58 ± 0.50	1.58 ± 0.36	1.66 ± 0.42	1.52 ± 0.71	0.36 ± 0.08	0.45 ± 0.10	0.09 ± 0.02	0.15 ± 0.05
TL*	5.87 ± 1.36	4.33 ± 1.78	2.50 ± 0.58	1.40 ± 0.40	2.33 ± 0.98	2.18 ± 1.25	0.37 ± 0.11	0.49 ± 0.13	0.08 ± 0.05	0.18 ± 0.07
CL*	5.85 ± 1.12	5.41 ± 1.58	2.84 ± 0.61	1.78 ± 0.34	2.05 ± 0.60	1.82 ± 0.80	0.40 ± 0.10	0.59 ± 0.13	0.07 ± 0.02	0.11 ± 0.03
PL*	5.10 ± 1.51	4.08 ± 1.24	2.24 ± 0.65	1.48 ± 0.34	3.04 ± 1.06	2.81 ± 1.49	0.39 ± 0.10	0.54 ± 0.15	0.06 ± 0.02	0.11 ± 0.06
OL*	4.34 ± 1.64	3.48 ± 1.70	1.88 ± 0.58	1.26 ± 0.39	3.54 ± 1.39	2.84 ± 1.57	0.38 ± 0.11	0.50 ± 0.14	0.07 ± 0.03	0.16 ± 0.10

Abbr: FL = Frontal Lobe, TL = Temporal Lobe, CL = Central Lobe, PL= Parietal Lobe and OL = Occipital Lobe



*Y=Young and S=Senior

Fig. 63. Topographic maps during static postural balance under the condition of absence of vision with sway reference support

5.3.6 Functional localisation of condition five (5) of the SOT

Functional localisation during postural balance under the condition of absence of vision with sway reference support was reported for the delta, theta, alpha, beta and gamma frequencies. The statistical threshold of the functional localisation of the cortical activity during postural balance under the condition of eyes closed, moving surface and fixed surrounding was defined according to the one-tailed statistical results, where the findings for the seniors were compared with those of the young participants (senior < young). The $p < 0.01$ = t 4.94, P < 0.05 = t 4.17 and (senior > young) p < 0.01 = t -4.98 p < 0.05 = t -4.20.

The **delta** activity showed no significant difference in sub-cortical functional localisation between the groups of the young and senior participants.

The **theta** activity was significantly lower in the senior participants when compared with that of the young participants in the study $p < 0.01$ in the cingulate gyrus, inferior frontal gyrus, medial frontal gyrus, middle frontal gyrus, orbital gyrus, paracentral lobule, precentral gyrus, sub-gyral and superior frontal gyrus in **frontal lobe**, anterior cingulate in **limbic lobe**, precuneus in **parietal lobe** and insula in **sub-lobar** and superior temporal gyrus in **temporal lobe**. Further, significantly low activity $p < 0.05$ was identified in the postcentral gyrus and rectal gyrus of the **frontal lobe**, in the posterior cingulate of the **limbic lobe**, in the inferior parietal lobule of the **parietal lobe,** and in the transverse temporal gyrus in the **temporal lobe** of the seniors than in the young participants. The t-values of the **theta** activity and location of the activity in the structure are stated in tab. 24.

Tab. 24. *Functional localisation of the theta activity in the seniors compared with that of the young participants under condition five (5) of the SOT*

Structure	X(MNI)	Y(MNI)	Z(MNI)	T-Value	BAs	Lobe
Middle Frontal Gyrus	30	20	50	-7.56**	8	Frontal
Superior Frontal Gyrus	30	25	55	-7.40**	8	Frontal
Inferior Frontal Gyrus	35	5	30	-7.10**	9	Frontal
Precentral Gyrus	35	10	40	-7.01**	9	Frontal
Medial Frontal Gyrus	10	65	15	-6.98**	10	Frontal
Insula	35	5	20	-6.77**	13	Sub-lobar
Cingulate Gyrus	15	10	40	-6.75**	32	Frontal
Anterior Cingulate	15	45	10	-6.39**	32	Limbic
Sub-Gyral	20	25	45	-6.37**	8	Frontal
Orbital Gyrus	10	55	-20	-5.29**	11	Frontal
Paracentral Lobule	0	-40	50	-5.16**	5	Frontal
Precuneus	0	-40	45	-5.07**	7	Parietal
Superior Temporal Gyrus	50	10	0	-5.05**	22	Temporal

Rectal Gyrus	5	55	-25	-4.96*	11	Frontal
Postcentral Gyrus	5	-45	70	-4.83*	5	Parietal
Inferior Parietal Lobule	60	-45	20	-4.69*	40	Parietal
Postcentral Gyrus	55	-15	35	-4.66*	4	Frontal
Transverse Temporal Gyrus	45	-25	10	-4.57*	41	Temporal
Posterior Cingulate	10	-65	10	-4.21*	30	Limbic

*** = $p < 0.01$, * $p < 0.05$*

The senior participants showed significantly low **theta** activity in the middle frontal gyrus at the -30 X(MNI), 20 Y(MNI) and 50 Z(MNI) MRI coordinates in Brodmann area 8, as seen in Fig. 64.

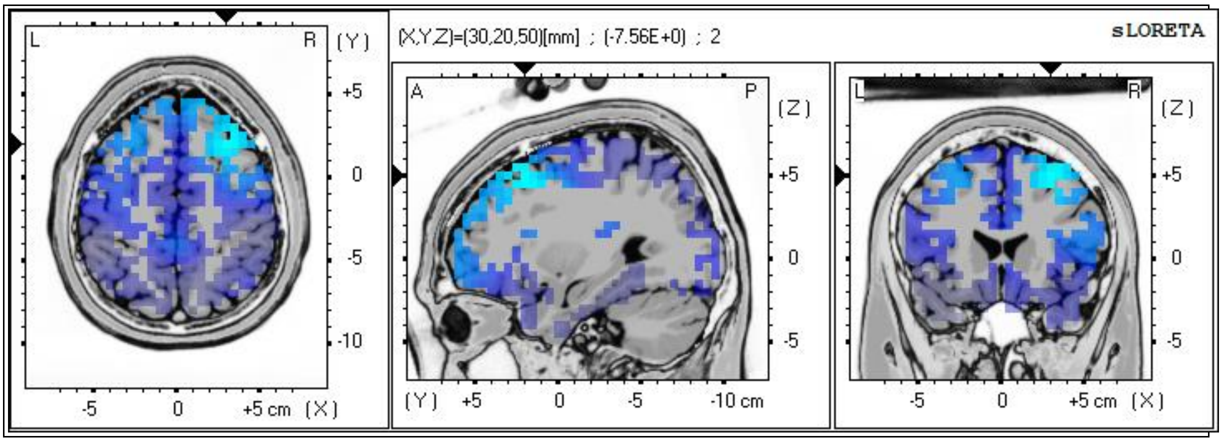


Fig. 64. Functional localisation of the theta activity in the seniors during postural balance under the condition of absence of vision with sway reference support

The **alpha** activity in the cortex of the seniors was also found to be significantly low $p < 0.01$ in the inferior frontal gyrus, medial frontal gyrus, middle frontal gyrus, orbital gyrus, precentral gyrus and superior frontal gyrus in **frontal lobe**, anterior cingulate and cingulate gyrus **limbic lobe**. Further, significantly low activity $p < 0.05$ was identified in the rectal gyrus of the **frontal lobe**, postcentral gyrus in **parietal lobe**, insula in **sub-lobar** and superior temporal gyrus in **temporal lobe** as compared with the young participants.The activity in the cortical structure and T-values are shown in Tab. 25.

Tab. 25. *Functional localisation of the alpha activity in the seniors compared with that of the young participants under condition five (5) of the SOT*

Structure	X(MNI)	Y(MNI)	Z(MNI)	T-Value	BAs	Lobe
Superior Frontal Gyrus	20	60	25	-6.74**	10	Frontal
Middle Frontal Gyrus	25	55	25	-6.45**		Frontal
Medial Frontal Gyrus	15	40	25	-6.17**	9	Frontal
Anterior Cingulate	15	35	25	-5.89**	32	Limbic
Inferior Frontal Gyrus	50	40	15	-5.38**	46	Frontal
Precentral Gyrus	55	-15	40	-5.37**	4	Frontal
Cingulate Gyrus	15	30	30	-5.24**	32	Limbic
Orbital Gyrus	10	55	-20	-5.10**	11	Frontal

Postcentral Gyrus	50	-20	40	-4.88*	3	Parietal
Insula	40	15	15	-4.82*	13	Sub-lobar
Rectal Gyrus	5	55	-25	-4.56*	11	Frontal
Superior Temporal Gyrus	65	-50	20	-4.21*	22	Temporal

*** = p < 0.01, * p <0.05*

The senior participants showed significantly low alpha activity in the superior frontal gyrus at the 20 X(MNI), 60 Y(MNI) and 25 Z(MNI) MRI coordinates in Brodmann area 10, as shown in Fig. 65

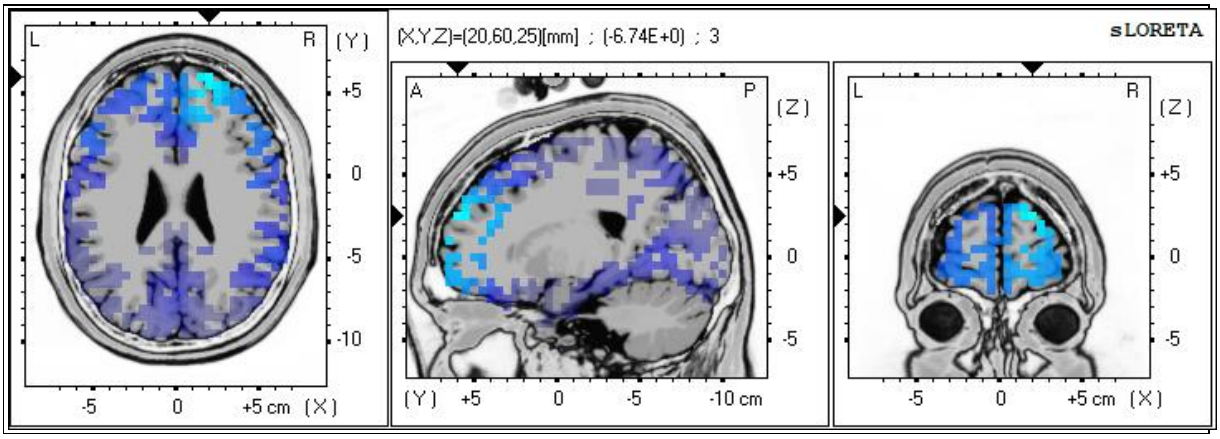


Fig. 65. Functional localisation of the alpha activity during postural balance under the condition of absence of vision with sway reference support

The **beta** activity showed no significant difference in the sub-cortical functional localisation between both the groups of young and senior participants.

The **gamma** activity was found to be found significantly high $p < 0.01$ in the cortex of the senior participants in the inferior frontal gyrus, middle frontal gyrus, precentral gyrus and superior frontal gyrus in **frontal lobe**, anterior cingulate in **limbic lobe**, postcentral gyrus in **parietal lobe**, extra-nuclear, insula in **sub-lobar**, superior temporal gyrus and transverse temporal gyrus in **temporal lobe** compared with the young participants in the study. Further, significantly higher activity of $p < 0.05$ was evident in the cingulate gyrus and posterior cingulate of the **limbic lobe**. cuneus, inferior occipital gyrus, lingual gyrus, middle occipital gyrus, precuneus and superior occipital gyrus in the **occipital lobe**, inferior parietal lobule in the **parietal lobe**, sub-gyral, middle temporal gyrus in the **temporal lobe**. The cortical activity and T-values are listed in Tab. 26.

Tab. 26. *Functional localisation of the gamma activity in the seniors compared with that of the young participants under condition five (5) of the SOT*

Structure	X(MNI)	Y(MNI)	Z(MNI)	T-Value	BAs	Lobe
Insula	30	15	15	7.88**	13	Sub-lobar
Inferior Frontal Gyrus	35	5	30	6.99**	9	Frontal
Middle Frontal Gyrus	35	15	35	6.76**	9	Frontal

Extra-Nuclear	35	20	0	6.05**	47	Sub-lobar
Precentral Gyrus	15	40	40	6.38	9	Frontal
Superior Frontal Gyrus	45	35	35	5.84**	9	Frontal
Anterior Cingulate	5	10	25	5.56**	33	Limbic
Postcentral Gyrus	65	-10	25	5.44**	3	Parietal
Transverse Temporal Gyrus	60	-10	15	5.26**	42	Temporal
Superior Temporal Gyrus	60	-5	10	5.24**	22	Temporal
Cuneus	15	-75	10	4.92*	23	Occipital
Posterior Cingulate	20	-70	10	4.86*	30	Limbic
Cingulate Gyrus	10	15	30	4.79*	24	Limbic
Precuneus	20	-75	15	4.79*	31	Occipital
Inferior Parietal Lobule	65	-25	25	4.75*	40	Parietal
Lingual Gyrus	10	-90	0	4.65*	17	Occipital
Middle Occipital Gyrus	15	-90	10	4.62*	18	Occipital
Middle Temporal Gyrus	45	-85	15	4.44*	19	Temporal
Inferior Occipital Gyrus	30	-95	-10	4.28*	18	Occipital
Superior Occipital Gyrus	40	-85	20	4.27*	19	Occipital
Sub-Gyral	45	-5	-10	4.18*	21	Temporal

*** = p < 0.01, * p <0.05*

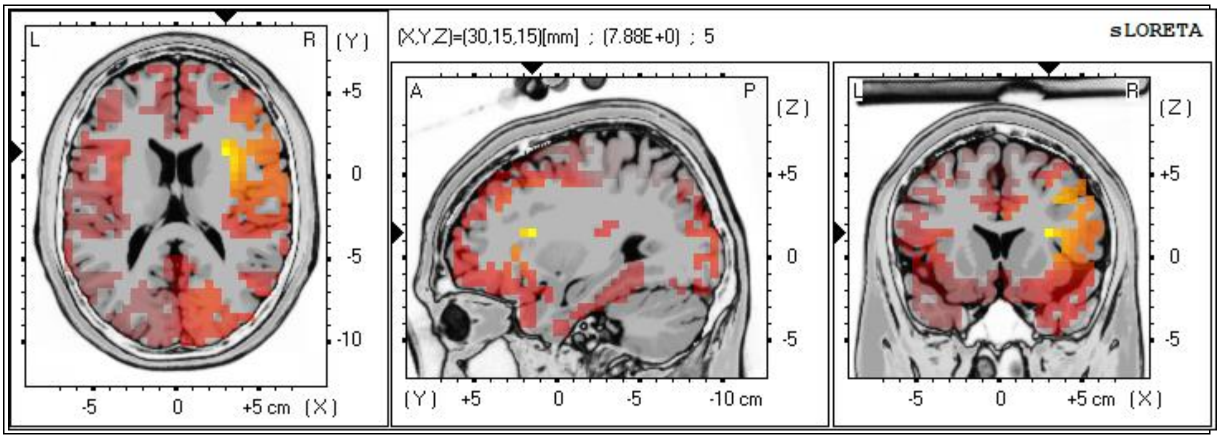


Fig. 66. Functional localisation of the gamma activity during postural balance under condition of the absence of vision with sway reference support.

The senior participants showed significantly high gamma activity in the insula at the 30 X(MNI), 15 Y(MNI) and 15 Z(MNI) MRI coordinates as shown in Fig. 66.

5.4 *Sensory integration during postural balance*

The sensory organisation test (SOT) determined the influence of the somatosensory visual, vestibular and visual on postural balance.

5.4.1 Sensory influence on postural balance in the young participants

The young participants in the study showed significant differences in postural balance under the somatosensory, visual and vestibular information (p <

0.001, E_R^2 = 0.40). The young participants showed no significant difference between their postural balance abilities under the influence of somatosensory and when influenced by visual information. However, they showed a significant decline in the postural abilities under vestibular information. Mdn = 83.82, IQR = 80.72 – 84.95 ($p < 0.001$, r = 85.55) than under somatosensory information. Mdn = 97.41, IQR 96.52 – 98.28. Further, under visual information, Mdn = 92.24, IQR = 96.22 – 98.77; they also showed high ($p < 0.001$, r = 85.53) postural abilities than when under the influence of the vestibular information, Mdn =83.82, IQR = 80.72 – 84.95.

5.4.2 Sensory influence on the postural balance in senior participants

The senior participants in the study showed a significant difference in postural balance under the influence of the somatosensory, visual and vestibular information ($p < 0.001$, $\eta^2 = 0.81$). They showed a decline under visual ($p < 0.001$, $\omega^2 = 0.46$) and vestibular ($p < 0.001$, $\omega^2 = 0.80$) information than under somatosensory to maintain postural balance. The senior participants also showed high postural balance abilities ($p < 0.001$, $\omega^2 = 0.68$) under the influence of visual information than with the vestibular information mean are stated in Tab. 27.

Tab. 27. *Postural balance abilities under the sensory influence*

Sensory influence during postural balance	Young *M (SD)*	Senior *M (SD)*
Somatosensory (%)	97.18 ± 1.77	91.22 ± 1.96
Visual (%)	97.03 ± 2.27	91.79 ± 3.60
Vestibular (%)	83.23 ± 3.18	70.94 ± 8.86

5.4.3 Sensory influence on the postural balance between the young and the seniors

The young participants Mdn = 92.24, IQR = 96.22 – 98.77 % showed significantly high postural abilities ($p < 0.001$, r = 71.86) under the influence of visual information than did the seniors Mdn = 91.82, IQR = 89.82 – 94.59 %. They also showed significantly high postural abilities ($p < 0.001$, $\omega^2 = 0.45$) under the influence of vestibular influence. No significant difference was observed in the postural abilities, however, under the influence of somatosensory information. The mean postural balance results are stated in the Tab.26 and shown in Fig. 67.

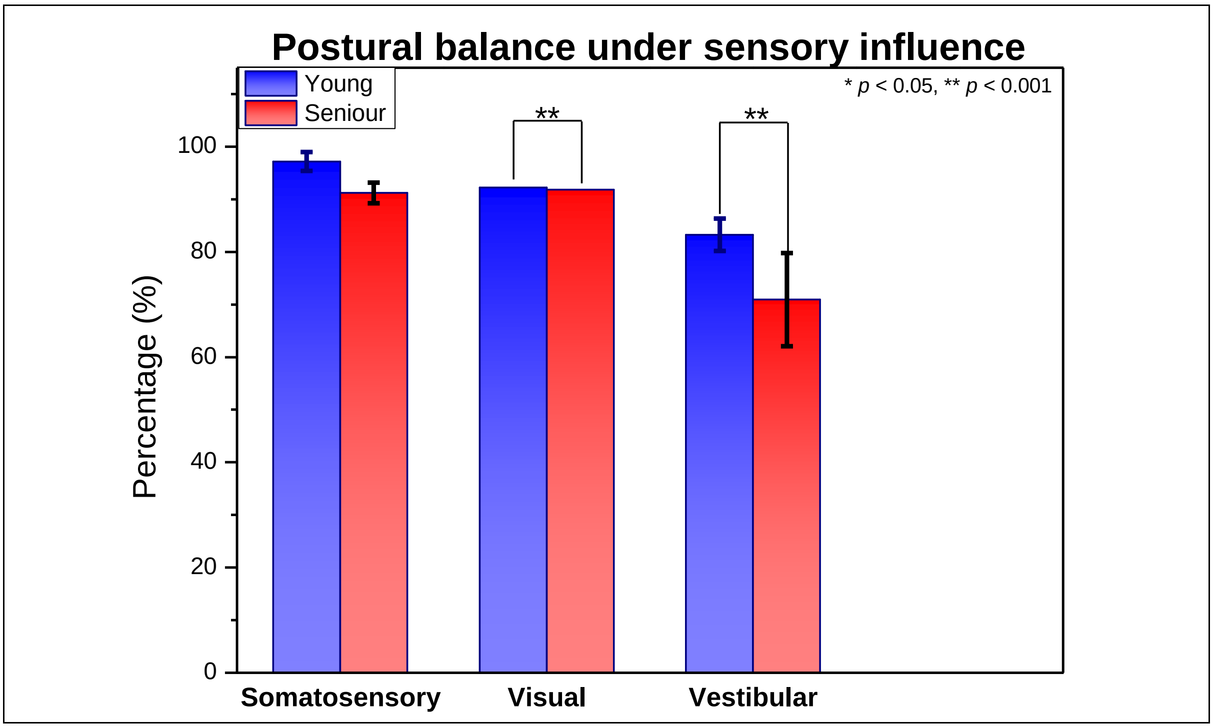


Fig. 67. Postural balance under the influence of sensory input. (Means are stated with the error bar, while the medians are stated without the error bar)

5.5 *Cortical activity under the influence of sensory information*

The power spectrum of the senior and young participants was compared with each other under specific sensory influence in comparison with the baseline or condition one (1) of the sensory organisation test in terms of ratio, to identify the influence of the somatosensory, visual and vestibular inputs on static postural balance. However, as statistically no provision of ratio is available in the *e*LORETA software, the influence of the sensory information in functional localisation and linear connectivity was individually analysed for the senior and young participants.

5.5.1 Power spectrum under the somatosensory influence

The power spectrum in the frontal, temporal, central, and parietal and occipital lobes during postural balance under the influence of somatosensory, visual, vestibular and visual are stated below:

The **delta** activity was significantly high in the frontal lobe of the young participants ($p < 0.05$, $\omega^2 = 0.12$) compared with that of the senior participants but no significant difference was found in the temporal, central, parietal and occipital lobes.

The **theta** and **alpha** activities showed no significant difference in frontal, temporal, central, parietal and occipital lobes between the young and senior participants.

The **beta** activity was found significantly higher only in the frontal lobe of the seniors when compared with that of the young participants ($p < 0.01$, $\omega^2 = 0.15$). No significant difference was found in the temporal, central, parietal and occipital lobes between both groups.

The **gamma** activity was found significantly higher in the occipital lobe of the seniors Mdn = 77.90, IQR = 53.39 – 92.21 (%μV^2) when compared with the young participants Mdn = 46.59, IQR= 34.74 – 72.90 (%μV^2) ($p < 0.05$, r = 32.5). No significant difference was found in the frontal, temporal, central, and parietal lobes between both the groups. The mean power spectrum under the somatosensory influence to balance the posture is stated in Tab. 28.

While the delta activity was found to be significantly low, the beta activity was found to be higher in the frontal lobe of the seniors when compared with the young participants in the study. Besides, the gamma activity was also noted to be significantly higher in the occipital lobe of the cortex in the seniors, as seen in Fig. 68.

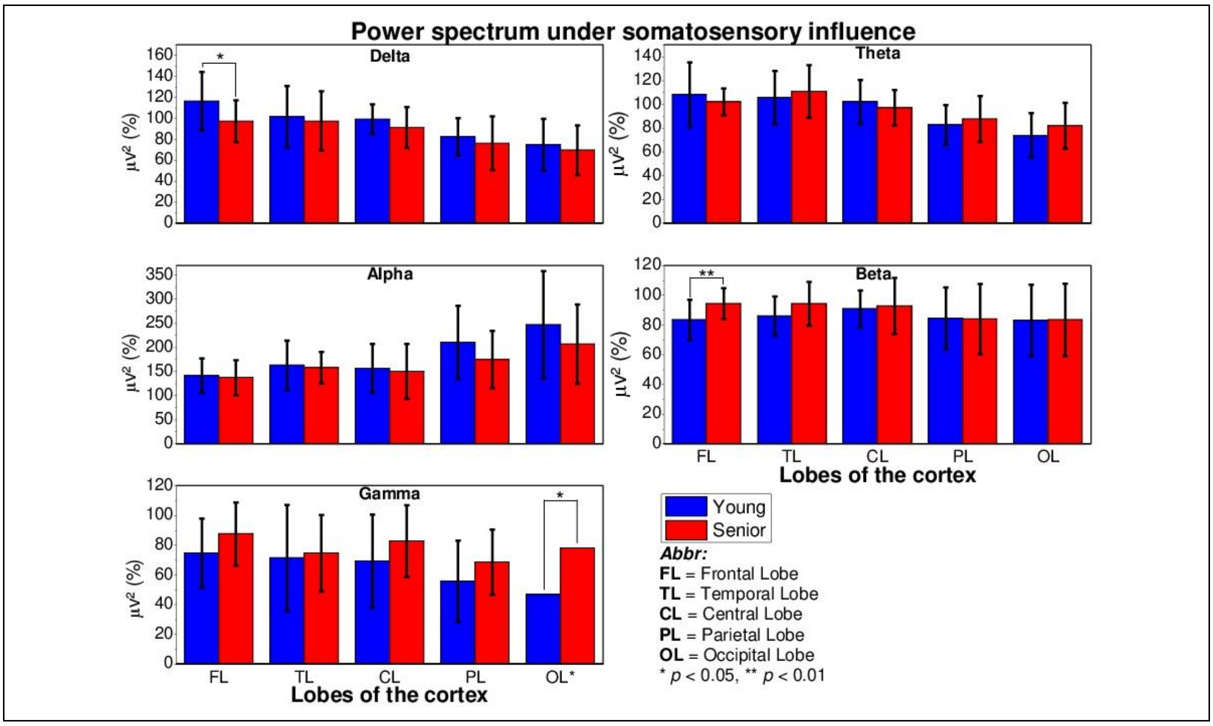


Fig. 68. Power spectrum during static postural balance under the somatosensory influence. (Means are stated with the error bar while the medians are stated without the error bar)

The overview of the power spectrum is shown as topographic maps during the static postural balance cortical activity of the young and senior participants in the study under the somatosensory influence, as presented in Fig. 69.

Tab. 28. *Power spectrum mean activity during static postural balance under somatosensory influence.*

ROI	Delta(δ) [%µV^2] M (SD)		Theta (θ) [%µV^2] M (SD)		Alpha (α) [%µV^2] M (SD)		Beta (β) [%µV^2] M (SD)		Gamma (γ) [%µV^2] M (SD)	
	Young	**Senior**	**Young**	**Senior**	**Young**	**Senior**	**Young**	**Senior**	**Young**	**Senior**
FL*	116.48 ± 27.71	97.18 ± 20.02	108.11 ± 26.98	102.14 ± 11.16	141.16 ± 35.57	137.16 ± 36.25	83.32 ± 13.63	94.23 ± 10.29	74.57 ± 23.20	87.38 ± 21.27
TL*	101.53 ± 29.08	97.45 ± 28.30	105.65 ± 22.43	110.77 ± 22.14	162.83 ± 51.19	157.38 ± 32.70	85.92 ± 13.28	94.20 ± 14.74	71.33 ± 35.56	74.37 ± 25.78
CL*	99.05 ± 14.13	91.01 ± 19.48	101.99 ± 18.63	97.09 ± 15.02	156.26 ± 50.82	149.89 ± 57.22	90.86 ± 12.26	92.83 ± 18.77	69.27 ± 31.32	82.63 ± 24.12
PL*	82.11 ± 17.77	76.12 ± 25.61	82.75 ± 16.77	87.58 ± 19.35	209.95 ± 75.82	174.38 ± 59.30	84.23 ± 20.80	83.82 ± 23.53	55.53 ± 27.42	68.34 ± 21.93
OL*	74.67 ± 24.63	69.47 ± 23.75	73.76 ± 18.66	81.95 ± 19.35	246.85 ±111.3	206.70 ± 82.64	82.82 ±24.09	83.32 ± 24.27	55.23 ± 25.42	74.18 ± 31.82

Abbr: FL = Frontal Lobe, TL = Temporal Lobe, CL = Central Lobe, PL= Parietal Lobe and OL = Occipital Lobe

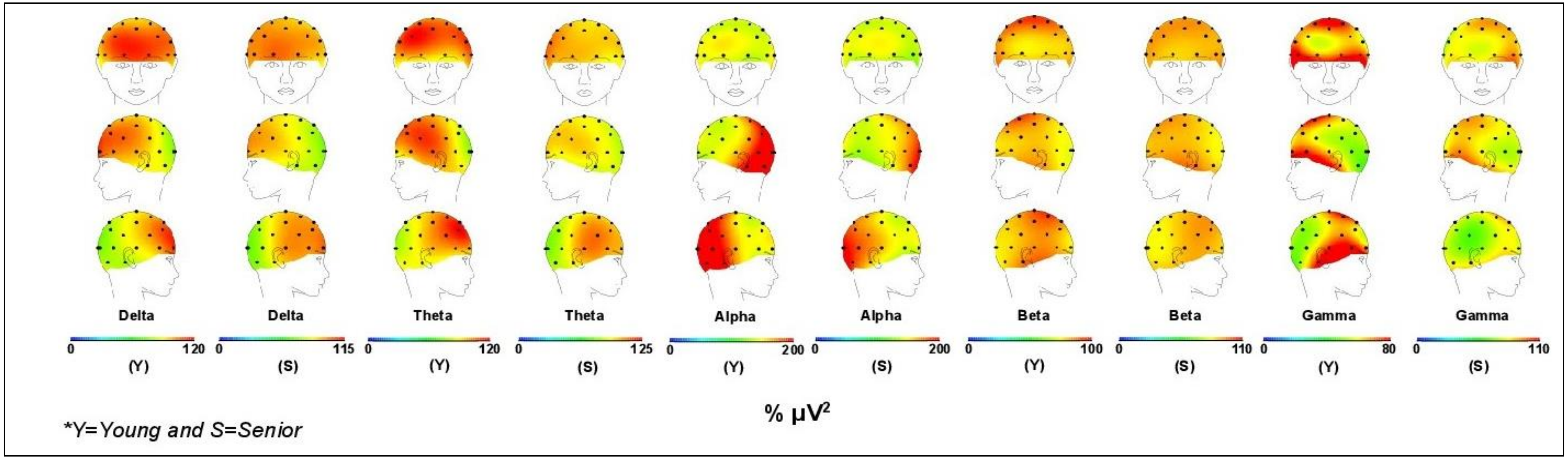


Fig. 69. Topographic maps during static postural balance under somatosensory influence

5.5.2 *Functional localisation under the somatosensory influence of young participants*

Functional localisation during postural balance under the somatosensory influence is seen in the delta, theta, alpha, beta and gamma frequencies. The statistical threshold of the functional localisation of the cortical activity during postural balance under somatosensory influence was defined according to the one-tailed statistical results for the young participants (condition 1 < condition 2). The $p < 0.01$ = t 5.93, P < 0.05 = t 4.89 and (condition 1 condition 2) P < 0.01 = t -5.84 P < 0.05 = t -4.88.

The **delta** activity was expressively high in the baseline $p < 0.05$ during postural balance under somatosensory influence in the posterior cingulate (10 X(MNI) -70 Y(MNI) 15 Z(MNI) at Brodmann area 31 with T-value -5.06) in the **limbic lobe**, and the cuneus (10 X(MNI) -70 Y(MNI) 30 Z(MNI) at Brodmann area 7 with T-value -5.35) in the **occipital lobe** and the precuneus (5 X(MNI) -70 Y(MNI) 25 Z(MNI) at Brodmann area 31 with T-value -5.76) in the **parietal lobe** Fig. 70.

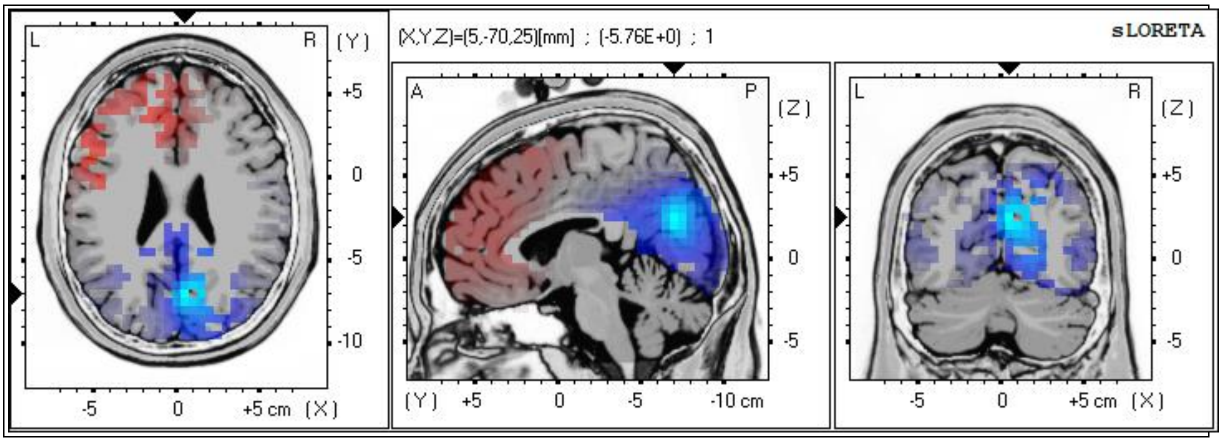


Fig. 70. Functional localisation of the delta activity of the young participants during postural balance under the somatosensory influence

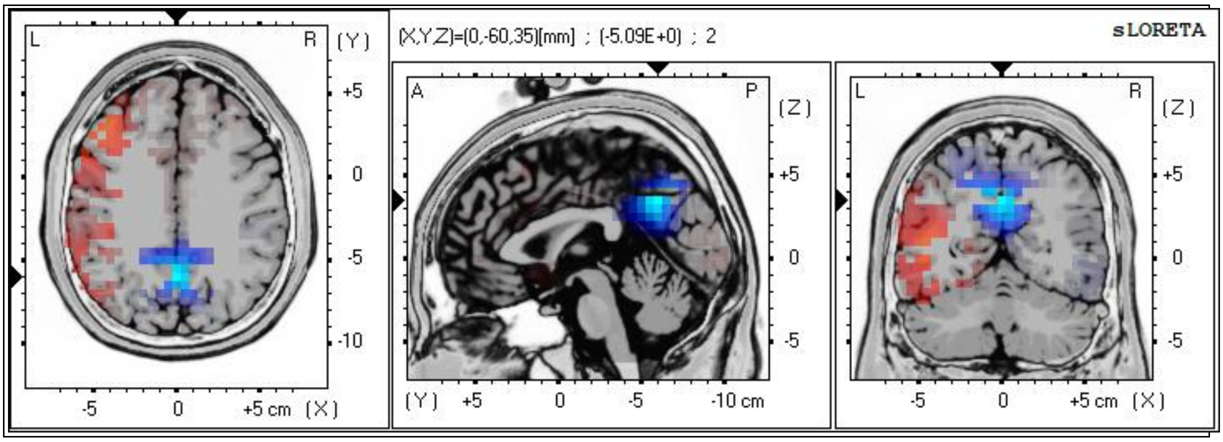


Fig. 71. Functional localisation of the theta activity of the young participants during postural balance under the somatosensory influence

Significantly high **theta** activity was found in the baseline $p < 0.05$ under the somatosensory influence in the precuneus (0 X(MNI) -60 Y(MNI) 35 Z(MNI) at Brodmann area 7 with T-value 5.09) in the **parietal lobe** as shown in Fig. 71.

Higher **alpha** activity was noted higher under somatosensory influence $p < 0.01$ in cingulate gyrus, posterior cingulate, parahippocampal gyrus in **limbic lobe**, cuneus, precuneus, lingual gyrus, superior occipital gyrus, middle occipital gyrus, inferior occipital gyrus and fusiform gyrus in **occipital lobe**, superior parietal lobule, inferior parietal lobule in **parietal lobe**, insula in **sub-lobar**, middle temporal gyrus, angular gyrus, superior temporal gyrus, sub-gyral and inferior temporal gyrus in **temporal lobe**. Further higher **alpha** activity was noted $p < 0.05$ in postcentral gyrus, paracentral lobule in **frontal lobe and** supramarginal gyrus in **temporal lobe.** The T-values of the alpha activity and structural details are stated in Tab. 29.

Tab. 29. *Functional localisation of the alpha activity of the young participants during postural balance under the somatosensory influence*

Structure	X(MNI)	Y(MNI)	Z(MNI)	T-Value	BAs	Lobe
Cingulate Gyrus	15	-45	25	10.72**	31	Limbic
Cuneus	0	-75	20	10.43**	18	Occipital
Posterior Cingulate	10	-60	20	10.20**	31	Limbic
Precuneus	0	-75	25	10.18**	31	Occipital
Lingual Gyrus	5	-85	0	9.19**	18	Occipital
Superior Occipital Gyrus	-30	-85	25	8.42**	19	Occipital
Middle Occipital Gyrus	-5	-100	10	8.37**	18	Occipital
Inferior Occipital Gyrus	-30	-95	-10	8.26**	18	Occipital
Parahippocampal Gyrus	-25	-55	0	7.94**	30	Limbic
Fusiform Gyrus	-30	-85	-20	7.89**	19	Occipital
Middle Temporal Gyrus	-35	-85	20	7.87**	19	Temporal
Angular Gyrus	-35	-80	30	7.71**	39	Temporal
Superior Temporal Gyrus	40	-55	20	7.45**	22	Temporal
Superior Parietal Lobule	-30	-80	45	7.30**	7	Parietal
Sub-Gyral	-30	-60	25	6.96**	39	Temporal
Inferior Parietal Lobule	-40	-70	40	6.85**	39	Parietal
Inferior Temporal Gyrus	-50	-75	-5	6.48**	19	Temporal
Insula	-30	-40	20	6.09**	13	Sub-lobar
Supramarginal Gyrus	50	-50	20	5.30*	40	Temporal
Postcentral Gyrus	-35	-25	40	5.06*	3	Frontal
Paracentral Lobule	0	-35	45	4.92*	31	Frontal

*** = p < 0.01, * p < 0.05*

The baseline has significantly low alpha activity under the somatosensory influence of the young participants in the cingulate gyrus at the 15 X(MNI), 45 Y(MNI) and 25 Z(MNI) MRI coordinates in Brodmann area 31, as showed in Fig. 72.

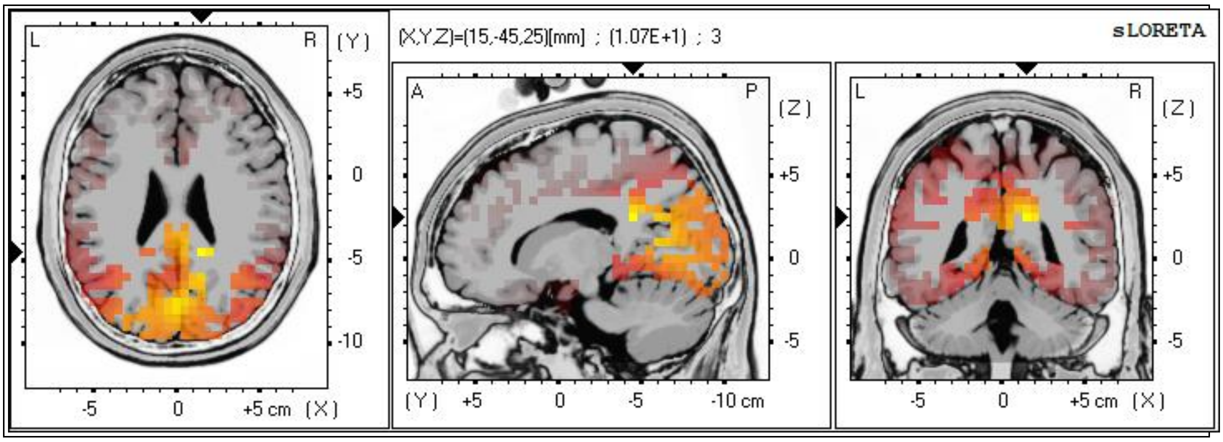


Fig. 72. Functional localisation of the alpha activity of the young participants during postural balance under the somatosensory influence

The **beta** activity was found significantly higher during baseline when compared with the somatosensory influence $p < 0.05$ in the inferior frontal gyrus, middle frontal gyrus and superior frontal gyrus of the **frontal lobe** and in the anterior cingulate in the **limbic lobe**. The T-values of the alpha activity and structure details are listed in Tab. 30.

Tab. 30. *Functional localisation of the beta activity of the young participants during postural balance under the somatosensory influence*

Structure	X(MNI)	Y(MNI)	Z(MNI)	T-Value	BAs	Lobe
Inferior Frontal Gyrus	-20	30	-5	-5.33	47	Frontal
Middle Frontal Gyrus	-20	40	-15	-5.12	11	Frontal
Superior Frontal Gyrus	-25	45	-15	-5.02	11	Frontal
Anterior Cingulate	-10	35	-5	-4.97	32	Limbic

The baseline shows significantly high beta activity under the somatosensory influence in the young participants in the inferior frontal gyrus at the -20 X(MNI), 30 Y(MNI) and 5 Z(MNI) MRI coordinates in Brodmann area 47, as evident in Fig. 73.

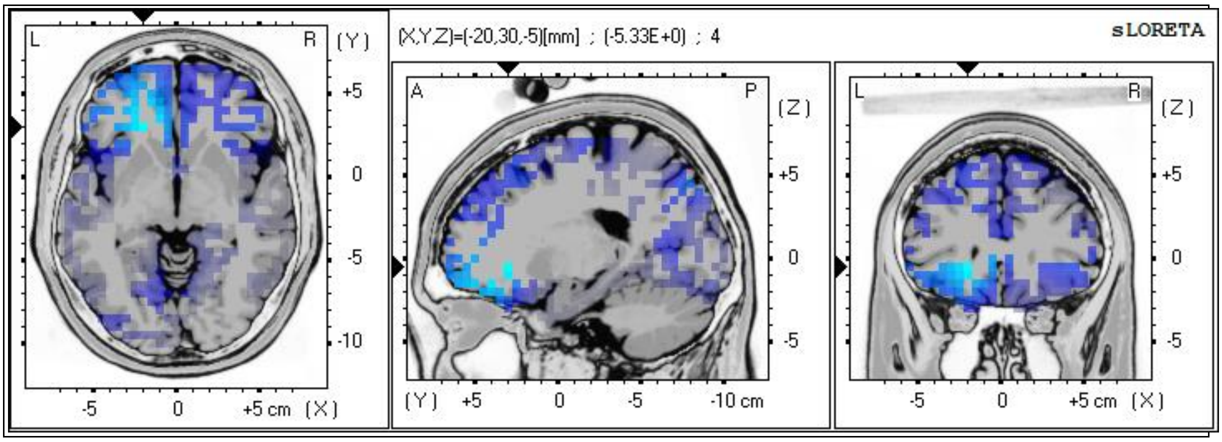


Fig. 73. Functional localisation of the beta activity of the young participants during postural balance under the somatosensory influence

The **gamma** activity was found to be significantly higher at baseline when compared with the somatosensory influence $p < 0.01$ The T-values of the alpha activity and structure details are stated in Tab. 31.

Tab. 31. *Functional localisation of the gamma activity of the young participants during postural balance under the somatosensory influence*

Structure	X(MNI)	Y(MNI)	Z(MNI)	T-Value	BAs	Lobe
Precuneus	-10	-60	20	-6.8**	31	Parietal
Posterior Cingulate	-5	-60	20	-6.57**	31	Limbic
Cingulate Gyrus	-5	-60	25	-6.12**	31	Limbic
Insula	-35	-5	15	-5.46*	13	Sub-lobar
Cuneus	-10	-70	30	-5.45*	7	Occipital
Sub-Gyral	-20	-50	35	-5.28*	31	Limbic
Anterior Cingulate	-10	25	25	-5.14*	32	Limbic
Medial Frontal Gyrus	-20	35	25	-5.00*	9	Frontal

*** = $p < 0.01$, * $p < 0.05$*

The baseline of the young participants has significantly high gamma activity under the somatosensory influence in the precuneus at the -10 X(MNI), -60 Y(MNI) and 20 Z(MNI) MRI coordinates in Brodmann area 31, as shown in Fig. 74.

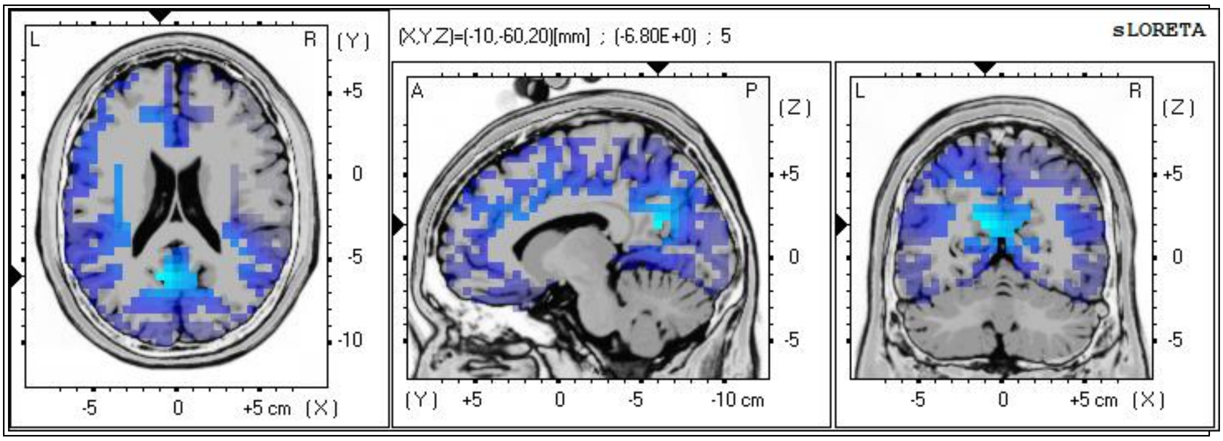


Fig. 74. Functional localisation of the gamma activity of the young participants during postural balance under the somatosensory influence

5.5.3 Functional localisation under the somatosensory influence in the senior participants

The source localisation during postural balance under the somatosensory influence is revealed in the delta, theta, alpha, beta and gamma frequencies. The statistical threshold of the functional localisation of the cortical activity during postural balance under somatosensory influence in the senior participants was defined according to the one-tailed statistical results (condition 1 < condition 2). The $p < 0.01 = t\ 5.71$, $p < 0.05 = t\ 4.83$ and (condition 1 < condition 2) $p < 0.01 = t\ -5.86$, $p < 0.05 = T\ -4.89$.

The **delta** and **theta** activities showed no significant difference in the cortical activity baseline compared with the somatosensory influence in the postural balance of the senior participants.

The **alpha** activity was observed to be significantly low at the baseline when compared with the somatosensory influence to balance the posture $p < 0.01$ in inferior frontal gyrus in **frontal lobe**, lingual gyrus and fusiform gyrus in **occipital lobe**, insula in **sub-lobar**, superior temporal gyrus in **temporal lobe**. further low alpha activity $p < 0.05$ was found in precentral gyrus, subcallosal gyrus in **frontal lobe**, parahippocampal gyrus, sub-gyral and uncus in **limbic lobe**, inferior occipital gyrus in **occipital lobe**, postcentral gyrus and inferior parietal lobule in **parietal lobe**, extra-nuclear in **sub-lobar**, supramarginal gyrus and middle temporal gyrus in **temporal lobe**. The T-values of the alpha activity and structure details are stated in Tab. 32.

Tab. 32. *Functional localisation of the alpha activity of the senior participants during postural balance under the somatosensory influence*

Structure	X(MNI)	Y(MNI)	Z(MNI)	T-Value	BAs	Lobe
Insula	40	10	-5	6.46**	13	Sub-lobar
Inferior Frontal Gyrus	45	15	-5	6.40**	47	Frontal
Superior Temporal Gyrus	50	15	-5	6.18**	22	Temporal
Lingual Gyrus	-5	-70	-5	6.09**	18	Occipital
Fusiform Gyrus	-20	-65	-15	5.83**	19	Occipital
Parahippocampal Gyrus	15	-40	-10	5.61*	30	Limbic
Extra-Nuclear	40	10	-10	5.59*	13	Sub-lobar
Sub-Gyral	-15	-45	-10	5.37*	19	Limbic
Precentral Gyrus	60	-20	45	5.20*	4	Frontal
Supramarginal Gyrus	60	-55	20	5.12*	40	Temporal
Uncus	20	-10	-35	5.11*	28	Limbic
Subcallosal Gyrus	20	5	-15	5.07*	34	Frontal
Middle Temporal Gyrus	55	-65	20	5.03*	39	Temporal
Postcentral Gyrus	55	-20	45	4.92*	3	Parietal
Inferior Parietal Lobule	50	-50	25	4.87*	40	Parietal
Inferior Occipital Gyrus	-35	-85	-20	4.85*	18	Occipital

*** = $p < 0.01$, * $p < 0.05$*

The baseline shows significantly low alpha activity under the somatosensory influence in the senior participants in the insula at the 40 X(MNI), 10 Y(MNI) and -5 Z(MNI) MRI coordinates in Brodmann area 13 as shown in Fig. 75.

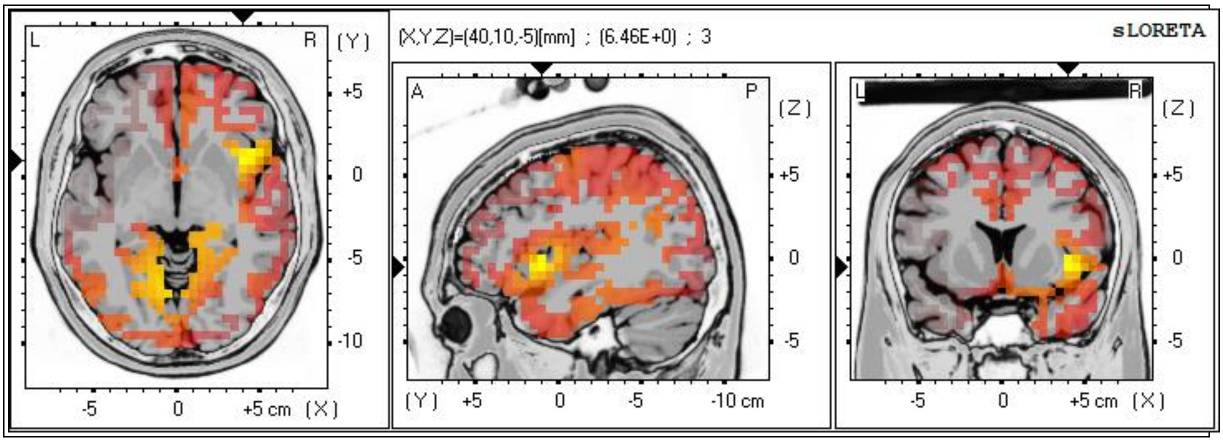


Fig. 75. Functional localisation of the alpha activity of the senior participants during postural balance under the somatosensory influence

The **beta** and **gamma** activities showed no significant difference in the cortical activity baseline compared with that of the somatosensory influence in maintaining the postural balance in the senior participants.

5.5.4 Functional connectivity under the somatosensory influence

The young participants showed significantly low functional connectivity in beta frequency $p < 0.05$ (t = -6) between the middle frontal gyrus at Brodmann area 11 and the parahippocampal gyrus at Brodmann area 28, out of the 84 defined regions of interest (Appendix D)., with the t-test showing significant thresholds for $p < 0.05$ as $t < -5.95$. They showed significantly weak functional connectivity at the baseline when compared with that under the somatosensory influence to balance the posture. However, the senior participants showed no significant difference in functional connectivity (Fig. 76).

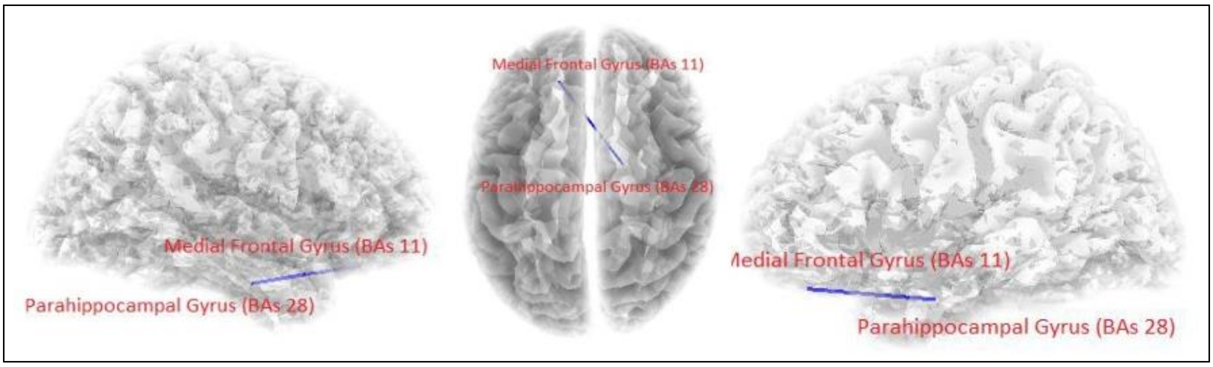


Fig. 76. Lagged linear connectivity in the young participants in the study under the somatosensory influence to balance the posture

5.5.5 Power spectrum under the visual influence

The power spectrum in the delta, theta, alpha, beta and gamma frequencies were reported during the postural control under the influence of visual information.

The **delta** activity was significantly high in the frontal lobe of the young participants, (105.92 = IQR = 89.99 – 120.68 (%μV^2) $p < 0.05$, r = 34.21) compared with that of the senior participants Mdn =87.5, IQR 77.95 – 105.15 (%μV^2) and no significant difference was found between the groups in the frontal, temporal, central and occipital lobes.

The **theta** activity was also significantly high in the frontal lobe of the young participants, Mdn = 112.03, IQR = 98.25 – 127.05 (%μV^2) ($p < 0.001$, r = 59.02) compared with that of the senior participants Mdn = 89, 26, IQR = 84.94 – 95.00. (%μV^2). Further, no significant difference was found between the groups in the frontal, temporal, central and occipital lobes.

The **alpha** showed no significant difference in the frontal, temporal, central, and parietal and occipital lobes between both groups.

The **beta** activity was found significantly higher only in the frontal lobe of the seniors when compared with that of the young participants ($p < 0.05$, $\omega^2 = 0.13$). No significant difference was found in the temporal, central, parietal and occipital lobes between both groups.

The **gamma** activity was found significantly higher in the frontal lobe of the seniors when compared with that of the young participants ($p < 0.01$, $\omega^2 = 0.20$). No significant difference was found in the temporal, central, parietal and occipital lobes between both the groups. The mean power spectrum under the influence of visual information to balance the posture is stated in Tab. 33.

Senior participants in the study revealed significantly low delta and theta activities in the frontal lobe; however, they also showed significantly high beta and gamma activities in the frontal lobe to balance the posture under the visual influence (Fig. 77).

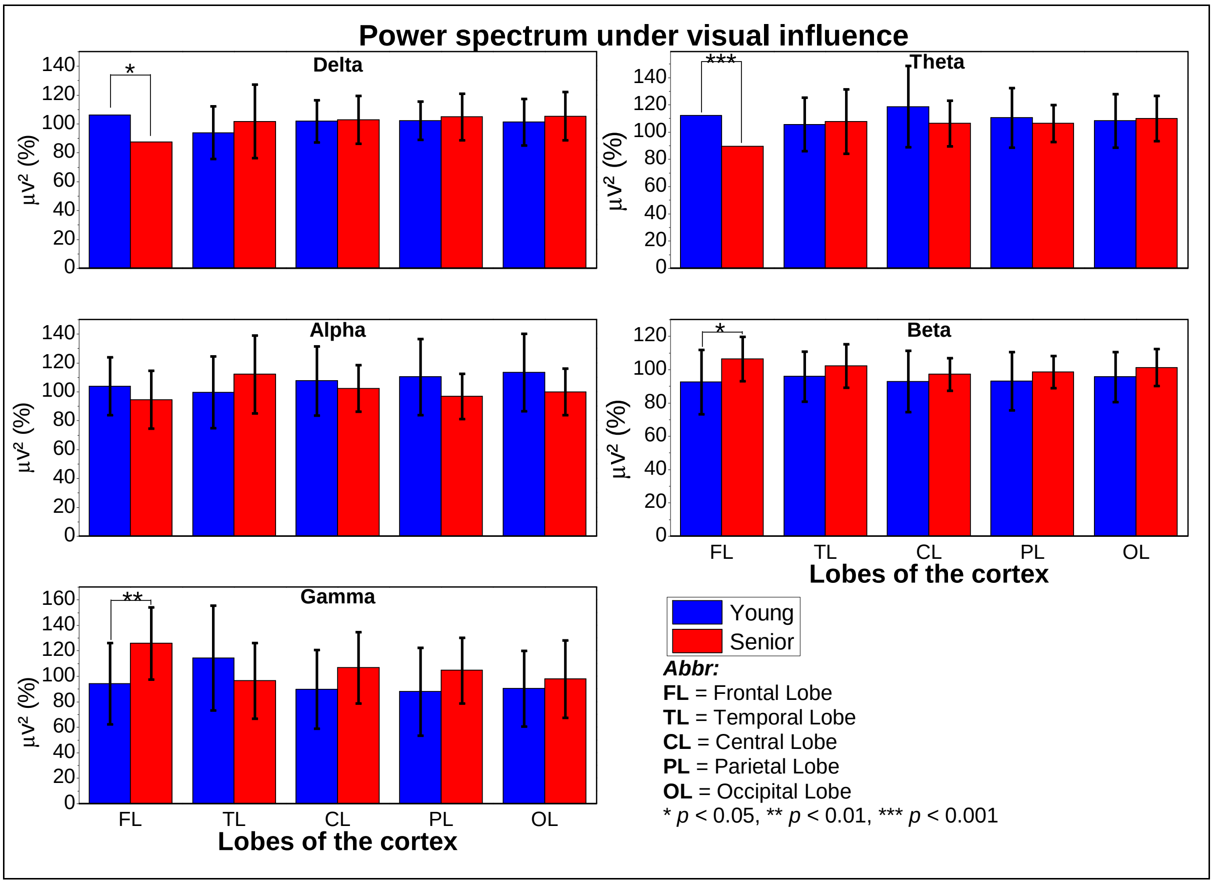


Fig. 77. Power spectrum during static postural balance under the visual influence. (Means are stated with the error bar, while the medians are stated without the error bar)

Tab. 33. *Power spectrum mean activity during static postural balance under visual influence*

ROI	Delta(δ) [%µV^2] M (SD)		Theta (θ) [%µV^2] M (SD)		Alpha (α) [%µV^2] M (SD)		Beta (β) [%µV^2] M (SD)		Gamma (%γ) [µV^2] M (SD)	
	Young	**Senior**	**Young**	**Senior**	**Young**	**Senior**	**Young**	**Senior**	**Young**	**Senior**
FL*	105.30 ± 19.13	92.78 ± 23.86	116.41 ± 27.03	89.34 ± 13.38	103.75 ± 20.03	94.43 ± 19.91	92.37 ± 19.31	106.20 ± 13.36	93.96 ±31.87	125.66 ± 28.26
TL*	93.78 ± 18.14	101.65 ± 25.31	105.40 ± 19.64	107.60 ± 23.73	99.54 ± 24.75	112.03 ± 26.94	95.71 ± 15.07	101.96 ± 13.06	114.16 ± 40.98	96.29 ± 29.62
CL*	101.71 ± 14.60	102.72 ± 16.68	118.58 ± 29.72	106.23 ± 16.73	107.43 ± 23.89	102.22 ± 16.10	92.78 ± 18.44	96.99 ± 9.68	89.60 ± 30.79	106.60 ± 27.95
PL*	102.15± 13.19	104.69 ± 16.04	110.44± 21.89	106.26 ± 13.54	110.11 ± 26.28	96.73 ± 15.75	92.92 ± 19.56	98.45 ± 9.57	87.85 ± 34.49	104.40 ± 25.81
OL*	101.16 ± 16.13	105.21 ± 16.78	108.18 ± 19.61	109.81 ± 16.74	113.26 ± 26.90	99.82 ± 16.12	95.43 ± 14.90	101.08 ± 11.05	90.10 ± 29.80	97.75 ± 30.38

Abbr: FL = Frontal Lobe, TL = Temporal Lobe, CL = Central Lobe, PL= Parietal Lobe and OL = Occipital Lobe

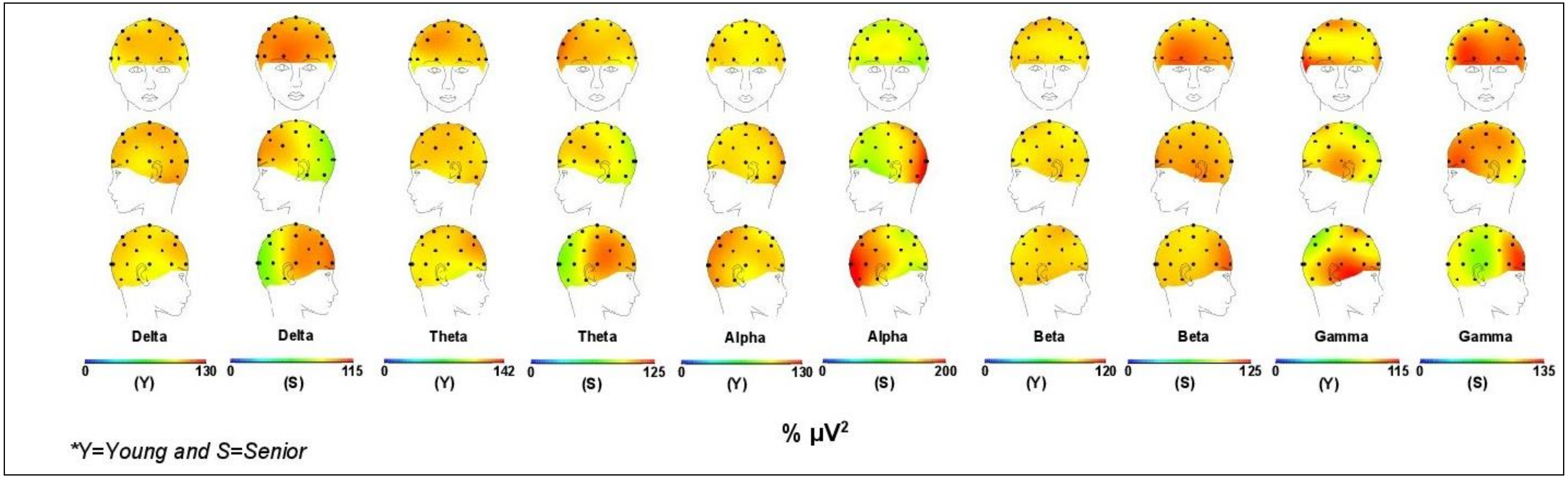


Fig. 78. Topographic maps during static postural balance under visual influence

An overview of the power spectrum is shown as topographic maps showing the cortical activity during the static postural balance in the young and senior participants in the study under the visual influence, as shown in Fig. 78.

5.5.6 Functional localisation under the visual influence in the young and senior participants

Functional localisation during postural balance under the visual influence showed no significant difference between the young and senior participants.

5.5.7 Power spectrum under the vestibular influence

The power spectrum in the delta, theta, alpha, beta and gamma frequencies was considered during the postural control under the influence of the vestibular information.

The **delta** and **theta** activities showed no significant differences in the frontal, temporal, central, parietal and occipital lobes between the senior and young participants.

The **alpha** activity was found to be significantly higher in the frontal ($p < 0.05$, r = 35.92) temporal ($p < 0.05$, $\omega^2 = 0.08$) occipital ($p < 0.05$, $\omega^2 = 0.14$) central ($p < 0.05$, r = 32.93) and parietal ($p < 0.05$, r = 40.20) lobes, in the young than in the senior participants. The median and interquartile data are stated in Tab. 34.

Tab. 34. *Alpha activity during static postural control under the vestibular influence*

Lobs	Young Alpha (α) [%µV^2] Mdn (IQR)	Senior Alpha (α) [%µV^2] Mdn (IQR)
Frontal	127.62 (114.69 – 161.02)	112.80 (84.65 – 131.71)
Central	128.27 (114.91 – 149.68)	112.19 (100.72 – 127.07)
Parietal	186.93 (148.84 – 206.66(	129.62 (109.47 – 154)

The **beta** activity was significantly higher in the frontal and temporal lobes of the senior participants ($p < 0.05$; $\omega^2 = 0.12$) and ($p < 0.05$, $\omega^2 = 0.11$) than in the young participants. No significant difference was found in the central, parietal and occipital lobes.

The **gamma** activity was found to be significantly higher in the frontal ($p < 0.01$, $\omega^2 = 0.14$) and temporal ($p < 0.05$, r = 31.65), central ($p < 0.01$, r = 44.90), parietal ($p < 0.001$, r = 56.04) and the occipital ($p < 0.05$, $\omega^2 = 0.11$) lobes of the senior participants when compared with those of the young participants. The median and interquartile data are shown in Tab. 35.

Tab. 35. *Gamma activity during the static postural control under the vestibular influence*

Lobs	Young Gamma (γ) [%µV^2] Mdn (IQR)	Senior Gamma (γ) [%µV^2] Mdn (IQR)
Temporal	56.31 (38.53 – 86.38)	85.20 (57.23 - 96.60)
Central	54.60 (46.95 – 82.83)	95.78 (72.01- 121.60)
Parietal	51.20 (42.22 – 74.48)	90.45 (77.80 – 103.25)

The mean power spectrum during postural balance under the vestibular influence is shown in Tab. 36.

The young and senior participants showed no significant difference in the delta and theta activities. The senior participants revealed significantly low alpha activity but high beta activity in the frontal and temporal lobes than did the young participants. The senior participants also showed high gamma activity in the frontal, temporal, central, parietal and occipital lobes than did the young participants in the study, as shown in Fig. 79.

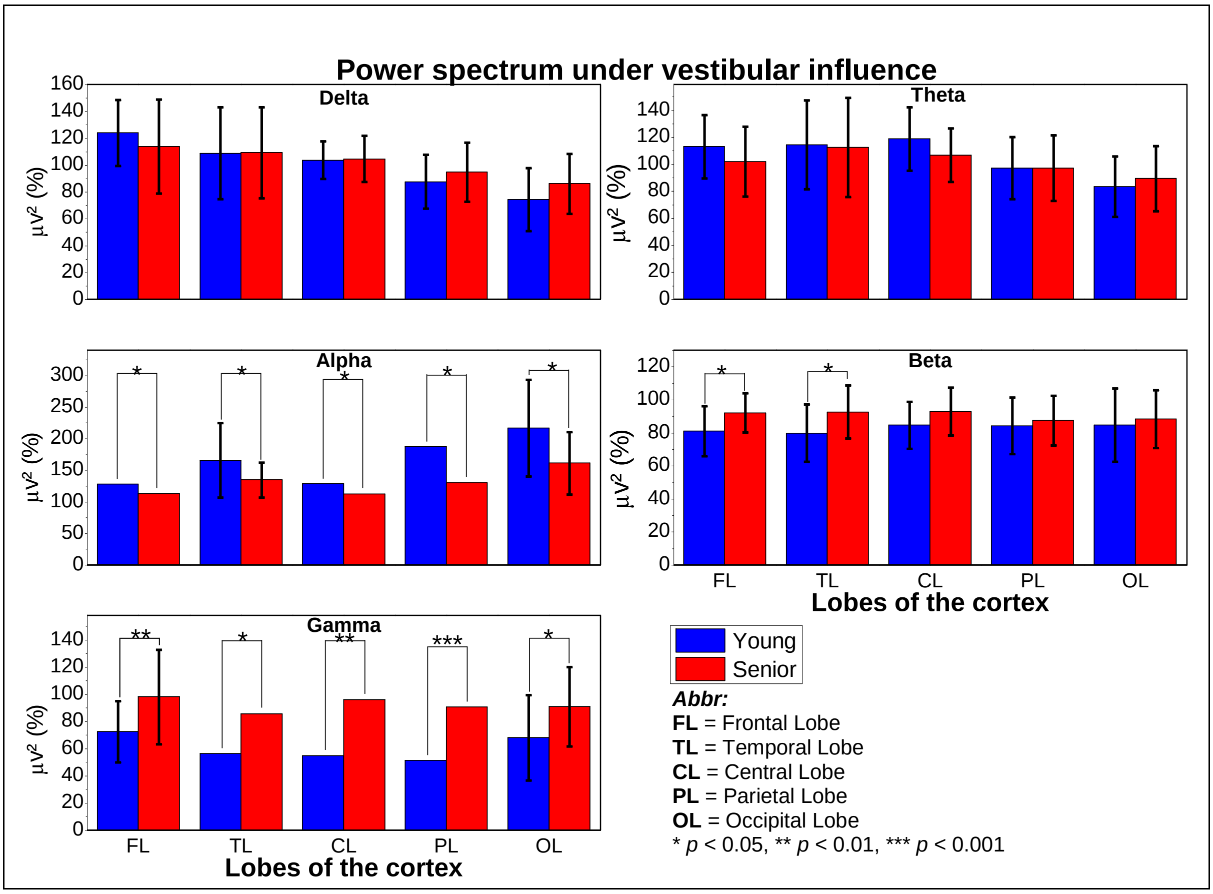


Fig. 79. Power spectrum during static postural balance under the vestibular influence. (Means are stated with the error bar while the medians are stated without the error bar)

An overview of the power spectrum is shown as topographic maps during the static postural balance cortical activity of the young and senior participants in the study under the vestibular influence as shown in Fig. 80.

Tab. 36. *Power spectrum mean activity during static postural balance under vestibular influence*

ROI	Delta(δ) [%μV^2] M (SD)		Theta (θ) [%μV^2] M (SD)		Alpha (α) [%μV^2] M (SD)		Beta (β) [%μV^2] M (SD)		Gamma (γ) [%μV^2] M (SD)	
	Young	**Senior**	**Young**	**Senior**	**Young**	**Senior**	**Young**	**Senior**	**Young**	**Senior**
FL*	123.85 ± 24.70	113.72 ± 35.02	112.89 ± 23.54	101.84 ± 25.99	136.89 ± 35.78	110.96 ± 27.62	80.93 ± 15.22	92.00 ± 11.78	72.34 ± 22.48	97.92 ± 34.71
TL*	108.74 ± 34.14	109.12 ± 33.91	114.30 ± 32.89	112.30 ± 36.72	165.48 ± 59.06	134.20 ± 27.65	79.72 ± 17.41	92.46 ± 16.09	64.98 ± 36.65	87.82 ± 39.40
CL*	103.57 ± 13.99	104.54 ± 17.27	118.61 ± 23.43	106.61 ± 19.76	136.58 ± 37.05	119.68 ± 28.26	84.47 ± 14.15	92.69 ± 14.50	66.05 ± 27.40	97.17 ± 36.62
PL*	87.49 ± 20.15	94.69 ± 22.04	97.15 ± 22.95	97.02 ± 24.33	180.44 ± 52.09	137.74 ± 38.30	84.10 ± 17.07	87.33 ± 14.89	58.55 ± 23.28	89.84 ± 24.50
OL*	74.18 ± 23.40	85.95 ± 22.28	83.38 ± 22.30	89.32 ± 24.10	216.28 ± 76.58	161.01 ± 49.50	84.67 ± 22.18	88.22 ± 17.47	67.80 ± 31.45	90.79 ± 29.14

Abbr: FL = Frontal Lobe, TL = Temporal Lobe, CL = Central Lobe, PL= Parietal Lobe and OL = Occipital Lobe

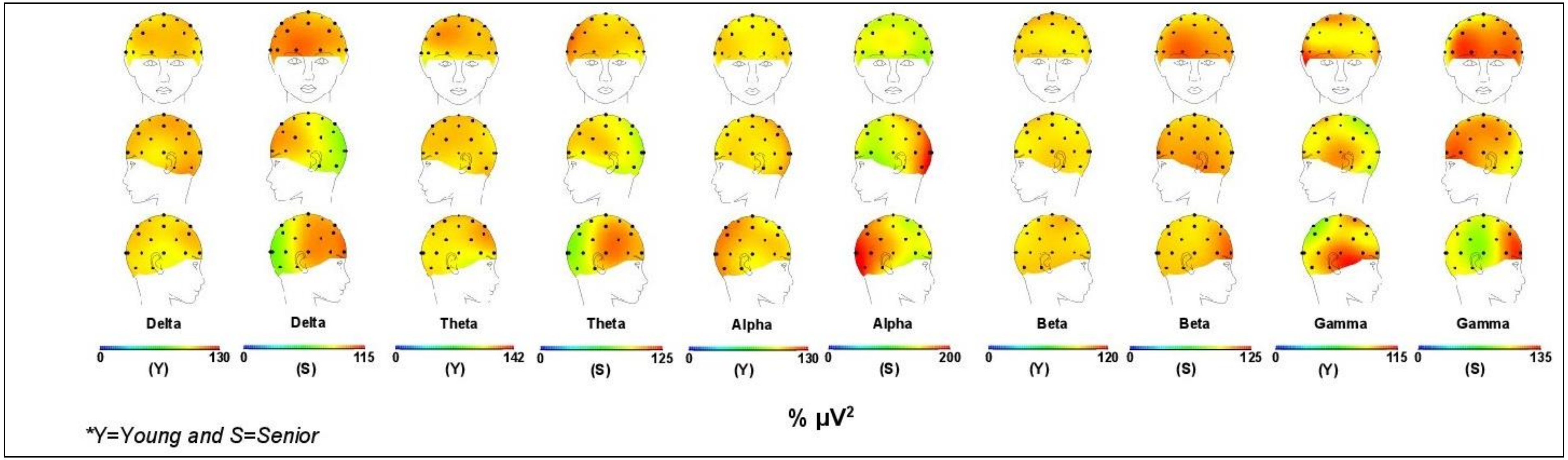


Fig. 80. Topographic maps during static postural balance under the vestibular influence

5.5.8 Functional localisation under the vestibular influence in the young participants

Functional localisation during postural balance under the vestibular influence was reported in delta, theta, alpha, beta and gamma frequencies. The statistical threshold of the functional localisation of the cortical activity during postural balance under the vestibular influence in the young participants was defined according the one-tailed statistical results (condition 1 < condition 5). The $p < 0.01$ = t 6.03, $p < 0.05$ = t 5.00 and (condition 1 < condition 5) $p < 0.01$ = t -5.92 $p < 0.05$ = t -5.07.

The **delta** activity was significantly high $p < 0.01$ in the baseline during postural balance under vestibular influence in the cuneus (0 X(MNI) -70 Y(MNI) 30 Z(MNI) at Brodmann area 7 with T-value 6.30) in the occipital lobe and precuneus (5 X(MNI) -70 Y(MNI) 25 Z(MNI) at Brodmann area 31 with T-value 6.40) in the **parietal lobe** and further low $p < 0.05$Posterior Cingulate(5 X(MNI) -70 Y(MNI) 15 Z(MNI) at Brodmann area 31 with T-value -5.06) in the limbic lobe as shown in Fig. 81.

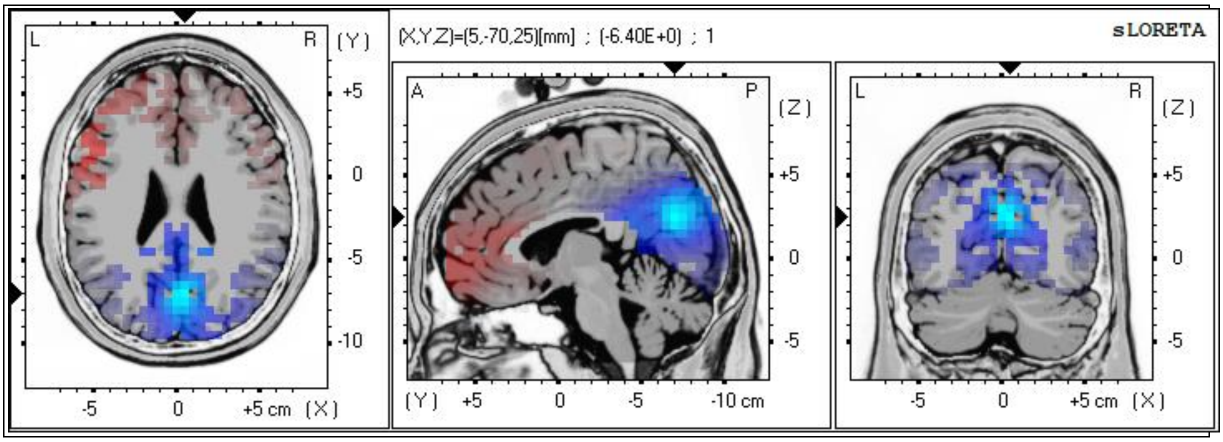


Fig. 81. Functional localisation of the delta activity in the young participants during postural balance under the vestibular influence

The **theta** activity showed no significant difference between the functional localisation of the baseline compared with the vestibular influence to balance the posture.

The ***alpha*** activity was significantly low in the baseline p < 0.01 in the cingulate gyrus. parahippocampal gyrus and posterior cingulate in **limbic lobe**, cuneus, inferior occipital gyrus, lingual gyrus, middle occipital gyrus and superior occipital gyrus in **occipital lobe**, angular gyrus, inferior parietal lobule, precuneus and superior parietal lobule in **parietal lobe**, insula in **sub-lobar** and middle temporal gyrus, superior temporal gyrus and supramarginal gyrus in **temporal lobe**. further, significantly low activity was found p < 0.05 at the baseline in the paracentral lobule and precentral gyrus in **frontal lobe**, fusiform gyrus and inferior temporal gyrus in **occipital lobe**, transverse temporal gyrus in **temporal lobe** and anterior cingulate and sub-gyral in **limbic lobe**. The t-values and the location of the structure are stated in Tab. 37.

Tab. 37. *Functional localisation of the alpha activity in the young participants during postural balance under the vestibular influence*

Structure	X(MNI)	Y(MNI)	Z(MNI)	T-Value	BAs	Lobe
Precuneus	5	-65	20	-11.64**	31	Parietal
Posterior Cingulate	5	-65	15	-11.19**	23	Limbic
Cuneus	10	-70	30	-10.09**	7	Occipital
Cingulate Gyrus	5	-60	25	-9.66**	31	Limbic
Lingual Gyrus	5	-65	0	-7.86**	18	Occipital
Angular Gyrus	35	-65	35	-7.52**	39	Parietal
Superior Temporal Gyrus	35	-60	30	-7.42**	39	Temporal
Middle Temporal Gyrus	35	-65	25	-7.33**	39	Temporal
Parahippocampal Gyrus	10	-50	0	-7.31**	30	Limbic
Superior Parietal Lobule	25	-75	45	-7.25**	7	Parietal
Inferior Parietal Lobule	35	-65	40	-7.20**	39	Parietal
Insula	40	-45	20	-6.92**	13	Sub-lobar
Superior Occipital Gyrus	35	-75	25	-6.72**	19	Occipital
Middle Occipital Gyrus	40	-70	5	-6.56**	19	Occipital
Inferior Occipital Gyrus	35	-85	-10	-6.54**	18	Occipital
Supramarginal Gyrus	50	-50	20	-6.22**	40	Temporal
Fusiform Gyrus	-25	-85	-20	-6.08*	19	Occipital
Transverse Temporal Gyrus	40	-35	10	-6.01**	41	Temporal
Sub-Gyral	-20	-50	35	-5.63*	31	Limbic
Inferior Temporal Gyrus	45	-70	-5	-5.55*	37	Occipital
Anterior Cingulate	5	10	25	-5.28*	33	Limbic
Paracentral Lobule	-20	-45	50	-5.27*	5	Frontal
Precentral Gyrus	45	-20	40	-5.21*	4	Frontal

*** = $p < 0.01$, * $p < 0.05$*

The baseline reveals significantly low alpha activity under the vestibular influence in the precuneus at the 5 X(MNI), -65 Y(MNI) and 20 Z(MNI) MRI coordinates in Brodmann area 31 as shown in Fig. 82.

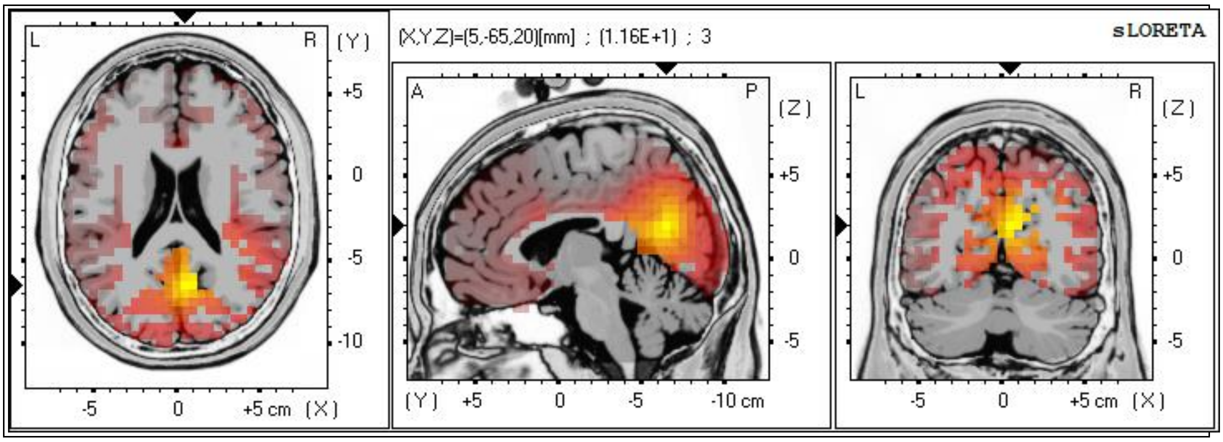


Fig. 82. Functional localisation of the alpha activity in the young participants during postural balance under the vestibular influence

The **beta** activity was significantly higher at the baseline $p < 0.05$ in the inferior frontal gyrus (-50 X(MNI) 10 Y(MNI) 20 Z(MNI) at Brodmann area 44 with a T-value 5.18, the precentral gyrus (-50 X(MNI) 10 Y(MNI) 15 Z(MNI) at Brodmann area 44 with a T-value 5.26 and middle frontal gyrus (-35 X(MNI) 40 Y(MNI) 15 Z(MNI) at Brodmann area 10 with a T-value 5.04 in the **frontal lobe** and insula (-40 X(MNI) 5 Y(MNI) 15 Z(MNI) at Brodmann area 13 with a T-value 5.52) in the **sub-lobar** region (Fig. 83).

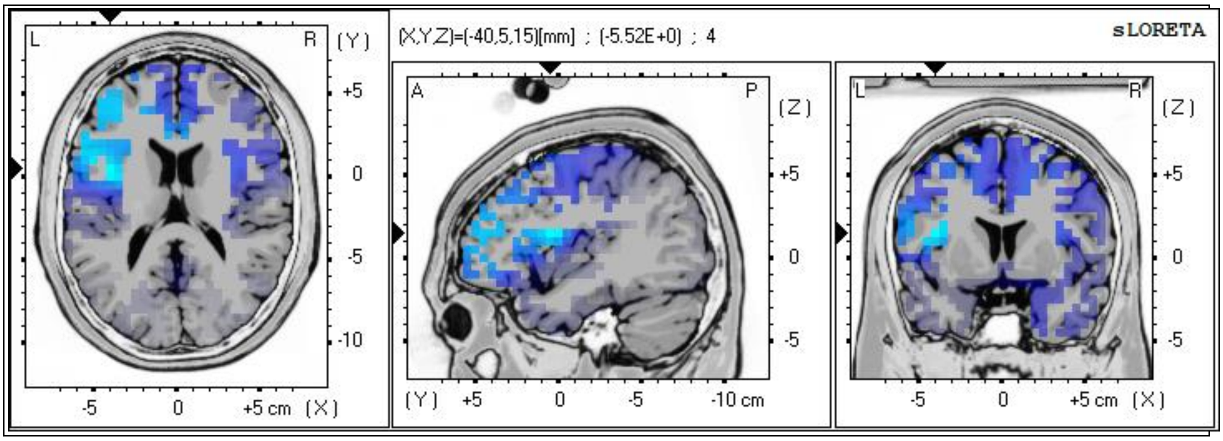


Fig. 83. Functional localisation of the beta activity of young participants during postural balance under the vestibular influence

The **gamma** activity was higher than in the baseline $p < 0.01$ in the middle frontal gyrus, superior frontal gyrus, medial frontal gyrus in the **frontal lobe** and in the cingulate gyrus of the **limbic lobe.** Further, $p < 0.05$ was identified in the precentral gyrus and the sub-gyral regions of the **frontal lobe and** anterior cingulate in the **limbic lobe**. The T-values and the structure location are given in Tab. 38.

Tab. 38. *Functional localisation of the gamma activity of young participants during postural balance under the vestibular influence.*

Structure	X(MNI)	Y(MNI)	Z(MNI)	T-Value	BAs	Lobe
Middle Frontal Gyrus	-25	15	50	-8.40**	8	Frontal
Superior Frontal Gyrus	-20	15	50	-7.92**	8	Frontal
Cingulate Gyrus	-15	10	40	-7.40**	32	Limbic
Medial Frontal Gyrus	-20	5	55	-6.54**	6	Frontal
Precentral Gyrus	-30	20	40	-6.09*	9	Frontal
Sub-Gyral	-15	25	45	-6.06*	8	Frontal
Anterior Cingulate	-15	40	15	-5.73*	32	Limbic

*** = $p < 0.01$, * $p < 0.05$*

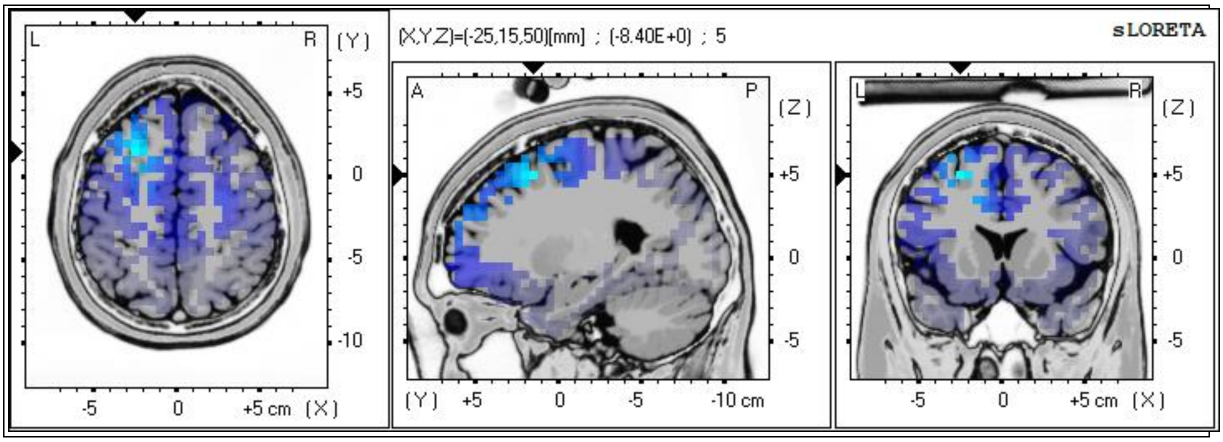


Fig. 84. Functional localisation of the gamma activity in the young participants during postural balance under the vestibular influence

High **gamma** activity was evident in the middle frontal gyrus under the vestibular influence at the -25 X(MNI), 15 Y(MNI) and 50 Z(MNI) MRI coordinates in Brodmann area 8 at the baseline, as seen in Fig. 84.

5.5.9 Source localisation of the cortical activity in the senior participants

The source localisation during postural balance under the vestibular influence are evident in the delta, theta, alpha, beta and gamma frequencies. The statistical threshold of the functional localisation of the cortical activity during postural balance under the vestibular influence was defined according to the one-tailed statistical results (condition 1 < condition 5). The $p < 0.01$ = t 5.73, $p < 0.05$ = t 4.81 and (condition 1 < condition 5) $p < 0.01$ = t -5.62 $p < 0.05$ = t -5.80.

The **delta** and **theta** activity showed no significant difference between the functional localisation of the baseline compared with the vestibular influence to balance the posture.

The **alpha** activity was significantly low in baseline with p < 0.01 at the sub-gyral, parahippocampal gyrus, posterior cingulate in **limbic lobe** and lingual gyrus in **occipital lobe**. Further higher alpha activity under vestibular influence found in cingulate gyrus in **limbic lobe**, cuneus in **occipital lobe**, precuneus in **parietal lobe** and fusiform gyrus, middle temporal gyrus and superior temporal gyrus in **temporal lobe**. The T-values and the location of the structures are stated in Tab. 39.

Tab. 39. *Functional localisation of the alpha activity in the senior participants during postural balance under the vestibular influence*

Structure	X(MNI)	Y(MNI)	Z(MNI)	T-Value	BAs	Lobe
Sub-Gyral	-15	-45	-10	6.38**	19	Limbic
Parahippocampal Gyrus	-15	-40	-10	6.21**	30	Limbic
Lingual Gyrus	-15	-45	-5	6.13**	19	Occipital
Posterior Cingulate	-10	-45	5	5.74**	29	Limbic
Fusiform Gyrus	-25	-40	-20	5.61*	37	Temporal
Precuneus	20	-65	30	5.19*	7	Parietal
Cingulate Gyrus	0	-40	25	5.13*	31	Limbic
Cuneus	-10	-60	5	5.08*	30	Occipital
Middle Temporal Gyrus	40	-60	20	5.05*	39	Temporal
Superior Temporal Gyrus	40	-55	20	4.88*	22	Temporal

*** = $p < 0.01$, * $p < 0.05$*

The alpha activity in the sub-gyral under the vestibular influence at the -15 X(MNI), -45 Y(MNI) and -10 Z(MNI) MRI coordinates in Brodmann area 19 was higher than at the baseline, as shown in Fig. 85.

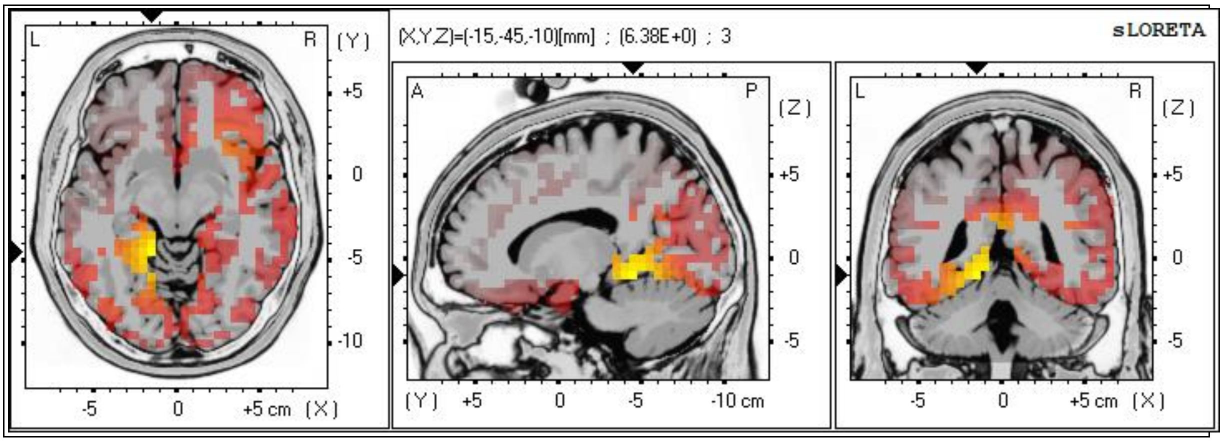


Fig. 85. Functional localisation of the alpha activity in the senior participants during postural balance under the vestibular influence

The **beta** activity was observed to be higher at the baseline $p < 0.01$ in the precuneus (0 X(MNI) -70 Y(MNI) 15 Z(MNI) at Brodmann area 31 with T-value -5.94 and in the 0 X(MNI) -75 Y(MNI) 10 Z(MNI) at Brodmann area 18 with T-value -5.88) in **occipital lobe and** $p < 0.05$ posterior cingulate (0 X(MNI) - 65 Y(MNI) 15 Z(MNI) at Brodmann area 23 with T-value -5.53 of **limbic lobe** (Fig. 86).

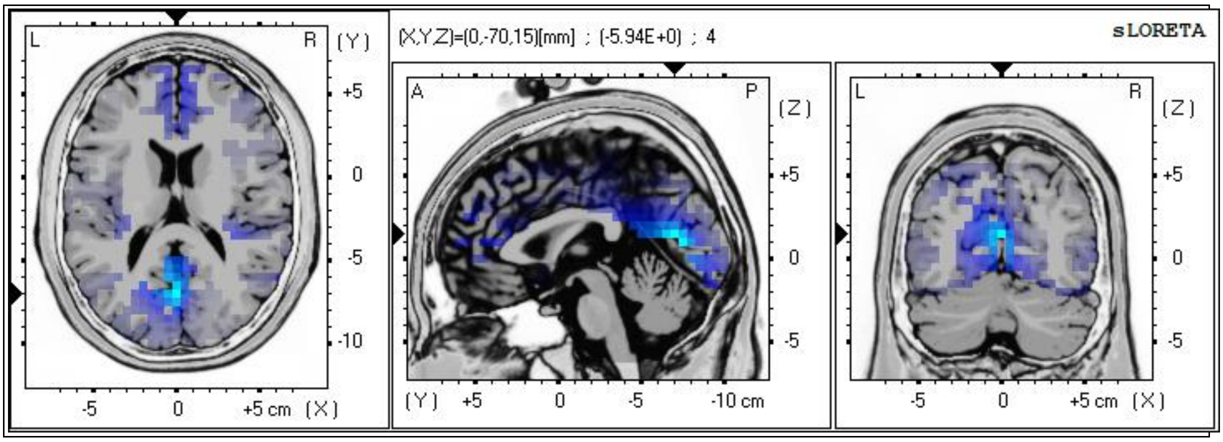


Fig. 86. Functional localisation of the beta activity in the senior participants during postural balance under the vestibular influence

5.6 *Summary of the results*

Significant parameters are reported in the summary of the results. The senior participants showed a lower degree of postural balance abilities, as well as a low strategy score. They also revealed less theta activity in the frontal lobe, decreased delta and theta but higher gamma activity in the temporal lobe, reduced theta and increased beta activity in the lobe central, lower delta and theta and higher beta activity in the parietal lobe and lower delta and theta but higher beta and gamma activity in the occipital lobe when compared with the young participants during static postural balance. Functional localisation of the cortical activity showed lower theta and alpha but higher gamma activity in the prefrontal cortex. Reduced theta and alpha activity were evident in the primary somatosensory cortex, while the premotor cortex showed reduced theta and alpha activity. The posteroparietal cortex showed decreased theta activity while the primary visual cortex also showed lower theta activity in the cortex of the seniors when compared with those of the young participants.

The senior participants revealed a significantly low SOT score and showed reduced postural balance abilities under the visual and vestibular influences when compared with that of the young participants. Besides, under the somatosensory influence, the percent ratio of the delta activity was found to decrease, while the gamma activity percentage ratio was found to increase in the frontal lobe of the seniors when compared with those of the young participants. In functional localisation, the delta, theta, beta, and gamma activities were reduced, while the alpha activity was increased in comparison to the baseline. The senior participants revealed an increase in the alpha activity, but no reduction in the activity was observed in relation to the baseline. Under the visual influence, the percent ratio of the delta and theta activities decreased, while the beta and gamma activities increased in the frontal lobe in the seniors when compared with those of the young participants, and no significant difference was found in functional localisation.

Besides, the senior participants displayed a low percentage ratio of the alpha activity, but higher beta and gamma activity in the frontal and temporal lobes, and reduced alpha activity and increased gamma activity in the central, parietal and occipital lobes when compared with the young participants. In functional localisation, the delta, beta and gamma activities decreased, while the alpha activity increased in relation to the baseline in the young participants. The senior participants showed an increase in the alpha activity and a decline in the beta activity in relation to the baseline. Further correlations were found for the different EEG frequencies with postural balance.

6 Discussion

Balance maintenance is a fundamental ability of human movement (Winter, 1995; Woollacott & Shumway-Cook, 2002). It plays a central role in maintaining body balance to accomplish the activities of daily living and assists in the prevention of injuries. Postural balance depends on muscle strength, central processing, motor control and the sensory input of the somatosensory, vestibular and visual systems (Alexander, 1994; Kollmitzer, Ebenbichler, Sabo, Kerschan, & Bochdansky, 2000). It has been investigated that, the postural balance of an individual relies mostly on the somatosensory system which shows higher sensitivity to balance disturbances over the visual and vestibular inputs (Nashner & Berthoz, 1978). Moreover, the visual information is dominant in balance maintenance in the static condition, in comparison to the vestibular function. The effects of these systems have extensively been studied (Fitzpatrick & McCloskey, 1994; Redfern, Yardley, & Bronstein, 2001). Nevertheless, when we alter the conditions and surroundings, the sensorial information also changes according to the difficulty of the balancing condition (Bronstein, Hood, Gresty, & Panagi, 1990; Marsden, Merton, & Morton, 1981).

Maintenance of balance is one of the primary problems in Parkinson’s disease, aging, a disorder of vestibular and neuromuscular function (Agrawal, Carey, Della Santina, Schubert, & Minor, 2009; Horst , Marian, 1999; Klawans, 1986; Pieterse *et al.*, 2006). Despite the fact that the mechanism of balance has been extensively studied, the cortical activity during the balance state has sporadically been discussed, in order to get a clear understanding of the brain’s response during the subsistence of balance. Although, a high degree of cognitive processing is involved in maintaining the balance (Woollacott & Shumway-Cook, 2002).

The objective of this study is to identify the strategies of balancing posture, the impact of aging on the static postural balance, and the sensory integration to balance the posture. Above and beyond, the cortical responses during posture balance and sensory integration to maintain the posture were ascertained both in the active young, as well as the active senior participants.

6.1 *Static postural balance*

This study depicts that the ability to maintain static postural balance declines with aging, accompanied by a change in the strategies of postural balance. The decline in the postural balance abilities has been well established with the aging processes (Amiridis *et al.*, 2003; Baloh *et al.*, 1998; Baloh, Fife, Zwerling, Socotch, Jacobson, Bell, 1994; Barbieri & Vitório, 2017; Bradley, 2011; Era *et al.*, 2006; Era *et al.*, 2002; Freitas *et al.*, 2005; Guralnik *et al.*, 1994; Hirabayashi & Iwasaki, 1995; Hytönen *et al.*, 1993; Maki *et al.*, 1994; Peterka & Black, 1990; Woollacott *et al.*, 1986).

The aging process does not impact only a single function or the ability of an individual(Erber, 2012; Fedarko, 2018; Ko *et al.*, 2018; Lunney, Lynn, Foley, Lipson, & Guralnik, 2003), it also induces a decline in the neural, cognitive, sensorimotor, and muscular systems. Postural balance is also a complex ability which requires the neural, cognitive, sensorimotor, and muscular systems to be accomplished (Barbieri & Vitório, 2017). It can be maintained by firstly obtaining the sensory information from the somatosensory, visual and vestibular systems and then sending it to the cortex for processing. The final step is achieved by generating the motoric response to stabilise the posture (Horak, 2006; A S Pollock *et al.*, 2000).

The aging process causes the somatosensory system to decline through inducing a change in the structure of the muscle spindle (Liu *et al.*, 2005; Swash & Fox, 1972). Aging reduces the intrafusal spindle fibres and distal sensory axons (Swash & Fox, 1972) apart from decreasing the sensitivity of the muscle spindles (Miwa *et al.*, 1995), muscle length, JPS (Liu *et al.*, 2005), response of the tendon organ (Proske & Gandevia, 2012), vibration perception in the skin receptors (Verrillo, 1979; Ronald *et al.*, 2002) and the mechanoreceptors in the foot (Lord & Ward, 1994). The aging-induced effects cause a reduction in the somatosensory information required to balance the posture. The loss of hair cells in the vestibular system also limits the sensory information from the vestibular system (Lopez *et al.*, 2005; Taylor *et al.*, 2015). Furthermore, the aging process affects the visual information which can also cause a decrease in the postural balance abilities due to a reduction in the contrast sensitivity and acuity. (Barbieri & Vitório, 2017). In correspondence to the current findings and the decline in the earlier discussed functions, we reject the null hypothesis (1H0) and accept the alternative hypothesis (1H1) that the decline in the postural balance in physically active and inactive individuals is correlated with aging. , even in those individuals who are involved in physical activity.

In addition to the postural balance abilities, the results of our study also highlight the low strategy score in the senior participants' group during the postural balance as compared to the young participants. The Balance Master computes the strategy score from 0 to 100. If the score is more inclined towards 100, it means that the participants in the study are using ankle strategy; whereas when the higher contribution of the hip is involved in balancing the posture, the score drops, moving towards 0. Therefore, a low strategy score implies that the seniors use more hip strategy as compared to the young participants in balancing the posture.

The motor plan initiates the strategies to balance the posture. The stiffness in the ankle joint and relaxation in the trunk muscles support the ankle strategy, while stiffness in the leg muscles and relaxation in hip muscles support the hip strategy (Maki & McIlroy, 1996; Brian & McIlroy, 1997; McIlroy & Maki, 1999; McIlroy & Maki, 1997). The posture strategies change as follows: when it becomes difficult for the ankle muscles to support the posture, then the hip muscles become active and lend support to balance the posture, producing a mixed strategy (Gatev *et al.*, 1999; Horak & Nashner, 1986). According to our findings, the seniors showed a decline in posture control and engaged hip strategy to support the posture, which was in correspondence with the strategy score indicating usage of hip strategy. Moreover, we also found a positive relationship with the strategy score and postural balance, which was also established by Day and his colleagues (Day *et al.*, 1993). The higher involvement of the hip strategy in the seniors to balance the posture was also reported by Amiridis *et al.* 2003. Even when the senior participants were engaged in physical activity, they still showed the involvement of the hip strategy to balance the posture when compared with the young participants. In light of these facts, we reject the null hypothesis (2H0) and accept the alternative hypothesis (2H1) that aging affects the strategies involved in postural balance.

6.2 *Sensory integration influence on the postural balance*

Postural balance is dependent on the input of the somatosensory, visual and vestibular systems (Alexander, 1994; Grace *et al.*, 2012; Kollmitzer *et al.*, 2000) and the visual system was dominant to control the postural balance (Fitzpatrick & McCloskey, 1994; Redfern, Yardley, *et al.*, 2001). The contribution of sensory information in postural balance depends on the individual's lifestyle, daily activities and involvement in physical activities. The conclusions drawn regarding the influence exerted by these factors are mentioned after reviewing the results of the sensory organisation test, according to Cohen, Heaten, & Congdon (1996); Grace *et al.* (2012); Hirabayashi & Iwasaki (1995); Johnson *et al.* (2018); Peterka & Black (1990); Pletcher *et al.* (2017).

In our study, we recruited young and senior participants who were involved in physical activities and sports. The results of this study showed a decline in the sensory integration abilities of the senior participants. This decline in the sensory integration abilities to balance the posture can be attributed to the decline in one or more sensory information systems to balance the posture.

The sensory integration abilities during postural balance were computed concerning the influence of every individual's preference for the somatosensory, visual, vestibular or visual system. The abilities of the sensory integration can be changed according to the individual's sensory function; therefore, sensory integration results in providing information on the combined influence of the sensory systems, Also found the decline in the sensory integration to balance the posture-induced by aging (Cohen *et al*., 1996; Dettmer, Pourmoghaddam, Lee, & Layne, 2015; Peterka & Black, 1990) due to decline in the sensory systems with the aging as already mentioned above.

The results of the sensory organisation test during postural balance also showed a positive correlation with the abilities for postural balance. As the seniors displayed less postural balance abilities, they also showed low sensory integration abilities whereas, the young participants, on the other hand, showed high sensory integration abilities and elevated postural balance abilities. The relationship between sensory integration and postural balance abilities was also established by Fabio & Badke, (1990); Kim, (2012); Tang, Moore, & Woollacott (1998) in consideration of the results of current study, literature and past research we reject the null hypothesis (3H0) and accept the alternative hypothesis (3H1), while senior participants of study showed less sensory integration abilities than young participants of study.

The young participants showed a dominance of the somatosensory influence in postural balance; however, it was not significant. In contrast, the young participants showed decreased balance abilities under the vestibular influence. It has been well established that healthy persons show 70 % dependence on the somatosensory inputs, 20 % on vestibular inputs and 10 % on the visual inputs (Peterka, 2002).

Further, it has been investigated that under normal circumstances, the postural balance of an individual relies mostly on the somatosensory system and is more sensitive to balance disturbances than with the visual and vestibular inputs (Nashner & Berthoz, 1978). The somatosensory system is usually favoured under stable surface conditions; therefore, in the case of an unstable support surface, the vestibular system takes on the significant control in the maintenance of an upright posture to avoid the postural sway (Nashner, 1982). This reflects the exact situation of the equilibrium score of condition 6 in the SOT when there are conflicting somatosensory and visual inputs due to the movement of the surface platform and the sway references, which leave the vestibular system as the only primary sensory system to control balance in the subjects during the test. Furthermore, the results of our study represent lower percentage equilibrium scores for conditions 5 and 6 in comparison to the baseline condition 1 of SOT, reiterating that the balance ability depends upon the vestibular information. Similar results regarding sensory integration during postural balance in the active young people were reported by other researchers as well (Grace *et al.*, 2012; Johnson *et al.*, 2018). Results of the current study suggested to reject the hypothesis (4H1b) and retain hypothesis (4H1a) as young participants showed dependence on the somatosensory system.

The senior participants showed reduced postural balance abilities under the vestibular and somatosensory influences than under the visual inputs, contradicting the results seen in the young participants. During postural balance, the visual system is considered to be the primary information system, and the senior active participants depend more upon it (Cohen, Heaton, Congdon, & Jenkins, 1996; Liaw, Chen, Pei, Leong, & Lau, 2009). Exercise was noted to play a significant role in improving the visual function (Gleeson, Sherrington, & Keay, 2014; Woods & Thomson, 1995), which can be one of the main reasons for the seniors in this study to show dependence on the visual influence during postural balance, because they have been involved in physical activity.

In our study, we also compared the results of the young and senior participants who were involved in sports and physical activities, with the aim of identifying the effect of aging on active individuals. The senior participants did not show any significant decline in postural balance under the somatosensory influence, whereas the young participants showed 97.18 % equilibrium score, while the seniors showed 91.22 % equilibrium score. The senior participants showed less postural balance abilities under the influence of visual and vestibular inputs compared to the young participants. Postural sway was observed to increase under conditions of altered visual and somatosensory environments (Camicioli, Panzer, & Kaye, 1997; Mirka & Black, 1990; Peterka & Black, 1990); however, in our study we found no significant difference during the somatosensory influence on the postural balance, which can be attributed to the involvement of the participants in physical activity. As reported, (Rehfeld *et al.*, 2017) the positive impact of the somatosensory influence on postural balance showed a decline under the condition of visual influence, which could be due to low contrast sensitivity and acuity. Regarding the aging process (Barbieri & Vitório, 2017) and decline in maintaining postural balance under the condition of vestibular influence, the loss of hair cells in the vestibular system, could also cause limiting the sensory information coming from the vestibular system (Lopez *et al.*, 2005; Taylor *et al.*, 2015). In consideration of the outcome of seniors, sensory dependence showed visual dominance, so we reject the hypothesis (5H1a) and retain hypothesis (5H1b).

6.3 *Cortical activity during the postural balance*

The cortical activity and cognitive process are highly involved in balancing the posture (Dubost *et al.,* 2006; Plummer *et al.,* 2015; Priest *et al.,* 2008; Takakusaki, 2017a). The subcortical structure contributes to the posture balance in the animal studies (Armstrong, 1988; Drew *et al.,* 2004), along with cerebral cortex which aids in balancing the posture in humans (Mihara *et al.,* 2008):

The aging process causes the degeneration in structure, function, and behaviour changes in the neuromotor system. Further, structure degeneration causes functional degeneration (Rivner, Swift, & Malik, 2001). In an attempt to overcome the structure degeneration, a compensation response is generated by the neuromotor system to stabilise functional abilities (Mattay *et al.,* 2002). The same phenomenon occurs in postural balance (Papegaaij *et al.,* 2014). The decline in sensorimotor tracts makes the senior people use more high-level cortical processing (Boisgontier & Nougier, 2013a). In the current study, the effect of aging on the cortical activity was analysed using EEG, and the analysis of the functional localisation in the subcortical structure during postural balance was carried out via EEG signals by using voxel to voxel approach with eLORETA software.

Similar to the studies carried out by Ozdemir, Contreras-Vidal, & Paloski (2018), in EEG studies usually, researcher use sitting position as a baseline,but its also a kind of postural control or balance activity (Nichols *et al.,* 1996). In this regards to find out the effect of aging on the cortical modulation the EEG activity of young participants, was considered as a baseline while taking into account the static postural balance.

In the current study, senior participants showed less delta and theta activity along with high alpha, beta, and gamma activities during posture balance in comparison to young participants. However, these all frequencies are not significant. Decline in the EEG activities can be due to a reduction of neural efficiency and degradation in neurotransmission with the aging process (Bäckman, Nyberg, Lindenberger, Li, & Farde, 2006), in addition to, structure decline in grey and white matter (Raz *et al.*, 2005; Sullivan, Rohlfing, & Pfefferbaum, 2010) as well as decline in the functional connectivity (Grady *et al.,* 2010). The aging process affects the cortical activity even in resting state in such a way that delta theta and alpha frequency get reduced, while beta activity gets increased (Zappasodi, Marzetti, Olejarczyk, Tecchio, & Pizzella, 2015). Even in sensory-motor task, the young and seniors showed similar trends (Dushanova & Christov, 2014) which was subsequently followed by the results of the current study. Specifically, all five regions of interest showed different activity including a sub-cortical structure in the cortex during posture balance in seniors as compared with the young participants of the current study discussed below.

6.3.1 Frontal lobe

According to the outcomes of the current study, senior participants exhibited less theta activity as compared to young participants in frontal lobe with less postural balance abilities. It is a well-known fact that theta activity is a predictor of error monitoring during the motor performance (Slobounov, Ray, Johnson, Slobounov, & Newell, 2015; Chang, Yang, Yang, & Chern, 2016). The reduced theta activity may predict less error-related cortical responses found during posture balance (Hülsdünker *et al.,* 2016a). The reduction of theta activity during balance could be due to decline in memory function (Rogge, Röder, Zech, & Hötting, 2018), which get reduced with aging process (Stebbins *et al.*, 2002), Moreover, memory is one of the cognitive function associated with balance (Rogge *et al.*, 2017). The decrease in theta activity in senior could be because of the aging process with a reduction in memory function and less error detection ability to balance the posture. Less theta activity we also found in the cortical structure of seniors, which also contributes to the memory function too. Similarly, Ozdemir, Contreras-Vidal, Lee, & Paloski (2016) also reported less theta activity in the frontal lobe of seniors along with working memory impairment, in his walk related study, where seniors stabilised the posture under the influence of dual task, which supports our results. The less theta can be due to a decline in the memory function in the seniors which in turn reduces their ability to balance the posture.

In addition to this, the positive correlation between beta and gamma, and theta activity presented a negative correlation with postural balance in young participants in the frontal lobe. Beta activity is a predictor of high-level cortical modulation and sensorimotor integration (Chang *et al.,* 2016), It is also related to sensory-motor task (Gwin, Gramann, Makeig, & Ferris, 2011). On the other hand, gamma activity is related to the communication with the different region of the cortex to accomplish a complex motor task (Fries, 2009; Teixeira *et al.,* 2010a). Further, theta activity gets increased with conflict or error in the cortical response. However, theta activity increases with the decrease in the balance as it recruits more cortical sources (Slobounov, Teel, & Newell, 2013). According to the study of Hülsdünker, Mierau, Neeb, Kleinöder, & Strüder (2015), theta activity reduces with an increase in the difficulty of postural balance task. Moreover, beta (Zhavoronkova, Zharikova, Kushnir, & Mikhalkova, 2012) and gamma (Oliveira, Arguissain, & Andersen, 2018; Amy, Gwin, Makeig, & Ferris, 2013) response develop in the cortex to stabilise the posture. Nevertheless, both frequencies were increased to support the stabilisation of the posture In consideration of frequencies characteristics, negative correlation of theta activity showed static postural balance was not challenging for young participants while beta and gamma activities support to balance the posture.

Senior participants of the current study showed no correlation with any EEG activity in the frontal lobe which depicts they used different cortical resources than young participants of the study. However, combined EEG data of young and seniors showed positive correlation in theta activity in the frontal lobe, which could be due to decreased theta activity in the frontal lobe of the seniors along with less postural balance abilities and its impact on the complete data of both groups.

The frontal lobe plays a significant role in balancing the posture (Sehm *et al.,* 2014). Generally, it involves motor functions, multiple cognitive processes like executive function attention, memory, and language (Chayer & Freedman, 2001). The power spectrum of frontal lobe gives us general information about the cortical activity during postural balance. To find out the specific activation in the frontal lobe the current source density results are reported from eLORETA software. According to the results of the substructure, seniors showed overall low delta, theta and alpha but higher beta and gamma activities as compared to the young participants. Indeed, it is the pioneer study which reports the effect of aging on the cortical substructure activity, and the function related to the postural balance of each structure has been taken into consideration for the interpretations. In the present study, senior participants exhibited less theta activity in subcallosal gyrus: which can play a role to get visual contrast motion (Roberts *et al.,* 2017), and can also contribute in balancing the posture (Holten, Smagt, Verstraten, & Donker, 2016).

Further, the paracentral lobule showed less theta activity. Which is situated between frontal and parietal lobes of the cortex and it includes primary motor and sensory areas for the lower limbs (Johns, 2014), fibers reaching this area from the thalamus course through the periventricular white matter. Additionally, it can also contribute to the poor balance (Michael. Aminoff, Franc¸ Ois Boller, 2016). In the current study, senior exhibited the high perturbation in COP which could cause the low theta activity in paracentral lobule. The aging process declines the visual contrast motion (Owsley, 2011; Snowden & Kavanagh, 2006) and high perturbation in COP could have caused the less theta activity in above two structures.

Seniors demonstrated further less theta and less alpha activity in (a) medial frontal gyrus: involved in visual-vestibular conflict (Roberts *et al.,* 2017) thereby contributing in postural balance (Akiduki *et al.,* 2003), (b) orbital gyrus: which supports the process in the memory related to previous sensory experiences (M Husain & Schott, 2016) and plays a role in converting the new informations to memory (Frey & Petrides, 2000), where memory plays a vital role in balancing the posture (Rogge *et al.,* 2017) and (c) precentral gyrus: a part of the primary motor cortex, which generates the neural impulse to execute the movement (Orhan E. Arslan, 2015). Apart from this, rectal gyrus also showed less theta and alpha activity, but its function is not yet clear. As stated above, theta activity is related to error detection, while the alpha frequency, which consists of inhibitory and excitatory phases that are proposed to get information transmission between the cortex and the thalamus (Lorincz, Kékesi, Juhász, Crunelli, & Hughes, 2009), played an important role in balance (Del, Babiloni, Marzano, Iacoboni, Infarinato, Vecchio, Lizio, Aschieri, Fiore, Toràn, *et al.,* 2009; Slobounov, Cao, Jaiswal, & Newell, 2009b), and thus can be predictor of attention in the cortical activity (Boiten, Sergeant, & Geuze, 1992; Klimesch, 1999; Slobounov *et al.*, 2009b). Therefore, if alpha frequency gets reduced then higher frequencies undergo an increase (Zappasodi *et al.,* 2015). In context to the primary motor cortex, it is also related to motor preparation (Deiber *et al.,* 2012). With aging process visuovestibular conflict ability (Roller, Cohen, Kimball, & Bloomberg, 2002), memory function (Sokunbi *et al.*, 2011) and execution of movement abilities (Inuggi *et al.,* 2011) get reduced, which could be the reason of less theta and less alpha activity in above stated structure.

Seniors also showed less theta, alpha, but higher gamma activity in (i) inferior frontal gyrus: plays an essential role in inhibition and attentional control or executive control (Hampshire, Chamberlain, Monti, Duncan, & Owen, 2010) which in turn controls the posture balance (Reilly, Donkelaar, Saavedra, & Woollacott, 2008), (ii) superior frontal gyrus: involved in self-awareness regarding coordination of actions of sensory systems (Goldberg, Harel, & Malach, 2006) which are necessary components of postural balance (Alexander, 1994; Kollmitzer *et al.,* 2000) and in (iii) middle frontal gyrus: which is involved in memory function (Peach & Shapiro, 2012). With the aging process, the reduction in attention and executive function (Dieuleveult, Siemonsma, Erp, & Brouwer, 2017a) along with sensory integration (He *et al.,* 2017a) could be a reason of less theta and alpha activity. However, higher gamma activity seems to be the compensation response required for completing the task, while gamma activity is related to communication with the different region in the cortex to accomplish a complex motor task (Fries, 2009; Teixeira *et al.*, 2010). A higher gamma activity exhibited by this three structure could be compensation of the cognitive decline to balance the posture.

6.3.2 Temporal lobe

In the present investigation, in comparison to young participants, senior participants showed low delta and theta but higher gamma activity in temporal lobe along with less postural balance abilities. Primarily, temporal lobe plays a role in cognitive functions like episodic memory, semantic memory, procedural memory, and perceptual representation system (Husain & Schott, 2016). On the other hand, the delta activity represents the internal processing and can denote the cortical representations of changing sensory conditions in postural tasks (Ozdemir, Contreras-Vidal, Lee, & Paloski, 2016; Harmony, 2013). Additionally, temporal lobe also plays a vital role in integrating information from different sensory modalities and across processing (Binder, Desai, Graves, & Conant, 2009; Noppeney, Josephs, Hocking, Price, & Friston, 2008). Further, until now, six significant association fiber tracts have been identified in temporal lobe, i.e. inferior longitudinal fasciculus, inferior frontal-occipital fasciculus, middle longitudinal fasciculus, arcuate fasciculus, corpus callosum, and anterior commissure, for accomplishing the tasks of complex interaction with other cortical regions (Bajada *et al.,* 2017), which are highly connected with the subcortical structure (Kiernan, 2012). Moreover, integration of sensory information abilities diminishes with the aging process(Dieuleveult, Siemonsma, Erp, & Brouwer, 2017) which can be a cause for demonstrating less delta activity and theta activity in the temporal lobe in seniors in the areas related to memory function.

In that context, gamma activity, which plays a mirror-role in the binding of cortical areas to preparation, perception, and execution of movement for the motor task (Teixeira *et al.,* 2010), could be considered as a compensation response to the decline in delta and theta activity. .As stated above, temporal lobe is highly connected to other areas of the cortex, while gamma activity seems to increase the communication with the other areas of cortex to accomplish the task. Further, during the phenomenon of frequencies concerning multisensory integration, Friese *et al.* (2016) reported a decrease in delta and theta activities with an increase in gamma activities in the temporal lobe. However, the postural balance needs sensory integration for accomplishment. Therefore, the decrease in the sensory integration abilities with the aging process can be the reason for illustrating less delta, theta, and higher gamma activity. Additionally, the evidence of the role of the temporal lobe in the postural balance, although being not extensively studied in EEG studies, however, evidence of the temporal lobe in the postural balance is shown in the literature by Karim, Fuhrman, Sparto, Furman, & Huppert (2013); Shine *et al.* (2013).

Beta activity is a predictor of high-level cortical modulation and sensorimotor integration (Chang *et al.,* 2016) and is related to sensory-motor task (Gwin et al., 2011). Correspondingly, postural balance is a sensory-motor task and the young participants showed a positive correlation in beta frequency owing to higher postural balance abilities. Alternatively, the EEG power spectrum of combined groups showed a positive correlation in delta and theta, whereas a negative correlation in gamma activity with postural balance, even though delta and theta activities were less in seniors, with gamma activity being higher in seniors.

Regarding the functional localization of structure, seniors showed low delta and theta in transverse temporal gyrus: which plays a role in visuovestibular conflict (Roberts *et al.,* 2017), and contributes in postural balance (Akiduki *et al.,* 2003) as well as gets affected by aging process (Roller *et al.,* 2002). Reduced theta activity was mainly reported in seniors in fusiform gyrus: which is involved in face recognition (Gazzaley *et al.,* 2007; Postle, Druzgal, & D'Esposito, 2003; Rainer, Rao, Miller, & D'Esposito, 1999; Rämä & Courtney, 2005). Generally, the ability of the face recognition is allied up with spatiotemporal visual processing (Geurts, Ribbers, Knoop, & van Limbeek, 1996) which declines with the aging process (Owsley, 2011; Norton, McBain, & Chen, 2009). Further less theta activity, was reported in middle temporal, sub-gyral and supramarginal gyrus, where middle temporal gyrus supports in the integration of sensory information (M Husain & Schott, 2016), while sub-gyral and supramarginal gyrus is vital for the working memory and higher-order cognitive processes (Menon & Uddin, 2010; Seeley *et al.,* 2007; Sridharan, Levitin, & Menon, 2008). Additionally, less delta, theta, and alpha activity activities were also reported in superior temporal gyrus: which is related to vestibular function and being a part of the parieto-insular vestibular cortex (PIVC)(Jahn et al., 2004)aids in identifying the position of the head (Shinder & Newlands, 2014)

With aging, visuovestibular conflict, spatiotemporal visual processing, working memory (Klencklen, Banta Lavenex, Brandner, & Lavenex, 2017; McNab *et al.,* 2015), sensory integration (Dieuleveult *et al.,* 2017a) and vestibular related function in postural balance (Sturnieks, George, & Lord, 2008; Wiesmeier *et al.,* 2017) are found to get reduce in the subcortical structure of temporal lobe. Thus, less alpha activity in superior temporal gyrus gave another interpretation that the higher frequencies in this structure can increase as discussed in the frontal lobe alpha properties. However, the increase in higher frequencies was insignificant. Nevertheless, in consideration of alpha activity properties, this area also produces higher level activities, which is responsible for parieto-insular vestibular cortex and vestibular function.

6.3.3 Central lobe

In the central lobe, senior participants showed low theta and high beta activity as compared to young participants while balancing the posture in the current study. Central lobe, which is located on central sulcus (Klem *et al.,* 1958) separates the parietal lobe from the frontal lobe, and the primary motor cortex from the primary somatosensory cortex (Culham & Kanwisher, 2001). Thus, EEG activity corresponding to central lobe was found to be in association with primary motor cortex, primary somatosensory cortex, and parietal lobe. Moreover, in the central lobe, less theta activity and higher beta activity was observed. Theta and beta activities depict the error detection ability, with higher beta activity explaining the utilisation of the large-scale communication between sensory-motor and other areas of the cortex by the senior participants (Kilavik, Zaepffel, Brovelli, MacKay, & Riehle, 2013). Apart from this, the beta activity also demonstrates the extent of contraction of muscles (Jacobs, Wu, & Kelly, 2015). In the present investigation, seniors showed higher displacement during balancing the posture which can lead to high contraction of muscles as compared to the young participants. Since beta activity corresponds the primary motor cortex, primary somatosensory cortex, and parietal lobe, it serves as a high communication in the central lobe, which in turn aids in accomplishing the task. Further, the involvement of beta activity in balancing the posture in central lobe during postural displacement older adults, with and without Parkinson’s disease, was also reported in the study carried out by Smith, Jacobs, & Horak (2012).

Young participants showed a negative correlation in theta activity and positive correlation between beta activity similar to frontal lobe with postural balance. In contrast, senior participants showed a negative correlation between gamma activity and postural balance, where a reduction in the postural balance, increases the gamma activity (Slobounov *et al.,* 2008). In our study, senior participants showed less postural balance abilities, which can cause higher gamma activity in the central lobe. Hence a negative correlation in postural balance was obtained. Further, both young and senior groups showed a positive correlation between theta activity and postural balance where young showed higher theta activity and seniors showed less theta activity, with the combined results showing a positive correlation in central lobe.

Predominantly, functional localisation was reported, in limbic lobe structure and sub-lober. Seniors showed significantly less theta activity in comparison to young participants in (i) uncus: which communicate with the hippocampus and prefrontal cortex with primarily being involved in memory function (Zeidman & Maguire, 2016), and (ii) cingulate gyrus: generally involved in the sensory-motor process (Taylor, Seminowicz, & Davis, 2009). Seniors also showed lesser delta and theta in the parahippocampal gyrus: entailed in visuospatial processing, episodic memory, (Aminoff, Kveraga, & Bar, 2013) and navigation (Epstein & Kanwisher, 1998). Further, seniors displayed less theta and alpha in anterior cingulate: which is involved in error detection (Bush, Luu, & Posner, 2000; Marlin, Mochizuki, Staines, & McIlroy, 2014), convergence, combination, and integration of multisensory information, (Seghier, 2013). It also contributes towards comprehending the position of the body (Clemente, Rodríguez, Rey, & Alcañiz, 2014).

Seniors also exhibited less delta and theta activity, as well as higher beta activity in comparison to the young participants in posterior cingulate: a central node in the default mode network (DMN), which is broad scale network that interacts with each other in cortex to have highly correlated activity (Xu, Yuan, & Lei, 2016). Principally, DMN can be seen in active mode when a person is thinking about himself or planning for the future but seems to be disturbed in people who have the Alzheimer's disease (Buckner, Andrews-Hanna, & Schacter, 2008). On the other hand, in Sub-lober, seniors showed less theta activity in extra-nuclear; involved in memory function (Sokunbi *et al.,* 2011) with less delta, theta, and alpha activity in the insula, which plays a role in sensorimotor processing, high-level attention, and decision making (Seghier, 2013). Insula also contributes to the selection of information regarding the conflict of visual-vestibular conflict and multisensory integration (Macauda *et al.,* 2015) in seniors.

In the present study, less activity in seniors could be due to the decline in the sensory-motor (He *et al.,* 2017; Vercillo, Carrasco, & Jiang, 2017), visuospatial processing (Bo, Borza, & Seidler, 2009; Bruin, Bryant, MacLean, & Gonzalez, 2016), episodic memory (Kinugawa *et al.,* 2013; Talamini & Gorree, 2012), integration of sensory informations (Dieuleveult *et al.,* 2017), visuovestibular conflict ability (Roller *et al.,* 2002), and memory function (Sokunbi *et al.,* 2011) owing to aging process. However, higher beta activity in posterior cingulate showed activation in the default mode network (DMN). However, DMN is inactive during task-oriented processes to make attention for the task (Raichle *et al.,* 2001), but becomes more active with the aging process and can be a cause of the reduction in the internal attention. Further, Crockett, Hsu, Best, & Liu-Ambrose (2017), also reported the effect of activation of DMN in walking study.

6.3.4 Parietal lobe

Low delta, theta, and higher beta activity were reported, in the parietal lobe of seniors. The parietal lobe is concerned with somatosensory and visuospatial perception (Johns, 2014) and plays a vital role in integrating sensory information (Blakemore & Frith, 2005) as well as in the formation of a multimodal representation of the body schema (Haggard & Wolpert, 2005; Head & Holmes, 1911). Additionally, the role of the parietal lobe in short-term or working memory, have also been established (Baddeley, 2003).

The less activity of delta can be due to a decline in the sensory integration in the case of seniors, as discussed in the temporal lobe. Basically, less theta indicates less error detection abilities, as parietal lobe is also involved in the dynamic representation of the body schema (Pellijeff, Bonilha, Morgan, McKenzie, & Jackson, 2006) and it also detects postural instability (Slobounov, Wu, & Hallett, 2006). Therefore, error detention can exert influence on the postural balance. Delta and theta activity can also be declined by the normal aging process (Dushanova & Christov, 2014). Higher beta activity seems to be the compensation response, which represents high-level cortical modulation and sensorimotor integration in the parietal lobe (Chang, Yang, Yang, & Chern, 2016).

The power spectrum of young participants showed a positive correlation between beta activity with postural balance because beta activity supports the postural balance task. Further, both groups showed a positive correlation in delta and theta with postural balance, which came from the combined data of both the groups. However, seniors showed less theta and delta activity, whereas young participants showed higher activity in both frequencies.

In the case of functional localization in the parietal lobe, seniors showed less theta activity in (a) angular gyrus: which converges multisensory information, with further combining and integrating it (Seghier, 2013), thereby revealing the position of the body (Clemente *et al.,* 2014), (b) precuneus: playing role in visuomotor coordination (Brodal, 2010), navigation, and directing attention in space (Cavanna & Trimble, 2006) along with visuomotor coordination, which contribute to posture balance (Brewer & Barton, 2012), and (c) superior parietal lobule: which coordinates with spatial coordinates of the trunk and inferior limbs and contributes to the preparatory stages of movement planning (Leiguarda & Marsden, 2000), oculomotor coordination (Anderson *et al.*, 2012) and voluntary orientation of attention (Corbetta & Shulman, 2002). Seniors also exhibited less theta and less alpha in inferior parietal lobule and postcentral gyrus, where inferior parietal lobule receives both somatosensory and visual inputs (Kandel, Schwartz, & Jessell, 2000), while postcentral gyrus acts as the primary receiving and processing area of somatosensory information from the body (Siegel & Sapru, 2011).

With the progress in the aging process, visuomotor coordination (Lee, Kwon, Son, Nam, & Kim, 2013; Ryu, Lee, Lee, & Park, 2016), integration of sensory informations (Dieuleveult *et al.,* 2017), movement planning (Stöckel, Wunsch, & Hughes, 2017), voluntary attention (Wang, Fu, Greenwood, Luo, & Parasuraman, 2012), orientation (Casco, Barollo, Contemori, & Battaglini, 2017) abilities can get affected, which could be the reasons for the occurrence of the postural abilities in seniors as compared to young participants. It is further manifested, by less delta and theta and alpha activities in the structure of parietal lobe. Moreover, balancing the posture requires integration of visual, vestibular, and somatosensory information for perceiving the position of the body (Alexander, 1994; Kollmitzer, Ebenbichler, Sabo, Kerschan, & Bochdansky, 2000).

6.3.5 Occipital lobe

Occipital lobe participates in processing and providing the visual information. It also contributes to visual perception, orientation, spatial frequency, and direction of motion, stereoscopic disparity, and colour (Braddick, 2015). The current study reported less delta, theta activity and higher beta and gamma activity presented by senior participants in the occipital lobe. These results indicated that the seniors possess less attention and internal processing, attained from less delta activity in the occipital lobe (Harmony *et al.,* 1996) while theta activity normally gives the perception of error detection as discussed before. Hülsdünker, Mierau, Neeb, Kleinöder, & Strüder (2015) also reported higher theta activity in the challenging postural balance task and mentioned that the partial lobe would be responsible for it, which further needs review because in current study theta activity in the structure-activity was observed. Therefore, theta activity exists in the occipital lobe. Less delta and theta activity can be affected by the normal aging process also (Dushanova & Christov, 2014) with higher beta and gamma activity appearing as compensation response in seniors.

Beta activity in the occipital lobe represents high-level cortical modulation and sensorimotor integration in the occipital lobe (Chang *et al.,* 2016). On the other hand, gamma activity in occipital lobe showed the communication with the different region to accomplish the task (Fries, 2009). Whereas, less delta, theta, and higher gamma activity can also be due to multisensory integration in the occipital lobe (Friese *et al.,* 2016).

As such the occipital lobe, is not well studied concerning postural balance tasks, however, beta activity in occipital was reported during the cognitive task (Kakizaki, 1987; Kakizaki, 1988). Crabbe & Dishman (2004) also described the higher beta activity with less theta activity in occipital lobe after the exercise, which indicates that beta activity has involvement in the occipital lobe concerning cognitive task and physical activity. Similarly, Slobounov, Tutweiler, Slobounova, Rearick, & Ray (2000) delineated participants showing higher beta activity during the recognition of the non-stable postures of a computer animated human body model. Alternatively, the study of Desmedt & Tomberg (1994) reported the increased gamma activity in occipital lobe during selective attention tasks. Thus, one can conclude that postural balance demands attention abilities (Brewer & Barton, 2012), so in our study seniors used the higher attention abilities to balance the posture along with sensorimotor integration as manifested by the higher beta and gamma activities in the occipital lobe.

The young participants exhibited a positive correlation between beta activity with postural balance, and the power spectrum of both groups showed a positive correlation between delta and theta activity. Indeed, young participants showed higher theta activity with high postural balance abilities, and seniors showed less theta activity with the less postural balance due to which the data of both groups showed a positive correlation in the theta activity.

In consideration of the functional localisation, seniors showed less theta activity in (a) cuneus: which interact with the lowest levels of the cortical system before processing and proceeds more widely to other visually responsive areas (Vanni, Tanskanen, Seppä, Uutela, & Hari, 2001), (ii) inferior occipital gyrus: which is a part of visual cortex and is associated with the visual processing as well as visual association cortex (Toga, 2015), (iii) inferior temporal gyrus: being related to complex visual processing regarding objects and shapes (Chao, Haxby, & Martin, 1999) and in (iv) middle occipital gyrus: which takes part in processing visual information (Sergent, Ohta, & Macdonald, 1992). Seniors also exhibited less delta and theta in lingual gyrus, a part of visual cortex which receives visual information to form the opposite field (Arslan, 2015).

These results suggest that seniors use more cortical sources from occipital lobe as compared to young participants, which could be due to a reduction in the functional ability of the occipital lobe with the progress in the aging process (Brewer & Barton, 2012) which in turn, reduces the ability to maintain balance. Further, it was manifested, by less delta and theta activity along with higher beta and gamma activity as shown by senior participants in the current study.

6.3.6 Summary of cortical activity during the static postural balance

The normal aging process causes a decrease in delta and theta activities (Zappasodi, Marzetti, Olejarczyk, Tecchio, & Pizzella, 2015; Zappasodi, Marzetti, Olejarczyk, Tecchio, & Pizzella, 2015). However, as compensation response, higher beta activity in central, parietal lobe, and occipital lobe was witnessed which led to the conclusion that the seniors used high-level cortical modulation and sensorimotor integration. Additionally, higher gamma activity in temporal and occipital lobe could be interpreted as the strong communication between the different region in the cortex to accomplish a complex motor task. The correlations in the cortical activity revealed that our results are in agreement with other studies of postural balance and cortical activities.

In functional localisation of cortical activity, senior participants showed less delta, theta, and alpha activities, while beta and gamma displayed higher activities in the structure. Functional neuroanatomy for Posture balance of Loram, (2015); Takakusaki (2017) and EROI, was taken into consideration for further interpretations. However, less error detention abilities were observed in the primary visual cortex, posterior parietal cortex, primary visual cortex, and primary sensory cortex. The compensation response was discerned in the form of less alpha activity in the structure of cortex, while the reduction observed in the alpha activity mean beta or gamma activity can undergo an increase as discussed above. However, the increase in beta and gamma activities were insignificant. But the alpha activity declined substantially because the reduction of alpha activity is a normal phenomenon of aging. Besides this higher gamma activity in inferior frontal gyrus, superior frontal gyrus, and middle frontal gyrus seems to support the functions of postural balance. One of the most remarkable outcomes was the higher beta activity in posterior cingulate: a central note of the default mode network (DMN) which exerts a negative impact on the postural control. Further, higher activity in this structure can reduce internal attention as discussed earlier. The effect of these all activities came up at primary motor cortex and the supplementary motor area which exhibited less theta and less alpha activity. Moreover, less alpha activity means an increased cortical activation (Hülsdünker, Mierau, & Strüder, 2016; Khowailed & Khowailed, 2014) for balancing the posture. Indubitably, it is the first-ever detailed study to find out the effect of aging on the cortical activity during postural balance. Zwergal *et al.* (2012) identified age-related changes with fMRI during mental imagery of locomotion and stance and also reported higher activity in superior frontal gyrus, middle frontal gyrus, inferior frontal gyrus, postcentral gyrus, inferior parietal lobule, insula, and superior temporal gyrus. However, new areas were identified, in the medial frontal gyrus, precentral gyrus, orbital gyrus, rectal gyrus, and anterior cingulate, which get more active in seniors participants of the study than in the young participants.

Upon considering power spectrum and structure response, the null hypothesis (6H0) was rejected while an alternative hypothesis (6H1) was accepted because senior participants showed higher beta and gamma activities.

According to the alternative hypothesis (6H1), seniors use higher cortical sources to balance the posture as compared to young participants of the study, which could be due to diminishing sensory-motor track in seniors, thereby using more high-level cortical processing to compensate the sensory-motor track for balancing the posture (Boisgontier & Nougier, 2013)

6.4 *Cortical activity under sensory integration*

As postural balance is a complex skill, it is generally attained by receiving the sensory information from the somatosensory, visual, and vestibular systems which are processed by the cortex for generating a motoric response which further stabilises the posture (Horak, 2006; Pollock *et al.,* 2000). The cortical activity during sensory integration required for balancing the posture and effect of aging on it was considered to understand the neural mechanism behind it as well as the role of the aging process. Further, the cortical activity under the sensory influence showed trend of reduce activity in young participants in comparison to the senior participants, while Zwergal *et al.* (2012a) already presented in his study that young participants somatosensory cortical areas and multisensory vestibular cortical areas get deactivated during imaginary locomotion task, while in seniors both areas become active. These findings support the trends of cortical activity in the seniors which elucidates less reduction in the young participants. Therefore, the present study showed higher activation in the cortex in seniors than in the young participants. According to the characteristics of frequencies, the fewer alpha, higher beta and gamma activity are the interpretation of high activity in the cortex (already discussed in the postural balance part).

6.4.1 Somatosensory influence

In the frontal lobe, the senior participants of the current study showed lower delta activity and high beta activity, while in the occipital lobe higher gamma activity was observed, under the influence of somatosensory as compared to the young participants. The influence of somatosensory information was computed, from condition two relative to the condition one of SOT. The trend of less activity was noted in condition two relatives to the condition one, which means that the participants of the study used more cortical sources in the baseline, i.e. condition one of SOT where visual, vestibular, and somatosensory sources were available than in condition two, where the visual influence was isolated to get somatosensory influence. Further, both the groups exhibited higher alpha activity trend. However, higher alpha activity leads to lowering of the beta and gamma activity (Wittenberg, Thompson, Nam, & Franz, 2017). Apart from this, alpha activity played a significant role in balancing the posture (Hülsdünker, Mierau, & Strüder, 2016; Mierau *et al.*, 2017), which got increased in our findings. Moreover, both groups exhibited less activity, due to which both groups showed less postural balance ability, which is caused by isolation of visual information while balancing the posture as stated by Barry & Blasio (2017). Higher alpha activity is also reported by Percio *et al.* (2007) in eyes closed conditions postural balance.

Delta activity in frontal lobe symbolises cortical representations of changing sensory conditions in postural tasks (Ozdemir, Contreras-Vidal, Lee, & Paloski, 2016; Harmony, 2013). Alternatively, beta activity in frontal lobe reflects the large-scale communication between sensory-motor and other areas of cortex under somatosensation (Kilavik *et al.,* 2013). On the other hand, gamma activity in occipital lobe showed the communication with the different region to accomplish the task (Fries, 2009a), which is related to the communication to the different areas of the cortex (Fries, 2009b) and attention function in the occipital lobe (Tallon-Baudry, Bertrand, Hénaff, Isnard, & Fischer, 2005).

In the present case, the alteration in the sensory condition could be responsible for the less delta activity. Further, the posture balance of senior participants under somatosensory influence needs large-scale communication between sensory-motor and other areas of cortex shown by higher beta activity in the frontal lobe. Besides this, the higher beta activity also represents a contraction of the muscles (Jacobs *et al.,* 2015), which was witnessed due to high sway in the senior participants in the current study. Additionally, this occipital lobe showed higher sensory-motor coordination, with the activation of the primary visual cortex which also guided the motor action in the space (Milner & Goodale, 2008; Ungerleider & Haxby, 1994). Thus, under the somatosensory influence, seniors used more cognitive sources in frontal and occipital lobe to balance the posture.

In previous studies, Ozdemir, Contreras-Vidal, Lee, & Paloski (2016) reported higher delta activity in the frontal lobe of the seniors due to cognitive load. Whereas, in our study, there was no cognitive load but followed by changes in sensory conditions during postural balance. Further, Slobounov, Ray, Johnson, Slobounov, & Newell (2015); Thibault, Lifshitz, Jones, & Raz (2014) along with Thibault, Lifshitz, Jones, & Raz (2014), stated higher beta activity in the frontal lobe leading to difficulty in postural balance task. Similarly, Zhavoronkova *et al.* (2012) described an increase in beta activity in frontal lobe during complicated balance condition. Additionally, an increased gamma was reported in the occipital lobe by Chang *et al.* 2016 when the participants experienced an unexpected response while balancing the posture.

The functional localisation was computed separately for young and senior participants due to the statistical limitations of the eLORETA software. Young participants showed a decline in gamma, beta, theta, and delta activities and an increase in alpha activity. In contrast, senior participants of the study showed no decline in any activity instead exhibited only a higher alpha activity. These findings are in line with the power spectrum where participants showed higher activity in the baseline as compared with the somatosensory influence.

The effect of aging was interpreted from the eLORETA results of condition one and the results of condition two in consideration of functional neuroanatomy for posture balance of Loram, (2015) & Takakusaki (2017b), Seniors exhibited higher gamma activity in the primary visual cortex including occipital lobe, which is in line with the results of the power spectrum under somatosensory condition. Beside this, gamma activity in the posterior parietal cortex can be due to effect of aging on visuo-motor integration (Kim, Park, Byun, Park, & Kim, 2014)(Gwin, Gramann, Makeig, & Ferris, 2011) and gamma activity in the cortex can be due to a decline in visuo-motor integration (Gwin et al., 2011). The decline in visuo-motor integration and less delta activity could be a result of absence of vision to get the somatosensory influence on the postural balance. Which can make difficulty in the visuo-motor integration and less delta activity Can represents cortical representations of changing sensory conditions in postural tasks(Ozdemir, Contreras-Vidal, Lee, & Paloski, 2016 ; Harmony, 2013) and theta activity error monitoring during motor performance (Slobounov, Ray, Johnson, Slobounov, & Newell, 2015; Chang, Yang, Yang, & Chern, 2016).

Primary sensory cortex, supplementary motor area and primary motor cortex also showed less theta activity in seniors, which mean seniors recruits less cortical sources to stabilize the posture (Slobounov, Teel, & Newell, 2013). Besides this higher gamma activity retained by the seniors in medial frontal gyrus and posterior cingulate is another evidence we found regarding the activity of DMN (Uddin, Kelly, Biswal, Castellanos, & Milham, 2009) during balance the posture. x Higher gamma activity in anterior cingulate and supplementary motor area and prefrontal cortex seems to play a role of compensation to stabilise the posture. Further, the role of the insula, middle temporal gyrus and superior temporal gyrus to balance the posture in relation to processing sensory signals was also identified by Zwergal et al. 2012. These could be reasons that the higher gamma activity was retained by seniors in the baseline condition one of SOT.

6.4.1.1 Linear connectivity

The eLORETA provided the information on the existence of a difference in linear connectivity during postural balance between senior and young participants undergoing sensory organisation test. Young participants showed less linear connectivity in beta activity between middle frontal gyrus BA11: responsible for working and spatial memory (Peach & Shapiro, 2012) and parahippocampal Gyrus BA 28: associated with visuospatial processing and episodic memory (Elissa. Aminoff, Kestutis Kveraga, 2013) under the influence of somatosensory to balance the posture. Both areas were also found to be responsible for visuospatial navigation (Jahn & Zwergal, 2010). Parahippocampal and middle frontal gyrus connectivity were related to default mode network DMN (Xu, Yuan, & Lei, 2016b), and the less connectivity in beta frequency showed less activity of DMN in the default mode network. Deactivated DMN during task-oriented processes serves an indicator of the attention for the task (Raichle *et al.,* 2001). In the present case, this connectivity showed higher internal attention while higher beta activity in posterior cingulate was also reported in condition one of SOT which is the node of the DMN, thereby further supporting the result of DMN activation in the senior participants of study during posture balance.

We found linear connectivity only under the absence of visual information because of a stable base of support , in the case of an unstable support surface, the vestibular system takes on the significant control in the maintenance of an upright posture to avoid the postural sway (Nashner, 1982).

The senior participants used less internal processing and attention abilities in the frontal lobe but utilised higher sources to manage sensory-motor task in the frontal lobe. In functional localisation seniors retain higher gamma activity under the influence of somatosensory influence to counter the less theta activity and active DMN. In focus of the results obtained in the present study, the null hypothesis (7H0) was rejected, while the alternative hypothesis (7H1) was accepted, which in turn indicated that with the progress of the aging process higher cortical sources were employed in seniors than in young people during posture balance under the somatosensory influence.

6.4.2 Visual influence

In the frontal lobe of the cortex, senior participants showed less delta and theta, but higher beta and gamma activity in comparison to the young participants. Further, the visual influence was computed from condition four of SOT concerning condition one, which is baseline and static postural balance. In the condition four, the frontal lobe of seniors showed less delta, theta, and alpha activity with higher beta and gamma activity trends in relation to baseline. Thus, the above-stated changes in the frequencies were found, from these changes of activities.

The results of visual influence revealed that the senior participants depend on the visual system to balance the posture. Less theta activity was found in the frontal lobe during condition one which was same as condition one of SOT, while young participants generate higher theta activity to balance the posture under visual influence (Slobounov *et al.,* 2013), one leg postural challenging task and (Semyon Slobounov, Cao, Jaiswal, & Newell, 2009c) and walking on the beam (Sipp, Gwin, Makeig, & Ferris, 2013). On the other hand, the seniors exhibited less delta and higher beta activity, where lower delta activity could be due to change of sensory influence, and higher beta could be due to somatosensation. Further, the force plates were swayed, with participants of reference study under the visual condition. As the seniors sway more than young participants, thus, they use more somatosensation to stabilise the posture, being discussed under the somatosensory part. The major significance is of the higher gamma activity, which can be generated to stabilise the posture as a compensatory postural adjustment (S. Slobounov *et al.,* 2005). It also plays a role in communicating with the different region in the cortex to accomplish a complex motor task (Fries, 2009; Teixeira *et al.,* 2010)

Under the visual condition, seniors showed less error detection ability, change of sensory influence, higher somatosensation, and compensatory postural adjustment as compared to young participants. Ozdemir, Contreras-Vidal, Lee, & Paloski (2016), reported higher delta and theta activity under cognitive load. In the current study, there is no cognitive load so activity can be less. Additionally, senior participants showed less postural balance ability, which gave the perception of the difficulty in the completion of a task than young participants. These results were in accordance with the results of Zharikova, Kushnir, & Mikhalkova (2012) who reported a higher beta in frontal lobe associated with the difficulty of the task. Further, higher gamma activity during posture balance was reported by Ozdemir, Contreras-Vidal, & Paloski (2018) in seniors as compared to the young participants.

Under the visual influence, seniors presented less internal processing with less delta and theta activity with beta and gamma activities as compensation in the frontal lobe. Even though seniors showed high cortical modulation during visual influence, the postural balance abilities get reduced as compared to the young participants. Further, the aging process reduces the somatosensory, and vestibular function (Lord, Clark, & Webster, 1991; Lord & Ward, 1994; Peterka & Black, 1990). Thus, senior participants have to rely more on the visual system (Choy, Brauer, & Nitz, 2003) for maintaining balance. Additionally, no significant results were obtained, in the functional localisation in both groups in consideration of baseline which is in the line of the above findings. As shown by the results of the power spectrum, seniors used high cortical sources in frontal lobe to balance the posture, we reject the null hypothesis (8H0), while accepting the alternative hypothesis (8H1).

6.4.3 Vestibular influence

The postural balance under vestibular influence showed high recruitment of cortical sources by the senior participants to balance the posture as compared to the young participants in the current study. However, seniors showed higher alpha, beta, and gamma activities in both frontal and temporal lobe. Moreover, seniors also demonstrated high alpha and gamma activities in the central, parietal, and occipital lobe. The condition one of SOT and condition five of SOT were used to compute the vestibular influence on the postural control. Young participants showed reduced beta and gamma activities than senior participants, from the baseline, under the vestibular influence. Further, seniors used higher beta and gamma activities, but these activities were still less than the baseline. Taking into consideration the alpha activity of both groups increased the alpha activity in condition five of SOT, but seniors increased more alpha activity as compared to young participants, due to which they exhibited higher alpha activity than young participants.

Higher beta activity explains the utilisation of large-scale communication by seniors between sensorimotor and other areas of cortex under somatosensation (Kilavik *et al.,* 2013) in the frontal and temporal lobe. Further, the higher the sway in the posture also contributes to it. On the other hand, higher gamma activity gains information about communication with the different region in the cortex to accomplish a complex motor task (Fries, 2009; Teixeira *et al.,* 2010). Alternatively, the alpha activity reflects the presence of higher attention (Aftanas & Golocheikine, 2001; Klimesch, 2012; Mulholland & Runnals, 1962) and difficulty of the task for the seniors during postural balance (Petrofsky & Khowailed, 2014; Slobounov, Hallett, Cao, & Newell, 2008). In the study carried out by Pirini, Mancini, Farella, & Chiari (2011) alpha activity increased in the athletes in closed-eye conditions during one and two leg balance task, compared to non-athletes. Therefore, the alpha activity could be interpreted, as attention and access to the stored information function (Aftanas & Golocheikine, 2001; Klimesch, 2012; Mulholland & Runnals, 1962). In the current study, seniors showed higher alpha activity, but it seems that the amount of quality of sensory feedback decreases like in the study carried out by Tse *et al.* (2013), where alpha, beta, and sigma activities increase with the altered sensory surface. Nevertheless, it could also be a requirement of high attention (Aftanas & Golocheikine, 2001; Klimesch, 2012; Mulholland & Runnals, 1962). Primarily, increased gamma activity was also reported in seniors during vestibular influence as compared to young people (Ozdemir *et al.,* 2018)

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The functional localisation was computed, under the vestibular influence. In this context, young participants showed reduced gamma, beta, and delta activities and increased theta and alpha activities in the structure. Whereas, senior participants exhibited reduced beta activity and increased alpha activity in the structure. Alpha activity increases at a certain level with decreased the beta activity. (Klimesch, 2012). The interpretation of the vestibular influence on the structure-activity also made from the condition one of SOT and condition five of the SOT. The senior participants used higher gamma activity in the sensory areas such as insula, middle temporal gyrus, inferior parietal lobule and superior temporal gyrus under the vestibular influence. Similar findings were also reported by Zwergal et al. 2012 and the proposed that it is the cortical response of agingPosterior Cingulate note of DMN activity (Xu, Yuan, & Lei, 2016) also showed same trends of activity, which give the perception of less internal attention (Raichle et al., 2001). Above mentioned changes in activities are also found in our study under somatosensory feedback whereas higher gamma activity was found in cingulate gyrus under the vestibular influence. Cingulate gyrus generally involves in the sensory-motor process (Taylor, Seminowicz, & Davis, 2009).

According to EROI senior participants showed higher gamma activity in the primary sensory cortex, supplementary motor and primary motor cortex. Gamma activity is a predictor of mirroring the binding of cortical areas to preparation, perception and execution of movement for the motor task. (Teixeira et al., 2010). Further gamma activity can be increased with the decline in postural balance (Slobounov, Tutweiler, Slobounova, Rearick, & Ray, 2000). The similar trend is found in our results, where senior showed less postural balance abilities under vestibular influence compared with young participants. The higher gamma activity in the central lobe was also reported in the senior people under the vestibular influence by (Ozdemir, Contreras-Vidal, & Paloski, 2018).

Senior participants used high attention abilities, with increased levels of cortical modulation and sensorimotor integration in the frontal and temporal lobe, using higher cortical sources in central and parietal lobe as compared to young participants. Further sensory-motor areas showed higher activity along with PIVC, DMN as it was challenging for seniors.The challenging nature of the task is also confirmed by the higher gamma activity in the cingulate gyrus. From these results, the use of higher cortical sources to balance the posture under the vestibular influence by the seniors, in comparison to young participants of the study, was retrieved. Thus, the null hypothesis (9H0) was rejected, with subsequent acceptance of the alternative hypothesis (9H1). Considering the result of the current study, one can conclude that the effect of aging in the static postural balance followed during sensory integration to balance the posture. The young participants exhibited a decrease in more number of activities as the influence of each sensory information varied, whereas seniors showed a decrease in less number of activities. Apart from this, one can also derive the conclusion that senior participants use more high cortical sources during postural balance and under sensors integration to balance the posture.

6.5 *Summary and Conclusion*

We claim to be the pioneers in discussing the effect of aging on the cortical activity in detail along with the postural balance abilities. The senior participants of the study exhibited a decline in balancing abilities along with enhanced dependence on hip strategies as compared to young participants of the study. The senior participants evinced high-level cortical modulation to balance the posture, whereas the seniors exhibited less error detection abilities along with limited internal processing in the cortex. To compensate for these function, they used augmented sources to manage sensory-motor task from temporal, central, and occipital lobe along with increased cognitive function involvement. Mainly, the current study was based, on the electroencephalography frequency-based analysis, including many controversial interpretations found in the literature. In this context, we have reported a beneficiary method to interpret the results using the correlation of frequencies and the postural balance.

In functional localisation of cortical activity, senior participants exhibited a reduced error detection abilities in the primary visual cortex and posterior parietal cortex. Primary sensory cortex also showed less error detection ability. Nevertheless, it utilised more sources than young participants to balance the posture. Supplementary motor area and primary motor cortex used higher sources to stabilise the posture which could also be connected, with basal ganglia, hippocampus, and lower CNS system, which carry the signals regarding the movement of the body (Leisman, Braun-Benjamin, & Melillo, 2014). In addition to this, prefrontal cortex showed reduced attention and error detection abilities but utilised more resources for working, spatial memory, coordination, and actions of sensory systems. The noticeable finding is about the beta activity in posterior cingulate, which is a central note of the default mode network (DMN) and imparts a negative impact on the postural control, while higher activity in this structure can reduce internal attention. Further, the functions of postural balance could be supported, through higher gamma activity in inferior frontal gyrus, superior frontal gyrus, and middle frontal gyrus. The linear connective results also revealed that DMN has a role in postural balance abilities and with the progress in the aging process it becomes active, thereby causing less internal attention.

Additionally, the role of sensory integration in balancing the posture was interesting, where young participants showed better sensory integration to balance the posture along with the dominance of the somatosensory system, while seniors showed dependency on the visual system. Apart from this, senior participants also showed a reduced amount of postural balance abilities under the influence of visual and vestibular system, in comparison to young participants of the study.

Overviewing the cortical activity under the somatosensory influence to balance the posture, the senior participants used less internal processing and attention abilities in the frontal lobe but utilised higher sources to manage sensory-motor task in the frontal lobe. In functional localisation of cortical activity, the young participants displayed a decline in the use of cortical sources as compared to the static postural balance concerning higher frequencies. However, the attention abilities undergo an increase, which interprets the rise of alpha activity. Nevertheless, senior participants showed less decline in the sources which they used for the baseline, as they were more dependent on attention abilities than on the baseline. Further prefrontal cortex gets highly active in the seniors along with sensory areas like PIVC and us also evident the active DMN in seniors. In the current study, we used Low-Resolution Brain Electromagnetic Tomography method for the first time and observed the activity in the new cortical areas introducing unexplored domains like limbic lobe and sub-lobar, which will open doors for further studies.

Under the visual influence, senior participants used decreased internal processing and attention abilities, showing less error detection abilities in the frontal lobe. Indeed, they used higher sources to manage sensory-motor task in the frontal lobe. Further, in functional localisation, we found no significant differences. Balancing the posture under the vestibular influence, seniors used high attention abilities with increased levels of cortical modulation and sensorimotor integration in the frontal and temporal lobe, using large sources in central and parietal lobe as compared to young participants. Additionally, in the functional localisation of cortical activity, the young participants exhibited a decline in the cortical sources, when compared to the static postural balance, whereas the senior participants used enhanced resources like the attention to balance the posture under the influence of vestibular influence and reduce beta activity. Motor and sensory cortex showed high gamma activity to balance the posture

Our study also gives an overview on the basis of our results and the literature .The affected areas from the aging showed either low alpha activity or higher gamma activity, which can be further explored with sensory-motor task to understand the cortical response with the aging process.

In a nutshell, this study reveals that the aging process decreases the postural balance along with the sensory integration abilities. Senior participants used more cortical sources to balance the posture even under the somatosensory, visual, and vestibular influence when compared with young participants. In fact, under the sensory influence, young participants reduced the cortical activities as compared to baseline because they had less information to process, and senior participants did not reduce the higher activity under the influence of sensory integration. Our results further showed the decline in cognitive abilities, sensory integration abilities, and also in the sensory-motor track with aging. To improve the postural balance of seniors, only cognitive training or physical activity without cognitive load is insufficient. Therefore, it leads to the proposal that the training should include cognitive abilities in physical activity along with sensory influence. For best intervention, exercises like dance training with music, or running with visual effects should be given preference, which we claim to be more useful to improve postural balance abilities as reported before also (Rehfeld *et al.,* 2017).

7 Limitation of study

The current study is cross-sectional experimental along with a limited number of participants. Moreover, the cortical structure data of the participants were not available to make a more detailed interpretation. This is the first study of its kind in which we use the voxel-to-voxel approach with eLORETA software along with EEG data. We used the cognitive functions of the structure to make the interpretations of our results. 32 channel EEG system was used, so the resolution was not higher as the precision of the localisation of the EEG signal using these techniques increases with increasing number of channels (Sohrabpour *et al.*, 2015). We also found out the cortical response under the sensory influence to balance. To realise this, participants closed their eyes to get a somatosensory and vestibular response, so the response of closed eyes exists in the cortical activity data. We conclude with the statement that there is no conflict of interest and limitation of the current study.

8 Future recommendations

Postural balance requires further exploration, mainly focusing on the role of the cortex. It was proposed to investigate postural balance with event-related activity in the subcortical and cortical regions without defining any one region of interest because several questions need to be answered and a few areas like the temporal lobe need special attention which is reported rarely in the studies related to balance. Further, direction connectivity can provide the flow of the signals and LORETA is believed to be a reliable tool to identify the activities of the subcortical regions.

The influence of sensory influence on postural balance also requires a further intense study with event-related activities. In addition to the cortical response of the seniors, it may also be studied to event-related activities and directional connectivity. The findings of the current study take us to another question that the impact of physical activity on postural balance with aging and can be reconsidered in an intervention study together with changes in structure and cortical and subcortical activities. Besides physical activity, balance training is also helpful in neuroplasticity (Rogge *et al.*, 2018).

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Appendix A

Certificate of consent

I have read the foregoing information. I have had the opportunity to ask questions about it, and any questions that I have asked have been answered to my satisfaction. I consent voluntarily to participate as a participant in this research.

Name of Participant ________________________**Signature** ____________

Date ___________________________ **(Day/month/year)**

I have witnessed the accurate reading of the consent form to the potential participant, and the individual has had the opportunity to ask questions. I confirm that the individual has given consent freely.

Name of witness__________________ **Thumb print of participant**

Signature of witness ______________________

Date ________________________

Statement by the researcher.

I have accurately read out the information sheet to the potential participant, and to the best of my ability made sure that the participant understands that the following will be done:

1. Application of Electroencephalography (EEG)

2. Sensory organization test on NeuroCom Balance Master Systems

I confirm that the participant was given an opportunity to ask questions about the study, and all the questions asked by the participant have been answered correctly and to the best of my ability. I confirm that the individual has not been coerced into giving consent, and the consent has been given freely and voluntarily.

A copy of this ICF has been provided to the participant.

Name of Researcher ________________________

Signature of Researcher __________________________

Date ___________________________

Appendix B

Mini-Mental Status-Test (MMST)

Name und Vorname

Datum

1. Orientierung

In welchem Jahr leben wir? Welche ☐
Jahreszeit ist jetzt? Welches Datum ☐
haben wir heute? Welchen Monat ☐
haben wir? ☐
In welchem Bundesland sind wir hier? In ☐
welchem Land? ☐
In welcher Ortschaft? ☐
Wo sind wir (in welcher Praxis / Altenheim)? Auf ☐
welchen Stockwerk? ☐

2. Merkfähigkeit

Fragen Sie den Patienten, ob Sie sein Gedächtnis prüfen dürfen. Nennen Sie dann drei verschieden- artige Dinge klar und langsam (ca 1 pro sec) "Zitrone, Schlüssel, Ball". Nachdem Sie allle drei Worte ausgesprochen haben, soll der Patient sie wiederholen. Die erste Wiederholung bestimmt die Wertung (vergeben Sie für jedes wiederholte Wort einen Punkt), doch wiederholen Sie den Versuch, bis der Patient alle drei Wörter nachspre- chen kann. Maximal gibt es 5 Versuche. Wenn ein Patient nicht alle drei Wörter lernt, kann das Erinnern nicht sinnvoll geprüft werden.

Punkte 0-3 ☐

3. Aufmerksamkeit und Rechnen

Bitten Sie den Patienten, bei 100 beginnend in 7er Schritten rückwärts zu zählen. Halten Sie nach 5 Substraktionen (93, 86, 79, 72, 65) an und zählen Sie die in der richtigen Reihenfolge gegebenen Antworten. Bitten Sie daraufhin das Wort "Preis" rückwärts zu buchstabieren. Die Wertung entspricht der Anzahl von Buchstaben in der richtigen Reihen- folge (z.B. SIERP=5, SIREP=3). Die höhere der beiden Wertungen wird gezählt.

Punkte 0-5 ☐

4.Erinnern

Fragen Sie den Patienten, ob er die Wörter noch weiß, die er vorhin auswendig lernen sollte. Geben Sie einen Punkt für jedes richtige Wort.

Punkte 0-3 ☐

5. Benennen

Zeigen Sie dem Patienten eine Armbanduhr und fragen Sie ihn was das ist. Wiederholen Sie die Aufgabe mit einem Bleistift. Geben Sie einen Punkt für jeden erfüllten Aufgabenteil.

Punkte 0-3 ☐

6. Wiederholen

Bitten Sie den Patienten, den Ausdruck " Kein Wenn und Aber" nachzusprechen. Nur ein Versuch ist erlaubt.

Punkte 0-1 ☐

7. Dreiteiliger Befehl

Lassen Sie den Patienten den folgenden Befehl ausführen. " Nehmen Sie ein Blatt in die Hand, falten Sie es in der Mitte und legen Sie es auf den Boden." Geben Sie einen richtigen Punkt für jeden richtig ausgeführten Befehl.

Punkte 0-3 ☐

8. Reagieren

Schreiben Sie auf ein weißes Blatt in grossen Buchstaben: "Schließen Sie die Augen". Der Patient soll den Text lesen und ausführen. Geben Sie einen Punkt, wenn der Patient die Augen schließt.

Punkte 0-1 ☐

9. Schreiben

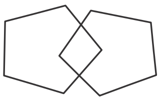
Geben Sie dem Patienten ein weißes Blatt, auf dem er für Sie einen Satz schreiben soll. Diktieren Sie den Satz nicht, er soll spontan geschrieben wer- den. Der Satz muß ein Subjekt und ein Verb enthalten und einen Sinn ergeben. Konkrete Grammatik und Interpunktion werden nicht verlangt.

Punkte 0-1 ☐

10. Abzeichnen

Zeichnen Sie auf ein weißes Blatt zwei sich über- schneidene Fünfecke und bitten Sie den Patienten, die Figur genau abzuzeichnen. Alle 10 Ecken müßen vorhanden sein und 2 müßen sich über- schneiden, um als ein Punkt zu zählen. Zittern und Verdrehen der Figur sind nicht wesentlich.

Punkte 0-1 ☐



Summe der Punkte .... ☐

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Appendix C

Statistics are stated in appendix C including postural balance under six conditions of SOT, postural balance strategies during static postural balance , postural balance under somatosensory, visual and vestibular influence, EEG Power spectrum under condition 1, 2, 4 and 5 of SOT and EEG power spectrum during postural balance under somatosensory, visual and vestibular influence. The following tables are included in appendix C.

Tab C-1: Parametric statistics of postural balance and strategies percentage during static condition

		Levene's Test for Equality of Variances		**t-test for Equality of Means**						
		F	**Sig.**	**t**	**df**	**Sig. (2-tailed)**	**Mean Difference**	**Std. Error Difference**	**95% Confidence Interval of the Difference**	
									Lower	**Upper**
Postural balance	Equal variances assumed	15.86	0.00	4.51	38.00	0.000	2.13	0.47	1.18	3.09
	Equal variances not assumed			4.51	24.59	0.000	2.13	0.47	1.16	3.11
Postural balance strategies	Equal variances assumed	1.70	0.20	2.50	38.00	0.017	0.58	0.23	0.11	1.06
	Equal variances not assumed			2.50	36.54	0.017	0.58	0.23	0.11	1.06
Sensory organisation test	Equal variances assumed	9.99	0.00	8.85	38.00	0.000	9.60	1.09	7.40	11.80
	Equal variances not assumed			8.85	24.93	0.000	9.60	1.09	7.37	11.84

Tab C-2: Parametric statistics of power spectrum during static postural balance (Condition 1 of SOT)

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Frontal Lobe (Delta)	Equal variances assumed	0.48	0.49	0.12	38.00	0.906	0.07	0.58	-1.10	1.23
	Equal variances not assumed			0.12	36.74	0.906	0.07	0.58	-1.10	1.23
Central Lobe (Delta)	Equal variances assumed	2.23	0.14	0.99	38.00	0.328	0.44	0.44	-0.46	1.34
	Equal variances not assumed			0.99	34.79	0.329	0.44	0.44	-0.46	1.34
Frontal Lobe (Theta)	Equal variances assumed	2.58	0.12	5.18	38.00	0.000	0.75	0.15	0.46	1.05
	Equal variances not assumed			5.18	36.05	0.000	0.75	0.15	0.46	1.05
Temporal Lobe (Theta)	Equal variances assumed	0.34	0.56	6.81	38.00	0.000	0.94	0.14	0.66	1.22
	Equal variances not assumed			6.81	37.24	0.000	0.94	0.14	0.66	1.22
Central Lobe (Theta)	Equal variances assumed	11.10	0.00	5.32	38.00	0.000	0.77	0.14	0.48	1.06
	Equal variances not assumed			5.32	28.12	0.000	0.77	0.14	0.47	1.06
Parietal Lobe (Theta)	Equal variances assumed	3.28	0.08	6.04	38.00	0.000	0.76	0.13	0.51	1.02
	Equal variances not assumed			6.04	32.14	0.000	0.76	0.13	0.51	1.02

Frontal Lobe (Alpha)	Equal variances assumed	6.65	0.01	-0.98	38.00	0.333	-0.13	0.14	-0.41	0.14
	Equal variances not assumed			-0.98	27.72	0.335	-0.13	0.14	-0.41	0.15
Temporal Lobe (Alpha)	Equal variances assumed	9.21	0.00	-0.82	38.00	0.420	-0.17	0.21	-0.59	0.25
	Equal variances not assumed			-0.82	29.44	0.421	-0.17	0.21	-0.59	0.26
Central Lobe (Alpha)	Equal variances assumed	3.91	0.06	-0.07	38.00	0.946	-0.01	0.17	-0.35	0.33
	Equal variances not assumed			-0.07	31.36	0.946	-0.01	0.17	-0.35	0.33
Parietal Lobe (Alpha)	Equal variances assumed	18.04	0.00	-1.55	38.00	0.130	-0.37	0.24	-0.84	0.11
	Equal variances not assumed			-1.55	24.31	0.134	-0.37	0.24	-0.85	0.12
Occipital Lobe (Alpha)	Equal variances assumed	16.21	0.00	-0.75	38.00	0.461	-0.17	0.23	-0.65	0.30
	Equal variances not assumed			-0.75	23.53	0.463	-0.17	0.23	-0.65	0.31
Frontal Lobe (Gamma)	Equal variances assumed	0.01	0.93	-1.82	38.00	0.076	-0.03	0.02	-0.06	0.00
	Equal variances not assumed			-1.82	37.75	0.076	-0.03	0.02	-0.06	0.00
Temporal Lobe (Gamma)	Equal variances assumed	0.01	0.94	-3.01	38.00	0.005	-0.07	0.02	-0.12	-0.02
	Equal variances not assumed			-3.01	37.81	0.005	-0.07	0.02	-0.12	-0.02
Central Lobe (Gamma)	Equal variances assumed	0.04	0.84	-0.17	38.00	0.865	0.00	0.01	-0.03	0.02

	Equal variances not assumed			-0.17	37.49	0.865	0.00	0.01	-0.03	0.02
Parietal Lobe (Gamma)	Equal variances assumed	0.37	0.55	-0.62	38.00	0.538	-0.01	0.02	-0.04	0.02
	Equal variances not assumed			-0.62	35.66	0.538	-0.01	0.02	-0.04	0.02
Occipital Lobe (Gamma)	Equal variances assumed	7.33	0.01	-2.31	38.00	0.026	-0.06	0.03	-0.11	-0.01
	Equal variances not assumed			-2.31	28.51	0.028	-0.06	0.03	-0.11	-0.01

Tab C-3: Non parametric statistics of power spectrum during static postural balance (Condition 1 of SOT)

	Temporal Lobe (Delta)	**Parietal Lobe (Delta)**	**Occipital Lobe (Delta)**	**Occipital Lobe (Theta)**	**Frontal Lobe (Beta)**	**Temporal Lobe (Beta)**	**Central Lobe (Beta)**	**Parietal Lobe (Beta)**	**Occipital Lobe (Beta)**
Mann-Whitney U	82.00	78.00	78.00	29.00	178.00	144.00	82.00	73.00	111.00
Wilcoxon W	292.00	288.00	288.00	239.00	388.00	354.00	292.00	283.00	321.00
Z	-3.19	-3.30	-3.30	-4.63	-0.60	-1.51	-3.19	-3.44	-2.41
Asymp. Sig. (2-tailed)	.001	.001	.001	.000	.552	.130	.001	.001	.016
Exact Sig. [2*(1-tailed Sig.)]	0.001	0.001	0.001	0.000	0.565	0.134	0.001	0.000	0.015

Tab C-4: Parametric statistics postural balance conditions of SOT

		Levene's Test for Equality of Variances		**t-test for Equality of Means**						
		F	**Sig.**	**t**	**df**	**Sig. (2-tailed)**	**Mean Difference**	**Std. Error Difference**	**95% Confidence Interval of the Difference**	
									Lower	**Upper**
Postural balance (C3)	Equal variances assumed	2.56	0.12	2.80	38.00	0.008	2.33	0.83	0.64	4.02
	Equal variances not assumed			2.80	34.48	0.008	2.33	0.83	0.64	4.03
Postural balance (C5)	Equal variances assumed	10.06	0.00	6.53	38.00	0.000	13.67	2.09	9.43	17.90
	Equal variances not assumed			6.53	23.85	0.000	13.67	2.09	9.35	17.99
Postural balance (C6)	Equal variances assumed	10.45	0.00	7.09	38.00	0.000	20.02	2.82	14.30	25.73
	Equal variances not assumed			7.09	25.93	0.000	20.02	2.82	14.21	25.82

Tab C-5: Non parametric statistics postural balance conditions of SOT

	Postural balance (C2)	**Postural balance (C4)**
Mann-Whitney U	113.50	23.00
Wilcoxon W	323.50	233.00
Z	-2.35	-4.79
Asymp. Sig. (2-tailed)	0.019	0.000
Exact Sig. [2*(1-tailed Sig.)]	0.018	0.000

Tab C-6: Parametric statistics of power spectrum during static postural balance (Condition 2 of SOT)

		Levene's Test for Equality of Variances		**t-test for Equality of Means**						
		F	**Sig.**	**t**	**df**	**Sig. (2-tailed)**	**Mean Difference**	**Std. Error Difference**	**95% Confidence Interval of the Difference**	
									Lower	**Upper**
Frontal Lobe (Delta)	Equal variances assumed	1.28	0.26	2.05	38.00	0.047	1.33	0.65	0.02	2.64
	Equal variances not assumed			2.05	36.21	0.048	1.33	0.65	0.02	2.64
Central Lobe (Delta)	Equal variances assumed	1.20	0.28	1.83	38.00	0.074	0.85	0.46	-0.09	1.79
	Equal variances not assumed			1.83	35.45	0.075	0.85	0.46	-0.09	1.79
Parietal Lobe (Delta)	Equal variances assumed	0.10	0.75	3.26	38.00	0.002	1.47	0.45	0.56	2.39
	Equal variances not assumed			3.26	37.94	0.002	1.47	0.45	0.56	2.39
Frontal Lobe (Theta)	Equal variances assumed	3.00	0.09	6.45	38.00	0.000	0.87	0.13	0.60	1.14
	Equal variances not assumed			6.45	31.40	0.000	0.87	0.13	0.59	1.14
Temporal Lobe (Theta)	Equal variances assumed	8.71	0.01	6.55	38.00	0.000	0.96	0.15	0.66	1.25
	Equal variances not assumed			6.55	28.84	0.000	0.96	0.15	0.66	1.26
Central Lobe (Theta)	Equal variances assumed	7.04	0.01	5.70	38.00	0.000	0.84	0.15	0.54	1.14
	Equal variances not assumed			5.70	29.77	0.000	0.84	0.15	0.54	1.14

Parietal Lobe (Theta)	Equal variances assumed	6.26	0.02	3.85	38.00	0.000	0.58	0.15	0.28	0.89
	Equal variances not assumed			3.85	29.56	0.001	0.58	0.15	0.27	0.89
Occipital Lobe (Theta)	Equal variances assumed	2.44	0.13	3.35	38.00	0.002	0.54	0.16	0.21	0.86
	Equal variances not assumed			3.35	31.57	0.002	0.54	0.16	0.21	0.86
Temporal Lobe (Alpha)	Equal variances assumed	6.12	0.02	-0.71	38.00	0.482	-0.26	0.37	-1.01	0.48
	Equal variances not assumed			-0.71	30.52	0.483	-0.26	0.37	-1.01	0.49
Occipital Lobe (Alpha)	Equal variances assumed	1.69	0.20	0.55	38.00	0.585	0.31	0.56	-0.83	1.45
	Equal variances not assumed			0.55	35.15	0.586	0.31	0.56	-0.83	1.45
Temporal Lobe (Beta)	Equal variances assumed	1.86	0.18	-2.79	38.00	0.008	-0.11	0.04	-0.19	-0.03
	Equal variances not assumed			-2.79	35.03	0.008	-0.11	0.04	-0.19	-0.03
Central Lobe (Beta)	Equal variances assumed	7.52	0.01	-3.75	38.00	0.001	-0.16	0.04	-0.25	-0.07
	Equal variances not assumed			-3.75	30.76	0.001	-0.16	0.04	-0.25	-0.07
Parietal Lobe (Beta)	Equal variances assumed	6.34	0.02	-2.70	38.00	0.010	-0.14	0.05	-0.25	-0.04
	Equal variances not assumed			-2.70	27.21	0.012	-0.14	0.05	-0.25	-0.03
Frontal Lobe (Gamma)	Equal variances assumed	3.06	0.09	-3.64	38.00	0.001	-0.05	0.01	-0.07	-0.02

	Equal variances not assumed			-3.64	34.16	0.001	-0.05	0.01	-0.07	-0.02

Tab C-7: Non parametric statistics of power spectrum during static postural balance (Condition 2 of SOT)

	Temporal Lobe (Delta)	**Occipital Lobe (Delta)**	**Frontal Lobe (Alpha)**	**Central Lobe (Alpha)**	**Parietal Lobe (Alpha)**	**Frontal Lobe (Beta)**	**Occipital Lobe (Beta)**	**Temporal Lobe (Gamma)**	**Central Lobe (Gamma)**	**Parietal Lobe (Gamma)**	**Occipital Lobe (Gamma)**
Mann-Whitney U	79.00	87.00	198.00	170.00	196.00	104.00	132.00	100.00	128.00	140.00	94.00
Wilcoxon W	289.00	297.00	408.00	380.00	406.00	314.00	342.00	310.00	338.00	350.00	304.00
Z	-3.27	-3.06	-0.05	-0.81	-0.11	-2.60	-1.84	-2.71	-1.95	-1.62	-2.87
Asymp. Sig. (2-tailed)	0.001	0.002	0.957	0.417	0.914	0.009	0.066	0.007	0.051	0.105	0.004
Exact Sig. [2*(1-tailed Sig.)]	0.001	0.002	0.968	0.429	0.925	0.009	0.068	0.006	0.052	0.108	0.004

Tab C-8: Parametric statistics of power spectrum during condition four of SOT

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Frontal Lobe (Delta)	Equal variances assumed	1.05	0.31	1.90	38.00	0.065	0.99	0.52	-0.07	2.05
	Equal variances not assumed			1.90	36.64	0.065	0.99	0.52	-0.07	2.05
Central Lobe (Delta)	Equal variances assumed	1.69	0.20	1.11	38.00	0.275	0.43	0.39	-0.36	1.22
	Equal variances not assumed			1.11	35.11	0.276	0.43	0.39	-0.36	1.22
Occipital Lobe (Delta)	Equal variances assumed	1.04	0.32	3.68	38.00	0.001	1.68	0.46	0.75	2.60
	Equal variances not assumed			3.68	36.25	0.001	1.68	0.46	0.75	2.60
Frontal Lobe (Theta)	Equal variances assumed	9.59	0.00	7.27	38.00	0.000	1.07	0.15	0.77	1.37
	Equal variances not assumed			7.27	24.08	0.000	1.07	0.15	0.77	1.37
Temporal Lobe (Theta)	Equal variances assumed	0.32	0.58	5.46	38.00	0.000	0.86	0.16	0.54	1.17
	Equal variances not assumed			5.46	37.98	0.000	0.86	0.16	0.54	1.17
Central Lobe (Theta)	Equal variances assumed	5.62	0.02	-0.13	38.00	0.900	-0.02	0.14	-0.31	0.27
	Equal variances not assumed			-0.13	28.83	0.900	-0.02	0.14	-0.31	0.27

Parietal Lobe (Theta)	Equal variances assumed	10.23	0.00	-1.39	38.00	0.171	-0.34	0.24	-0.84	0.15
	Equal variances not assumed			-1.39	27.76	0.174	-0.34	0.24	-0.84	0.16
Occipital Lobe (Theta)	Equal variances assumed	11.73	0.00	0.36	38.00	0.724	0.05	0.14	-0.23	0.33
	Equal variances not assumed			0.36	26.87	0.725	0.05	0.14	-0.23	0.33
Central Lobe (Alpha)	Equal variances assumed	10.52	0.00	-0.56	38.00	0.581	-0.13	0.23	-0.58	0.33
	Equal variances not assumed			-0.56	25.11	0.583	-0.13	0.23	-0.59	0.34
Occipital Lobe (Alpha)	Equal variances assumed	9.81	0.00	0.47	38.00	0.641	0.10	0.21	-0.32	0.52
	Equal variances not assumed			0.47	28.29	0.642	0.10	0.21	-0.33	0.52
Frontal Lobe (Beta)	Equal variances assumed	0.79	0.38	-3.37	38.00	0.002	-0.10	0.03	-0.16	-0.04
	Equal variances not assumed			-3.37	36.78	0.002	-0.10	0.03	-0.16	-0.04
Temporal Lobe (Beta)	Equal variances assumed	0.50	0.49	-3.07	38.00	0.004	-0.10	0.03	-0.17	-0.03
	Equal variances not assumed			-3.07	37.35	0.004	-0.10	0.03	-0.17	-0.03
Central Lobe (Beta)	Equal variances assumed	1.29	0.26	-4.88	38.00	0.000	-0.18	0.04	-0.26	-0.11
	Equal variances not assumed			-4.88	36.53	0.000	-0.18	0.04	-0.26	-0.11
Parietal Lobe (Beta)	Equal variances assumed	0.05	0.83	-4.60	38.00	0.000	-0.18	0.04	-0.25	-0.10

	Equal variances not assumed			-4.60	37.15	0.000	-0.18	0.04	-0.25	-0.10
Occipital Lobe (Beta)	Equal variances assumed	0.85	0.36	-4.00	38.00	0.000	-0.14	0.03	-0.21	-0.07
	Equal variances not assumed			-4.00	35.53	0.000	-0.14	0.03	-0.21	-0.07
Frontal Lobe (Gamma)	Equal variances assumed	0.23	0.63	-4.61	38.00	0.000	-0.08	0.02	-0.11	-0.04
	Equal variances not assumed			-4.61	37.45	0.000	-0.08	0.02	-0.11	-0.04
Temporal Lobe (Gamma)	Equal variances assumed	0.00	0.97	-1.69	38.00	0.098	-0.04	0.03	-0.10	0.01
	Equal variances not assumed			-1.69	38.00	0.098	-0.04	0.03	-0.10	0.01
Parietal Lobe (Gamma)	Equal variances assumed	4.99	0.03	-2.00	38.00	0.053	-0.03	0.02	-0.07	0.00
	Equal variances not assumed			-2.00	33.76	0.053	-0.03	0.02	-0.07	0.00
Occipital Lobe (Gamma)	Equal variances assumed	12.35	0.00	-2.88	38.00	0.007	-0.07	0.02	-0.12	-0.02
	Equal variances not assumed			-2.88	26.02	0.008	-0.07	0.02	-0.12	-0.02

Tab C-9: Non parametric statistics of power spectrum during condition four of SOT

	Temporal Lobe (Delta)	Parietal Lobe (Delta)	Frontal Lobe (Alpha)	Temporal Lobe (Alpha)	Parietal Lobe (Alpha)	Central Lobe (Gamma)
Mann-Whitney U	101.00	89.00	196.00	178.00	176.00	142.00
Wilcoxon W	311.00	299.00	406.00	388.00	386.00	352.00
Z	-2.68	-3.00	-0.11	-0.60	-0.65	-1.57
Asymp. Sig. (2-tailed)	0.007	0.003	0.914	0.552	0.516	0.117
Exact Sig. [2*(1-tailed Sig.)]	0.007	0.002	0.925	0.565	0.529	0.121

Tab C-10: Parametric statistics of power spectrum during condition five of SOT

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Frontal Lobe (Delta)	Equal variances assumed	1.96	0.17	1.22	38.00	0.231	0.80	0.66	-0.53	2.13
	Equal variances not assumed			1.22	35.41	0.232	0.80	0.66	-0.53	2.13
Central Lobe (Delta)	Equal variances assumed	3.17	0.08	1.02	38.00	0.316	0.44	0.43	-0.44	1.32
	Equal variances not assumed			1.02	34.34	0.317	0.44	0.43	-0.44	1.32
Parietal Lobe (Delta)	Equal variances assumed	0.70	0.41	2.34	38.00	0.024	1.02	0.44	0.14	1.91

	Equal variances not assumed			2.34	36.52	0.025	1.02	0.44	0.14	1.91
Occipital Lobe (Delta)	Equal variances assumed	0.03	0.86	1.62	38.00	0.113	0.86	0.53	-0.21	1.93
	Equal variances not assumed			1.62	37.95	0.113	0.86	0.53	-0.21	1.93
Frontal Lobe (Theta)	Equal variances assumed	3.62	0.06	7.36	38.00	0.000	1.01	0.14	0.73	1.29
	Equal variances not assumed			7.36	34.33	0.000	1.01	0.14	0.73	1.29
Temporal Lobe (Theta)	Equal variances assumed	1.89	0.18	6.93	38.00	0.000	1.10	0.16	0.78	1.42
	Equal variances not assumed			6.93	33.71	0.000	1.10	0.16	0.78	1.42
Central Lobe (Theta)	Equal variances assumed	5.30	0.03	6.85	38.00	0.000	1.07	0.16	0.76	1.39
	Equal variances not assumed			6.85	29.38	0.000	1.07	0.16	0.75	1.39
Parietal Lobe (Theta)	Equal variances assumed	5.96	0.02	4.61	38.00	0.000	0.76	0.16	0.43	1.09
	Equal variances not assumed			4.61	28.41	0.000	0.76	0.16	0.42	1.09
Occipital Lobe (Theta)	Equal variances assumed	3.65	0.06	4.04	38.00	0.000	0.63	0.16	0.31	0.95
	Equal variances not assumed			4.04	33.54	0.000	0.63	0.16	0.31	0.95
Frontal Lobe (Alpha)	Equal variances assumed	4.11	0.05	0.77	38.00	0.447	0.14	0.19	-0.23	0.52
	Equal variances not assumed			0.77	30.80	0.449	0.14	0.19	-0.24	0.52

Temporal Lobe (Alpha)	Equal variances assumed	1.41	0.24	0.44	38.00	0.663	0.16	0.36	-0.56	0.88
	Equal variances not assumed			0.44	35.87	0.663	0.16	0.36	-0.56	0.88
Central Lobe (Alpha)	Equal variances assumed	1.91	0.17	1.01	38.00	0.320	0.23	0.22	-0.23	0.68
	Equal variances not assumed			1.01	35.35	0.320	0.23	0.22	-0.23	0.68
Parietal Lobe (Alpha)	Equal variances assumed	3.59	0.07	0.56	38.00	0.579	0.23	0.41	-0.60	1.06
	Equal variances not assumed			0.56	34.42	0.579	0.23	0.41	-0.60	1.06
Occipital Lobe (Alpha)	Equal variances assumed	0.27	0.60	1.51	38.00	0.140	0.71	0.47	-0.24	1.66
	Equal variances not assumed			1.51	37.44	0.140	0.71	0.47	-0.24	1.66
Frontal Lobe (Beta)	Equal variances assumed	0.29	0.59	-3.11	38.00	0.004	-0.09	0.03	-0.15	-0.03
	Equal variances not assumed			-3.11	36.64	0.004	-0.09	0.03	-0.15	-0.03
Temporal Lobe (Beta)	Equal variances assumed	0.12	0.73	-3.35	38.00	0.002	-0.12	0.04	-0.20	-0.05
	Equal variances not assumed			-3.35	37.17	0.002	-0.12	0.04	-0.20	-0.05
Central Lobe (Beta)	Equal variances assumed	1.84	0.18	-5.14	38.00	0.000	-0.19	0.04	-0.26	-0.12
	Equal variances not assumed			-5.14	34.21	0.000	-0.19	0.04	-0.27	-0.11
Parietal Lobe (Beta)	Equal variances assumed	2.09	0.16	-3.76	38.00	0.001	-0.15	0.04	-0.23	-0.07

	Equal variances not assumed			-3.76	33.17	0.001	-0.15	0.04	-0.24	-0.07
Occipital Lobe (Beta)	Equal variances assumed	0.91	0.35	-2.86	38.00	0.007	-0.12	0.04	-0.20	-0.03
	Equal variances not assumed			-2.86	36.00	0.007	-0.12	0.04	-0.20	-0.03
Frontal Lobe (Gamma)	Equal variances assumed	7.52	0.01	-4.91	38.00	0.000	-0.06	0.01	-0.09	-0.04
	Equal variances not assumed			-4.91	27.57	0.000	-0.06	0.01	-0.09	-0.04
Central Lobe (Gamma)	Equal variances assumed	2.66	0.11	-4.18	38.00	0.000	-0.04	0.01	-0.05	-0.02
	Equal variances not assumed			-4.18	30.63	0.000	-0.04	0.01	-0.05	-0.02
Parietal Lobe (Gamma)	Equal variances assumed	13.89	0.00	-3.59	38.00	0.001	-0.05	0.01	-0.07	-0.02
	Equal variances not assumed			-3.59	24.96	0.001	-0.05	0.01	-0.08	-0.02
Occipital Lobe (Gamma)	Equal variances assumed	15.30	0.00	-3.79	38.00	0.001	-0.09	0.02	-0.13	-0.04
	Equal variances not assumed			-3.79	23.42	0.001	-0.09	0.02	-0.13	-0.04

Tab C-11: Non parametric statistics of power spectrum during condition five of SOT

	Temporal Lobe (Delta)	**Temporal Lobe (Gamma)**
Mann-Whitney U	85.00	57.00
Wilcoxon W	295.00	267.00
Z	-3.11	-3.87
Asymp. Sig. (2-tailed)	0.028	0.005
Exact Sig. [2*(1-tailed Sig.)]	0.028	0.004

Tab C-12: Parametric statistics sensory organization test senior participants of study (ANOVA)

ANOVA	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	
Between Groups	7699.06	2.00	3849.53	121.07	0.000	
Within Groups	1812.30	57.00	31.79			
Total	9511.36	59.00				
Post Hoc Tests (Multiple Comparisons) Scheffe						
		Mean Difference (I-J)	**Std. Error**	**Sig.**	**95% Confidence Interval**	
					Lower Bound	**Upper Bound**
Somatosensory (S)	Visual (S)	5.43	1.78	0.014	0.94	9.91
	Vestibular (S)	26.28	1.78	0.000	21.80	30.76
Visual (S)	Somatosensory (S)	-5.43	1.78	0.014	-9.91	-0.94
	Vestibular (S)	20.85	1.78	0.000	16.37	25.34
Vestibular (S)	Somatosensory (S)	-26.28	1.78	0.000	-30.76	-21.80
	Visual (S)	-20.85	1.78	0.000	-25.34	-16.37

Tab C-13: Parametric statistics sensory organization test senior participants of study

		Levene's Test for Equality of Variances		**t-test for Equality of Means**						
		F	**Sig.**	**t**	**df**	**Sig. (2-tailed)**	**Mean Difference**	**Std. Error Difference**	**95% Confidence Interval of the Difference**	
									Lower	**Upper**
Somatosensory V/S Visual	Equal variances assumed	5.582	.023	5.907	38	0.000	5.42521	.91845	3.56591	7.28451
	Equal variances not assumed			5.907	29.313	0.000	5.42521	.91845	3.54765	7.30277
Somatosensory V/S Vestibular	Equal variances assumed	14.762	.000	12.950	38	0.000	26.27857	2.02925	22.17058	30.38656
	Equal variances not assumed			12.950	20.856	0.000	26.27857	2.02925	22.05674	30.50039
Visual V/S Vestibular	Equal variances assumed	7.627	.009	9.747	38	0.000	20.85336	2.13941	16.52236	25.18436
	Equal variances not assumed			9.747	25.136	0.000	20.85336	2.13941	16.44838	25.25834

Tab C-14: Non parametric statistics sensory organization test young participants of study (Kruskal-Wallis Test)

Sensory Organization Test (Kruskal-Wallis Test)		N	Mean Rank
Sensory Organization Test Balance	Somatosensory (Y)	20.00	41.15
	Visual (Y)	20.00	39.85
	Vestibular (Y)	20.00	10.50
	Total	60.00	
Chi-Square	39.41		
df	2.00		
Asymp. Sig.	0.000		

Tab C-15: Non parametric statistics sensory organization test young participants of study

	Somatosensory V/S Vestibular	Visual V/S Vestibular
Mann-Whitney U	0.000	0.000
Wilcoxon W	210.000	210.000
Z	-5.411	-5.410
Asymp. Sig. (2-tailed)	0.000	0.000
Exact Sig. [2*(1-tailed Sig.)]	0.000	0.000

Tab C-16: Parametric statistics sensory organization test young compared with seniors

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Sensory Organization Test Balance (Vestibular)	Equal variances assumed	9.50	0.00	5.84	38.00	0.000	12.29	2.11	8.03	16.55
	Equal variances not assumed			5.84	23.83	0.000	12.29	2.11	7.94	16.64

Tab C-17: Non parametric statistics sensory organization test young compared with seniors

	Somatosensory	**Visual**
Mann-Whitney U	196.00	32.00
Wilcoxon W	406.00	242.00
Z	-0.11	-4.54
Asymp. Sig. (2-tailed)	0.914	0.000
Exact Sig. [2*(1-tailed Sig.)]	0.925	0.000

Tab C-18: Parametric statistics of power spectrum during static postural balance under somatosensory influence

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Frontal lobe (Delta)	Equal variances assumed	2.36	0.13	2.52	38.00	0.016	19.30	7.64	3.82	34.77
	Equal variances not assumed			2.52	34.59	0.016	19.30	7.64	3.77	34.82
Temporal lobe (Delta)	Equal variances assumed	0.07	0.80	0.45	38.00	0.655	4.09	9.07	-14.28	22.46
	Equal variances not assumed			0.45	37.97	0.655	4.09	9.07	-14.28	22.46
Central lobe (Delta)	Equal variances assumed	1.92	0.17	1.49	38.00	0.143	8.04	5.38	-2.85	18.94
	Equal variances not assumed			1.49	34.66	0.144	8.04	5.38	-2.89	18.97
Parietal lobe (Delta)	Equal variances assumed	4.25	0.05	0.86	38.00	0.396	5.99	6.97	-8.12	20.10
	Equal variances not assumed			0.86	33.85	0.396	5.99	6.97	-8.18	20.16
Occipital lobe (Delta)	Equal variances assumed	0.05	0.82	0.68	38.00	0.501	5.20	7.65	-10.29	20.69
	Equal variances not assumed			0.68	37.95	0.501	5.20	7.65	-10.29	20.70
Temporal lobe (Theta)	Equal variances assumed	0.17	0.68	-0.73	38.00	0.472	-5.11	7.05	-19.38	9.15
	Equal variances not assumed			-0.73	37.99	0.472	-5.11	7.05	-19.38	9.15

Parietal lobe (Theta)	Equal variances assumed	1.24	0.27	-0.84	38.00	0.405	-4.83	5.73	-16.42	6.77
	Equal variances not assumed			-0.84	37.25	0.405	-4.83	5.73	-16.42	6.77
Occipital lobe (Theta)	Equal variances assumed	0.32	0.58	-1.36	38.00	0.182	-8.18	6.01	-20.35	3.99
	Equal variances not assumed			-1.36	37.95	0.182	-8.18	6.01	-20.35	3.99
Temporal lobe (Alpha)	Equal variances assumed	3.36	0.07	0.40	38.00	0.690	5.46	13.58	-22.04	32.96
	Equal variances not assumed			0.40	32.29	0.690	5.46	13.58	-22.20	33.12
Frontal lobe (Beta)	Equal variances assumed	0.84	0.36	-2.85	38.00	0.007	-10.90	3.82	-18.64	-3.17
	Equal variances not assumed			-2.85	35.35	0.007	-10.90	3.82	-18.66	-3.15
Temporal lobe (Beta)	Equal variances assumed	0.34	0.56	-1.87	38.00	0.069	-8.27	4.42	-17.22	0.69
	Equal variances not assumed			-1.87	37.54	0.069	-8.27	4.42	-17.22	0.69
Central lobe (Beta)	Equal variances assumed	1.25	0.27	-0.39	38.00	0.697	-1.96	5.01	-12.12	8.19
	Equal variances not assumed			-0.39	32.72	0.698	-1.96	5.01	-12.17	8.24
Parietal lobe (Beta)	Equal variances assumed	0.54	0.47	0.06	38.00	0.954	0.41	7.02	-13.81	14.63
	Equal variances not assumed			0.06	37.44	0.954	0.41	7.02	-13.81	14.64
Occipital lobe (Beta)	Equal variances assumed	0.19	0.67	-0.06	38.00	0.949	-0.49	7.65	-15.98	14.99

	Equal variances not assumed			-0.06	38.00	0.949	-0.49	7.65	-15.98	14.99
Frontal lobe (Gamma)	Equal variances assumed	0.65	0.42	-1.82	38.00	0.077	-12.81	7.04	-27.06	1.44
	Equal variances not assumed			-1.82	37.72	0.077	-12.81	7.04	-27.06	1.44
Temporal lobe (Gamma)	Equal variances assumed	4.13	0.05	-0.31	38.00	0.759	-3.04	9.82	-22.92	16.85
	Equal variances not assumed			-0.31	34.64	0.759	-3.04	9.82	-22.99	16.91
Parietal lobe (Gamma)	Equal variances assumed	1.87	0.18	-1.63	38.00	0.111	-12.80	7.85	-28.69	3.10
	Equal variances not assumed			-1.63	36.24	0.112	-12.80	7.85	-28.72	3.12

Tab C-19: Non parametric statistics of power spectrum during static postural balance under somatosensory influence

	Frontal lobe (Theta)	**Central lobe (Theta)**	**Frontal lobe (Alpha)**	**Central lobe (Alpha)**	**Parietal lobe (Alpha)**	**Occipital lobe (Alpha)**	**Central lobe (Gamma)**	**Occipital lobe (Gamma)**
Mann-Whitney U	195.00	173.00	177.00	182.00	141.00	156.00	144.00	124.00
Wilcoxon W	405.00	383.00	387.00	392.00	351.00	366.00	354.00	334.00
Z	-0.14	-0.73	-0.62	-0.49	-1.60	-1.19	-1.51	-2.06
Asymp. Sig. (2-tailed)	0.892	0.465	0.534	0.626	0.110	0.234	0.130	0.040
Exact Sig. [2*(1-tailed Sig.)]	0.904	0.478	0.547	0.640	0.114	0.242	0.134	0.040

Tab C-20: Parametric statistics of power spectrum during static postural balance under visual influence

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Temporal lobe (Delta)	Equal variances assumed	3.30	0.08	-1.13	38.00	0.266	-7.87	6.96	-21.97	6.23
	Equal variances not assumed			-1.13	34.44	0.266	-7.87	6.96	-22.01	6.28
Occipital lobe (Delta)	Equal variances assumed	0.39	0.54	-0.78	38.00	0.443	-4.04	5.21	-14.58	6.50
	Equal variances not assumed			-0.78	37.94	0.443	-4.04	5.21	-14.58	6.50
Temporal lobe (Theta)	Equal variances assumed	1.02	0.32	-0.32	38.00	0.752	-2.20	6.89	-16.14	11.75
	Equal variances not assumed			-0.32	36.72	0.752	-2.20	6.89	-16.15	11.76
Parietal lobe (Theta)	Equal variances assumed	3.57	0.07	0.73	38.00	0.471	4.19	5.76	-7.47	15.84
	Equal variances not assumed			0.73	31.69	0.472	4.19	5.76	-7.54	15.92
Occipital lobe (Theta)	Equal variances assumed	1.13	0.29	-0.28	38.00	0.780	-1.63	5.77	-13.30	10.05
	Equal variances not assumed			-0.28	37.08	0.780	-1.63	5.77	-13.31	10.06
Frontal lobe (Alpha)	Equal variances assumed	0.03	0.86	1.48	38.00	0.148	9.33	6.32	-3.45	22.12
	Equal variances not assumed			1.48	38.00	0.148	9.33	6.32	-3.45	22.12

Temporal lobe (Alpha)	Equal variances assumed	0.19	0.66	-1.53	38.00	0.135	-12.48	8.18	-29.04	4.08
	Equal variances not assumed			-1.53	37.73	0.135	-12.48	8.18	-29.05	4.08
Occipital lobe (Alpha)	Equal variances assumed	4.22	0.05	1.92	38.00	0.063	13.45	7.01	-0.75	27.65
	Equal variances not assumed			1.92	31.09	0.064	13.45	7.01	-0.85	27.75
Frontal lobe (Beta)	Equal variances assumed	2.53	0.12	-2.63	38.00	0.012	-13.83	5.25	-24.46	-3.20
	Equal variances not assumed			-2.63	33.79	0.013	-13.83	5.25	-24.50	-3.16
Temporal lobe (Beta)	Equal variances assumed	0.10	0.75	-1.40	38.00	0.170	-6.24	4.46	-15.27	2.79
	Equal variances not assumed			-1.40	37.24	0.170	-6.24	4.46	-15.27	2.79
Parietal lobe (Beta)	Equal variances assumed	4.06	0.05	-1.24	38.00	0.224	-5.53	4.47	-14.58	3.53
	Equal variances not assumed			-1.24	29.36	0.226	-5.53	4.47	-14.67	3.62
Occipital lobe (Beta)	Equal variances assumed	1.10	0.30	-1.36	38.00	0.182	-5.65	4.15	-14.04	2.75
	Equal variances not assumed			-1.36	35.04	0.182	-5.65	4.15	-14.07	2.78
Frontal lobe (Gamma)	Equal variances assumed	0.45	0.50	-3.33	38.00	0.002	-31.69	9.53	-50.97	-12.40
	Equal variances not assumed			-3.33	37.46	0.002	-31.69	9.53	-50.98	-12.40
Temporal lobe (Gamma)	Equal variances assumed	1.13	0.29	1.58	38.00	0.122	17.87	11.31	-5.02	40.76

	Equal variances not assumed			1.58	34.59	0.123	17.87	11.31	-5.09	40.84
Central lobe (Gamma)	Equal variances assumed	1.27	0.27	-1.83	38.00	0.076	-16.99	9.30	-35.82	1.84
	Equal variances not assumed			-1.83	37.65	0.076	-16.99	9.30	-35.82	1.84
Occipital lobe (Gamma)	Equal variances assumed	0.00	0.96	-0.80	38.00	0.427	-7.64	9.52	-26.91	11.62
	Equal variances not assumed			-0.80	37.99	0.427	-7.64	9.52	-26.91	11.62

Tab C-21: Non parametric statistics of power spectrum during static postural balance under visual influence

	Frontal lobe (Delta)	**Central lobe (Delta)**	**Parietal lobe (Delta)**	**Frontal lobe (Theta)**	**Central lobe (Theta)**	**Central lobe (Alpha)**	**Parietal lobe (Alpha)**	**Central lobe (Beta)**	**Parietal lobe (Gamma)**
Mann-Whitney U	120.00	199.00	183.00	62.00	168.00	192.00	150.00	200.00	140.00
Wilcoxon W	330.00	409.00	393.00	272.00	378.00	402.00	360.00	410.00	350.00
Z	-2.16	-0.03	-0.46	-3.73	-0.87	-0.22	-1.35	0.00	-1.62
Asymp. Sig. (2-tailed)	0.030	0.978	0.646	0.000	0.387	0.829	0.176	1.000	0.105
Exact Sig. [2*(1-tailed Sig.)]	0.030	0.989	0.659	0.000	0.398	0.841	0.183	1.000	0.108

Tab C-22: Parametric statistics of power spectrum during static postural balance under vestibular influence

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Temporal Lobe (Delta)	Equal variances assumed	0.01	0.93	-0.03	38.00	0.973	-0.37	10.76	-22.16	21.41
	Equal variances not assumed			-0.03	38.00	0.973	-0.37	10.76	-22.16	21.41
Central Lobe (Delta)	Equal variances assumed	0.07	0.79	-0.20	38.00	0.846	-0.97	4.97	-11.03	9.09
	Equal variances not assumed			-0.20	36.43	0.846	-0.97	4.97	-11.05	9.11
Parietal Lobe (Delta)	Equal variances assumed	0.09	0.76	-1.08	38.00	0.288	-7.20	6.68	-20.72	6.32
	Equal variances not assumed			-1.08	37.70	0.288	-7.20	6.68	-20.72	6.33
Occipital Lobe (Delta)	Equal variances assumed	0.49	0.49	-1.63	38.00	0.112	-11.77	7.23	-26.40	2.86
	Equal variances not assumed			-1.63	37.91	0.112	-11.77	7.23	-26.40	2.86
Parietal Lobe (Theta)	Equal variances assumed	0.40	0.53	0.02	38.00	0.986	0.13	7.48	-15.01	15.28
	Equal variances not assumed			0.02	37.87	0.986	0.13	7.48	-15.01	15.28
Occipital Lobe (Theta)	Equal variances assumed	0.37	0.55	-0.81	38.00	0.424	-5.94	7.34	-20.81	8.92
	Equal variances not assumed			-0.81	37.78	0.424	-5.94	7.34	-20.81	8.93

Temporal Lobe (Alpha)	Equal variances assumed	6.77	0.01	2.15	38.00	0.038	31.29	14.58	1.77	60.81
	Equal variances not assumed			2.15	26.95	0.041	31.29	14.58	1.37	61.21
Occipital Lobe (Alpha)	Equal variances assumed	4.02	0.05	2.71	38.00	0.010	55.28	20.39	14.00	96.56
	Equal variances not assumed			2.71	32.52	0.011	55.28	20.39	13.77	96.79
Frontal Lobe (Beta)	Equal variances assumed	0.71	0.41	-2.57	38.00	0.014	-11.07	4.30	-19.78	-2.35
	Equal variances not assumed			-2.57	35.75	0.014	-11.07	4.30	-19.80	-2.34
Temporal Lobe (Beta)	Equal variances assumed	0.83	0.37	-2.40	38.00	0.021	-12.74	5.30	-23.47	-2.00
	Equal variances not assumed			-2.40	37.77	0.021	-12.74	5.30	-23.47	-2.00
Parietal Lobe (Beta)	Equal variances assumed	0.86	0.36	-0.64	38.00	0.528	-3.23	5.07	-13.48	7.03
	Equal variances not assumed			-0.64	37.31	0.528	-3.23	5.07	-13.49	7.04
Occipital Lobe (Beta)	Equal variances assumed	0.75	0.39	-0.56	38.00	0.578	-3.55	6.31	-16.33	9.23
	Equal variances not assumed			-0.56	36.02	0.578	-3.55	6.31	-16.35	9.26
Frontal Lobe (Gamma)	Equal variances assumed	3.28	0.08	-2.77	38.00	0.009	-25.58	9.25	-44.30	-6.86
	Equal variances not assumed			-2.77	32.56	0.009	-25.58	9.25	-44.40	-6.75
Occipital Lobe	Equal variances assumed	0.31	0.58	-2.40	38.00	0.022	-22.98	9.59	-42.39	-3.57

(Gamma)	Equal variances not assumed			-2.40	37.78	0.022	-22.98	9.59	-42.40	-3.57

Tab C-23: Non parametric statistics of power spectrum during static postural balance under vestibular influence

	Frontal Lobe (Delta)	**Frontal Lobe (Theta)**	**Temporal Lobe (Theta)**	**Central Lobe (Theta)**	**Frontal Lobe (Alpha)**	**Central Lobe (Alpha)**	**Parietal Lobe (Alpha)**	**Central Lobe (Beta)S**	**Temporal Lobe (Gamma)**	**Central Lobe (Gamma)**	**Parietal Lobe (Gamma)**
Mann-Whitney U	146.00	129.00	198.00	139.00	116.00	123.00	106.00	140.00	126.00	95.00	69.00
Wilcoxon W	356.00	339.00	408.00	349.00	326.00	333.00	316.00	350.00	336.00	305.00	279.00
Z	-1.46	-1.92	-0.05	-1.65	-2.27	-2.08	-2.54	-1.62	-2.00	-2.84	-3.54
Asymp. Sig. (2-tailed)	0.144	0.055	0.957	0.099	0.023	0.037	0.011	0.105	0.045	0.005	0.000
Exact Sig. [2*(1-tailed Sig.)]	0.149	0.056	0.968	0.102	0.023	0.038	0.010	0.108	0.046	0.004	0.000

Appendix D

Table D-1: Region of interest of linear lagged connectivity

ROI*	X-MNI	Y-MNI	Z-MNI	Lobe	Structure	BA**
1	-55	-25	50	Parietal	Postcentral Gyrus	2
2	-45	-30	45	Parietal	Postcentral Gyrus	2
3	-35	-25	55	Frontal	Precentral Gyrus	4
4	-35	-20	50	Frontal	Precentral Gyrus	4
5	-15	-45	60	Frontal	Paracentral Lobule	5
6	-30	-5	55	Frontal	Middle Frontal Gyrus	6
7	-20	-65	50	Parietal	Precuneus	7
8	-20	30	50	Frontal	Superior Frontal Gyrus	8
9	-30	30	35	Frontal	Middle Frontal Gyrus	9
10	-25	55	5	Frontal	Superior Frontal Gyrus	10
11	-20	40	-15	Frontal	Middle Frontal Gyrus	11
12	-40	-10	10	Sub-lobar	Insula	13
13	-10	-90	0	Occipital	Lingual Gyrus	17
14	-15	-85	0	Occipital	Lingual Gyrus	17
15	-25	-75	10	Occipital	Cuneus	30
16	-45	-20	-30	Temporal	Fusiform Gyrus	20
17	-60	-20	-15	Temporal	Middle Temporal Gyrus	21
18	-55	-25	5	Temporal	Superior Temporal Gyrus	41
19	-5	-40	25	Limbic	Posterior Cingulate	23
20	-5	0	35	Limbic	Cingulate Gyrus	24
21	-10	20	-15	Frontal	Medial Frontal Gyrus	25
22	-20	-35	-5	Limbic	Parahippocampal Gyrus	27
23	-20	-10	-25	Limbic	Parahippocampal Gyrus	28
24	-5	-50	5	Limbic	Posterior Cingulate	29
25	-15	-60	5	Limbic	Posterior Cingulate	30
26	-10	-50	30	Parietal	Precuneus	31
27	-5	30	20	Limbic	Anterior Cingulate	24

28	-5	20	20	Limbic	Anterior Cingulate	33
29	-15	0	-20	Limbic	Parahippocampal Gyrus	34
30	-20	-25	-20	Limbic	Parahippocampal Gyrus	35
31	-30	-30	-25	Limbic	Parahippocampal Gyrus	36
32	-45	-55	-15	Temporal	Fusiform Gyrus	37
33	-40	15	-30	Temporal	Superior Temporal Gyrus	38
34	-45	-65	25	Temporal	Middle Temporal Gyrus	39
35	-50	-40	40	Parietal	Inferior Parietal Lobule	40
36	-45	-30	10	Temporal	Transverse Temporal Gyrus	41
37	-60	-25	10	Temporal	Superior Temporal Gyrus	42
38	-60	-10	15	Temporal	Transverse Temporal Gyrus	42
39	-50	10	15	Frontal	Precentral Gyrus	44
40	-50	20	15	Frontal	Inferior Frontal Gyrus	45
41	-45	35	20	Frontal	Middle Frontal Gyrus	46
42	-30	25	-15	Frontal	Inferior Frontal Gyrus	47
43	55	-25	50	Parietal	Postcentral Gyrus	2
44	50	-30	45	Parietal	Inferior Parietal Lobule	40
45	40	-25	50	Parietal	Postcentral Gyrus	3
46	35	-25	50	Parietal	Postcentral Gyrus	3
47	15	-45	60	Frontal	Paracentral Lobule	5
48	30	-5	55	Frontal	Middle Frontal Gyrus	6
49	15	-65	50	Parietal	Precuneus	7
50	20	25	50	Frontal	Superior Frontal Gyrus	8
51	30	30	35	Frontal	Middle Frontal Gyrus	9
52	25	55	5	Frontal	Superior Frontal Gyrus	10
53	20	45	-20	Frontal	Superior Frontal Gyrus	11
54	40	-5	10	Sub-lobar	Insula	13
55	10	-90	0	Occipital	Lingual Gyrus	17
56	15	-85	0	Occipital	Lingual Gyrus	17
57	25	-75	10	Occipital	Cuneus	30
58	45	-20	-30	Temporal	Fusiform Gyrus	20
59	60	-15	-15	Temporal	Middle Temporal Gyrus	21

60	55	-20	5	Temporal	Superior Temporal Gyrus	41
61	5	-45	25	Limbic	Posterior Cingulate	23
62	5	0	35	Limbic	Cingulate Gyrus	24
63	5	15	-15	Frontal	Subcallosal Gyrus	25
64	20	-35	-5	Limbic	Parahippocampal Gyrus	27
65	20	-10	-25	Limbic	Parahippocampal Gyrus	28
66	5	-50	5	Limbic	Posterior Cingulate	29
67	10	-60	5	Occipital	Cuneus	30
68	10	-50	35	Parietal	Precuneus	31
69	5	30	20	Limbic	Anterior Cingulate	24
70	0	20	20	Limbic	Anterior Cingulate	33
71	15	0	-20	Limbic	Parahippocampal Gyrus	34
72	25	-25	-20	Limbic	Parahippocampal Gyrus	35
73	30	-25	-25	Limbic	Parahippocampal Gyrus	35
74	45	-55	-15	Temporal	Fusiform Gyrus	37
75	40	15	-30	Temporal	Superior Temporal Gyrus	38
76	45	-65	25	Temporal	Middle Temporal Gyrus	39
77	50	-45	45	Parietal	Inferior Parietal Lobule	40
78	45	-30	10	Temporal	Transverse Temporal Gyrus	41
79	65	-25	10	Temporal	Superior Temporal Gyrus	42
80	60	-10	15	Temporal	Transverse Temporal Gyrus	42
81	55	10	15	Frontal	Precentral Gyrus	44
82	50	20	15	Frontal	Inferior Frontal Gyrus	45
83	45	35	20	Frontal	Middle Frontal Gyrus	46
84	30	25	-15	Frontal	Inferior Frontal Gyrus	47

*ROI = Region of interest, ** BA = Brodmann area

Appendix E

Table D-1: Functional localisation of EROI in the seniors compared with the young participants in the study

Condition 1 of SOT

EROI	Activity	Structure	X(MNI)	Y(MNI)	Z(MNI)	T-Value	BAs
Primary visual cortex	Theta	Inferior Occipital Gyrus	20	-95	-15	-4.62*	17
Posterior parietal cortex	Theta	Precuneus	10	-45	50	-5.54**	7
Posterior parietal cortex	Theta	Paracentral Lobule	10	-45	55	-5.44**	5
Primary sensory cortex	Theta	Postcentral Gyrus	65	-20	35	-5.03**	1
Primary sensory cortex	Theta	Postcentral Gyrus	55	-20	50	-4.32*	1
Primary sensory cortex	Alpha	Postcentral Gyrus	40	-30	30	-5.36**	2
Primary sensory cortex	Theta	Postcentral Gyrus	60	-25	50	-4.34*	2
Primary sensory cortex	Alpha	Postcentral Gyrus	60	-15	30	-5.03**	3
Primary sensory cortex	Theta	Postcentral Gyrus	55	-15	50	-4.41*	3
Supplementary motor area	Theta	Precentral Gyrus	50	-5	10	-5.41**	6
Supplementary motor area	Alpha	Middle Frontal Gyrus	45	0	55	-5.45**	6
Primary motor cortex	Theta	Precentral Gyrus	55	-5	15	-5.11**	4
Primary motor cortex	Alpha	Precentral Gyrus	50	-10	55	-4.81*	4

Condition 2 of SOT

EROI	Activity	Structure	X(MNI)	Y(MNI)	Z(MNI)	T-Value	BAs
Primary visual cortex	Gamma	Cuneus	20	-75	10	5.12**	17
Posterior parietal cortex	Gamma	Precuneus	-5	-35	45	-5.80**	7
Posterior parietal cortex	Delta	Cuneus	10	-70	30	-5.35**	7
Posterior parietal cortex	Theta	Paracentral Lobule	-15	-35	50	-5.67**	5
Primary sensory cortex	Theta	Postcentral Gyrus	-55	-20	50	-4.87*	1
Primary sensory cortex	Theta	Postcentral Gyrus	-35	-30	45	-5.16**	2
Primary sensory cortex	Theta	Postcentral Gyrus	-30	-25	45	-6.57*	3
Supplementary motor area	Theta	Precentral Gyrus	-25	-15	50	-8.25**	6
Supplementary motor area	Gamma	Precentral Gyrus	-35	0	30	4.64*	6

Primary motor cortex	Theta	Precentral Gyrus	-30	-20	45	-7.46**	4

Condition 5 of SOT

EROI	Activity	Structure	X(MNI)	Y(MNI)	Z(MNI)	T-Value	BAs
Primary visual cortex	Gamma	Cuneus	15	-80	10	4.87*	17
Posterior parietal cortex	Theta	Precuneus	0	-40	45	-5.07**	7
Posterior parietal cortex	Theta	Paracentral Lobule	0	-40	50	-5.16**	5
Primary sensory cortex	Theta	Postcentral Gyrus	65	-20	30	-4.43*	1
Primary sensory cortex	Alpha	Postcentral Gyrus	55	-20	50	-4.32*	1
Primary sensory cortex	Alpha	Postcentral Gyrus	55	-20	35	-4.32*	2
Primary sensory cortex	Gamma	Postcentral Gyrus	60	-20	30	4.96**	2
Primary sensory cortex	Gamma	Postcentral Gyrus	65	-10	25	5.44**	3
Primary sensory cortex	Alpha	Postcentral Gyrus	50	-20	40	-4.88*	3
Primary sensory cortex	Theta	Postcentral Gyrus	60	-15	30	-4.64*	3
Primary sensory cortex	Gamma	Postcentral Gyrus	65	-20	30	4.98**	1
Primary sensory cortex	Theta	Postcentral Gyrus	55	-20	30	-4.47*	2
Supplementary motor area	Alpha	Precentral Gyrus	60	-15	45	-5.30**	6
Supplementary motor area	Gamma	Precentral Gyrus	40	0	30	5.88**	6
Supplementary motor area	Theta	Middle Frontal Gyrus	30	10	50	-6.73**	6
Primary motor cortex	Theta	Precentral Gyrus	50	-10	45	-5.07**	4
Primary motor cortex	Alpha	Precentral Gyrus	55	-15	40	-5.37**	4
Primary motor cortex	Gamma	Precentral Gyrus	60	-10	25	5.47**	4

*** = $p < 0.01$, * $p < 0.05$*