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The influence of environmental sound on attention control and gait in older adults.

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Summary

The world guidelines for fall prevention outline that 30% of older adults has a fall each year, with half this figure continuing to have more frequent and life changing falls. The impact of falls can lead to increased risk of injury, fractures, pain, prolonged immobility and a difficulty or inability to be independent. The overarching aim of this research is to increase our knowledge of why some older adults may be at higher risk of abnormal gait and risk of falls than others. The main hypothesis running through this set of studies and thesis, is that some older adults experience degradation in their ability to resist attentional capture from highly salient but irrelevant environmental sounds, resulting in the shift of attention and thus processing resources, away from walking and gait maintenance, thus reducing their integrity and raising risk of falls. This thesis will present the outcome of three research projects (i) confrontation naming of sounds. Older adults were required to rate their perceptions of environmental sounds based on distractibility and pleasantness. Moreover, older adults were asked to categorise the environmental sounds heard. (ii) Influence of environmental sounds on attention control. Older adults took part in a computer-based attention control task to understand the degree to which environmental sounds influenced performance. (iii) Influence on environmental sounds on gait. A walking study will be presented outlining how gait is altered when listening to environmental sounds. Moreover, to gain a full understanding of how individual difference influences gait, measures were taken for balance, hearing acuity, cognitive ability (MOCA), and polypharmacy. Measures will be presented for gait perturbation and the types of environmental sounds altering gait patterns. Results indicate environmental sounds can induce a startle like affect that influence how participants felt they performed. Moreover, environmental sound we capable of inducing gait perturbation in older adults.

DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

Signed – [redacted] (candidate)

Date – 16th August, 2024

STATEMENT 1

This thesis is the result of my own investigations, except where otherwise stated. Where correction services have been used, the extent and nature of the correction is clearly marked in a footnote(s).

Other sources are acknowledged by footnotes giving explicit references. A bibliography is appended.

Signed – [redacted] (candidate)

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List of abbreviations

A1 - Primary Auditory Cortex
AC2 - Secondary Auditory Cortex
ACC – Anterior cingulate Cortex
ACE - Angiotensin Converting Enzyme
AcH - Acetylcholine
ACT - Auditory Cognitive Training
APP – Amyloid Precursor Protein
ARB - Angiotensin 2 Receptor Blocker
ASR - Auditory Startle Reflex
ATP – Adenosine Triphosphate
AVCN - Anterior Ventral cochlear Nucleus
BG-EPVS - Enlarged Perivascular Spaces of Basal Ganglia
CAA - Cerebral Amyloid Angiopathy
CE - Central Executive
CMA - Central Media Amygdala
CN - Cochlear Nucleus
COM - Centre of MASS
CTE - Chronic Traumatic Encephalopathy
DLPFC – Dorsolateral Prefrontal Cortex
DMGN - Dorsal Medial Geniculate Nucleus
DNLL - Dorsal Nucleus of the Lateral Lemniscus
DTI - Diffusion Tensor imaging
DV – Dependant Variable
EB - Episodic Buffer
ECG - Electrocardiogram
EEG – Electroencephalogram
EF - Executive Function
EMG – Electromyography
ENG - Electroneurogram
ERP – Event Related Potential
fMRI - functional Magnetic Resonance Imaging
FTLF – Frontotemporal Lobular Dementia
GABA - Gamma Amino Butyric Acid
GL - Glutamate
GSR - Galvanic Skin Response
GVD - Granulovacuolar Degeneration
HRV - Heart Rate Variability
HSC – Hematopoietic Stem Cells
Hz - Hertz
IC - Inferior Colliculus
INLL - Intermediate Nucleus of the Lateral Lemniscus
IV – Independent Variable
LSO - Lateral Superior Olive
LTM - Long Term Memory
MCI - Mild Cognitive Impairment
mDNA – mitochondrial DNA
MGN - Medial Geniculate Nucleus

MLR - Mesencephalic Locomotor Region
MMDN - Medial Medial Geniculate Nucleus
MMN - Mismatch Negativity
MOCA - Montreal Cognitive Assessment
MPC – Multipotent Stem Cells
MRI – Magnetic Resonance Imaging
MSO - Medial Superior Olive
NE - Norepinephrine
OSC – Oligopotent Stem Cells
PAG - Periaqueductal Grey
PEST - Parameter Estimation of Sequential Testing
PEST - Parameter Estimation of Sequential Testing
PL - Phonological Loop
PMC - Primary Motor Cortex
PnC - Caudal Pontine reticular Nucleus
PPI - PrePulse Inhibition
PPN - Pedunculopontine tegmental Nucleus
PSC – Pluripotent Stem Cells
PSP - Progressive Supranuclear Palsy
PTA - Pure Tone Average
PTSD – Post Traumatic Stress Disorder
PVCN - Posteroventral Cochlear Nucleus
RNA - Ribonucleic Acid
ROS – Reactive Oxygen Species
RT – Reaction time
SLR - Subthalamic Locomotor Region
SMC - Supplementary Motor Cortex
SOC - Superior Olivary Complex
STAC - Swansea Test of Attentional Control
STAC - Swansea Test of Attentional Control
STM - Short Term Memory
STM - Short Term Memory
TMS - Transcranial Magnetic Stimulation
TSC – Totipotent Stem Cells
USC – Unipotent Stem Cells
VBM – Voxel Based Morphology
VCN - Ventral Cochlear Nucleus
VCN - Vestibular Cochlear Nerve
VMGN - Ventral Medial Geniculate Nucleus
VNLL - Ventral Nucleus of the Lateral Lemniscus
VSS - Visuospatial Sketch Pad
WGBS – Whole Genome Bisulphate Sequencing
WM - Working memory

Introduction

Healthy ageing has long been associated with a healthy diet, exercise, challenging cognition via learning, health monitoring, positive mindset, and social interaction. A combination of each intervention is believed to maintain functional ability that enables wellbeing in old age and promote long term independence (WHO, 2023). Whilst each of us to a degree can dictate how we maintain a healthy body, biological processes, and external variables outside of our control may influence the degree to which we age well.

One feature of ageing that is open for decline in everyone is attention. Attention is a limited resource in both capacity and duration, thus for older adults who cannot actively focus on specific information, whilst turning out other irrelevant stimuli are at increased risk of attention redirection. One such problem associated with attention decline is the increased risk of slips trips and falls in older adults. The world guidelines for fall prevention, made up of 96 multidisciplinary experts in the field of falls outline that 30% of older adults are having a fall each year (Montero-Odasso et al., 2022), with approximately half of such individuals continuing to have more falls, increasing the risk of fractures, hospitalisation, social isolation, and life changing injuries. Leading theories have provided evidence that task irrelevant visual stimuli are able to capture and divide attention away from a task. However, what is of greater interest is sound. Sound is able to capture attention at a lower and faster threshold that any other sensory modality (Hidaka & Ide, 2015), whilst maintaining the ability to suppress visual stimuli. If this theory is correct, it may be that slips, trips and falls that are extremely prevalent in older adults, are due to the inability to filter out task irrelevant auditory stimuli, directing an individual towards the auditory stimuli away from the task (gait), thus altering gait pattern and inducing falls.

To test this hypothesis that sound, particularly environmental sound may influence walking integrity, this thesis provides a theoretical background and the outcome of three studies. First, it was important to understand what sounds within the environment are distracting. Providing such data, will allow for the development of an index of auditory sounds, that can be used in the future, to facilitate interventions to reduce falls in the environment or at home. Second, to understand the degree to which sound may influence attention control, a computer-based task was presented to a group of older adults under two conditions: no sound and sound. Finally, to understand the degree to which environmental sounds influence gait, an accelerometer was attached to the ankle of a group of older adults, which recorded gait synchronicity and perturbation in response to sound. As there are many external confounds that may influence gait, data was taken assessing balance, hearing function, cognition and polypharmacy, variables known to be leading causes of balance and gait problems in older adults. The benefit of introducing additional measures derives from the link to precision medicine. Precision medicine is important when looking at any research model or clinical diagnosis as it considers individual variability in genes, the environment and lifestyle factors that may influence a disease or disorder, rather than looking at one variable and assuming it provides adequate evidence.

The aim of this thesis was to provide comprehensive evidence of the influence of environmental sounds on trips and falls in older adults. The information gained in this research can facilitate multidisciplinary interventions to reduce the risk of falls, in an ever-growing ageing population. Moreover, It provides new evidence that older adults who are at increased risk of falls, may benefit from auditory cueing training as a means of early intervention. Evidence derived from this research additionally found that the auditory startle may play a defining role in falls and it is capable of altering gait, something that until now has been relatively under researched.

Overview of the thesis chapters

Chapter one summary 1 - Ageing:

Life expectancy is growing. Nearly every corner of the globe is seeing a growing rise in the amount of people living passed the age of 60 (World Health Organisation, 2023). The WHO predicts that the current global population of older adults will rise from 900 million to approximately 2 billion by 2050 (WHO, 2023). Explanations for the exponential population growth include, but not limited to, modern science which has provided vaccinations to fight pandemics and antibiotics to fight off disease. Medical innovations providing tools to target cancer, chromosomal defects and map the brain allowing researchers to understand how ageing affects the brain. Similarly, advancements in society have provided modern humans with the tools and opportunities to keep healthy. Humans know that a healthy diet, paired with physical activity and refraining from smoking and excessive drinking can contribute to improved health. Improvement in health can also be sought via socialising, family communication and community, which are thought to improve not only longevity but cognition and memory. Such advancements in ageing knowledge have contributed to a growing population of older adults who are ageing “healthy,” with healthy ageing defined as developing and maintain the functional ability that enables well-being in older adults (WHO, 2023). However, despite all the policies and interventions developed to increase the potential for healthy ageing, not everyone achieves this. An important example is the risk of falls. The world guidelines for fall prevention outline 30% of older adults, 65+, have a fall each year, with half this figure continuing to have more frequent and life changing falls. The impact of falls can lead to broken bones, pneumonia, long term disabilities and social isolation. Moreover, falls increase hospitalisation stays and care needs, which have a detrimental impact on mental health, available beds in hospitals and financial economy.

The overarching aim of this research is to increase our knowledge of why, during the ageing process, some older adults may be at higher risk of abnormal gait and risk of falls than others. The main hypothesis running through this set of studies and thesis, is that some older adults experience degradation in their ability to resist attentional capture from highly salient but irrelevant environmental sounds, resulting in the shift of attention and thus processing resources, away from walking and gait maintenance, thus reducing their integrity and raising risk of falls. Walking is a highly complex behaviour involving and requiring the integrity of many aspects of the brain and system functions. It is important to determine in greater details which specific components of this complex behaviour may be affected and why. The following section provide a detailed anatomical, physiological and psychological description of these components, including attentional control, visual auditory processing, musculoskeletal function and cognition. It is extremely important to understand such information as there are many inevitable age-related changes that can influence walking and gait.

Chapter two summary - Sound and the Auditory system:

This chapter provides a detailed description of the anatomical and functional organisation of the auditory system. Emphasis will be put on how sound waves are converted as they travel through the auditory system in a tonotopic form before reaching the auditory cortex. Evidence will also be presented for the influence noise has over the auditory system, particularly how loud noise can induce plasticity changes, influence source localisation, integration of auditory spectral cues, and alter physiological processes for a short time. A full outline of the auditory system and how sound is produced, was of importance to this thesis as it provides context for the implications of noise on human function (e.g. visual processing, attentional capture). For example, The World Health Organisation (2023), produced a report outlining environmental noise had some form of adverse effect on nearly all physiological, cognitive, and mental health measures. Such report outlines the need to evaluate sounds, particularly environmental sounds in as much detail as possible. This thesis will Combining the World Health Organisation report outline with the detailed anatomical and functional organisation of the auditory system, to provide evidence for later studies in this thesis including environmental sound perception, environmental sounds and attention control and the influence of incoming environmental sounds on gait.

Chapter three summary - Environmental sound perception

The everyday environment is busy, loud and presents with unexpected auditory stimuli, which are capable of capturing and redirecting attention. This is particularly worrisome for older adults, who are at increased risk of attention redirection due the age-related changes to the brain and auditory systems. The unexpected nature of environmental sound can also influence gait and balance, leading to an increased risk of slips, trips and falls. As such, it is important to understand what kind of sounds within the environment do older adults find the most distracting and attention grabbing. The aim of this chapter is to provide an overview of environmental sound and how they may influence attention. Moreover, it will provide research taken from a study undertaken during this PhD, to understand how older adults perceive and categorise sounds, via an auditory confrontation naming paradigm.

Chapter four summary - Attention and sound:

This chapter will provide a brief overview of the attention and the components that are relevant to this thesis. Moreover, evidence will be presented for what is already known about how sound may affect attention during performance of a visual test. This study is unique as it will use environmental sounds, as opposed to generic sounds that may be used in other lab-based experiments. This chapter will provide research where older adults participated in a computer based, attention control task under two conditions, with sound and without. The environmental sounds will be played at 80dB. Subjective views were also collected from participants to understand individual difference and how the sounds were subjectively believed to influence attention. The hypothesis for this chapter is, the sound condition, where environmental sounds are played, will influence task performance more than, a silent condition.

Chapter five summary - Gait efficiency and the influence of environmental sound on gait:

Becoming bipedal may be one of the greatest evolutionary adaptions. It changed how early human interacted and transversed continents, it freed up hands to use tool and increased survival. However, a detriment to becoming bipedal is the loss to agility and stability that we had when walking on all fours, hence the rates of slips, trips and falls, particularly in older adults who have additional age-related changes. Previous chapters have outlined how selective attention plays a defining role in how we attend to our environment. Moreover, it has also been presented in previous research that the unexpected and salient sounds that we hear in our environment are able to capture attention at a lower and faster threshold than other sensory modalities. When pairing distracting environmental sound and reduced selective attention, older adults are at increased risk of changes to their gait cycle. To understand the degree to which environmental sounds influence gait, this chapter will assess if the environmental sounds that were used in the STAC test (previous chapter) are capable of creating gait perturbation (I.e., redirecting attention away from gait, to focus on the distracting environmental sounds). First, an overview of what gait is, the gait cycle and the neuroanatomy that facilitates such movement will be presented. Moreover, this chapter will provide new research addressing gait cycle changes in older adults. Cognitive, hearing, balance and polypharmacy correlates were also taken, to understand the degree to which external factors may further exacerbate slips, trips and falls. The hypothesis is that environmental sounds will have a detrimental impact on gait, via perturbation in the gait cycle.

Summary - major findings and what is next:

The main aim of this PhD was to determine how environmental sounds may affect attention control and gait in older adults. We examined what sounds are deemed distracting within an older adult population, how different sound conditions influence attention control via the STAC test, and we examined how environmental sounds influence gait. The focus of this chapter is to draw the thesis together. It will re-present the finds of the studies, provide an overview of why these findings are important and how they improve and support research in this area.

Chapter 1- Ageing

Summary of chapter aims and context.

Life expectancy is growing. Nearly every corner of the globe is seeing a growing rise in the amount of people living passed the age of 60 (World Health Organisation, 2023). The WHO predicts that the current global population of older adults will rise from 900 million to approximately 2 billion by 2050 (WHO, 2023). Explanations for the exponential population growth include, but not limited to, modern science which has provided vaccinations to fight pandemics and antibiotics to fight off disease. Medical innovations providing tools to target cancer, chromosomal defects and map the brain allowing researchers to understand how ageing affects the brain. Similarly, advancements in society have provided modern humans with the tools and opportunities to keep healthy. Humans know that a healthy diet, paired with physical activity and refraining from smoking and excessive drinking can contribute to improved health. Improvement in health can also be sought via socialising, family communication and community, which are thought to improve not only longevity but cognition and memory. Such advancements in ageing knowledge have contributed to a growing population of older adults who are ageing "healthy," with healthy ageing defined as developing and maintain the functional ability that enables well-being in older adults (WHO,2023). However, despite all the policies and interventions developed, to increase the potential for healthy ageing, not everyone achieves this. An important example is the risk of falls. Currently 30% of older adults has a fall each year, with half this figure continuing to have more frequent and life changing falls. The impact of falls can lead to broken bones, pneumonia, long term disabilities and social isolation. Moreover, falls increase hospitalisation stays and care needs, which have a detrimental impact on mental health, available beds in hospitals and financial economy.

The overarching aim of this research is to increase our knowledge of why some older adults may be at higher risk of abnormal gait and risk of falls than others. The main hypothesis running through this set of studies and thesis, is that some older adults experience degradation in their ability to resist attentional capture from highly salient but irrelevant environmental sounds, resulting in the *shift of attention and thus processing resources, away from walking and gait maintenance, thus reducing their integrity and raising risk of falls. Walking is a highly complex behaviour involving and requiring the integrity of many aspects of the brain and system functions. It is important to determine in greater details which specific components of this complex behaviour may be affected and why. The following section provide a detailed anatomical, physiological and psychological description of these components, including attentional control, visual auditory processing, musculoskeletal function and cognition. It is extremely important to understand such information as there are many inevitable age-related changes that can influence walking and gait.*

1.1 Introduction

Ageing, resulting from the impact of the accumulation of a wide array of cellular and molecular changes / damage that occur over a life time (WHO, 2023). Ageing is complex and multifaceted and includes changes that are innocuous, such as changes in external characteristics, namely greying hair and the development of wrinkles. Other changes can be more destructive and impact health such as DNA damage (Schumacher, Pothof, Vijg & Hoeijmakers, 2021), Dementia (NIH, 2023) and neuronal vulnerability (Mattson & Magnus, 2006). Although theories of ageing have long been debated, the modern perspective driving research, indicates that there are three biological categories of ageing, namely, primary, antagonist and integrative hallmarks (Lopez-Otin et al., 2013). For example, a paper by Lopez-Otin et al (2013) outline 9 highly interlinked hallmarks include, genomic instability, telomere attrition, epigenetic alterations, loss of proteostasis, deregulated nutrient-sensing, mitochondrial dysfunction, cellular senescence, stem cell exhaustion, and altered intercellular communication. New advancements in research, aimed to improve health care and age-related disease interventions, as outlined in the Copenhagen ageing meeting 2022, have resulted in the introduction of new hallmarks of ageing to further inform and improve ageing research, namely, compromised autophagy, microbiome disturbance, altered mechanical properties, splicing dysregulation and inflammation. (Schmauck-Medine et al (2022). The ageing hallmarks provide a more comprehensive explanation of ageing, age related disease and musculoskeletal changes such as those relevant to falls, as the smallest biological hallmark change, can induce a cascade affect that impacts the whole body.

1.2 Biological hallmarks of ageing

Biological hallmarks are a complex network of cellular, molecular, and physiological changes that drive the ageing process (Colloca et al., 2020). There is not one specific change that defines how an individual ages, rather combinations of different biological hallmarks working together or against each other, that lead to a gradual impairment to structure, function, and maintenance (Dodig, Cepelak & Pivic, 2019). Whilst there is an open debate as to what the specific hallmarks of ageing are, research outlined by Lopez-Otin et al. (2013) & Schmauck-Medina et al. (2022), provide the most recognised and accepted explanation and categorisation of fourteen hallmarks. This next section will provide an overview of the hallmarks and their interconnectedness, whilst providing evidence of how such hallmarks may contribute to the ageing process. This section is imperative to this PhD thesis as how we age predicts expectancy and resilience to external stressors.

1.2.1 Telomere shortening

Chromosomes are thread-like structures made of protein and a single molecule of DNA, found in the nucleus of cells, with the primary goal of carrying genomic information from cell to cell (Genome Research Institute, 2023). The problem with chromosomes is that there are ends to each chromosome, for which, if not protected, can be damaged or merge with another loose DNA end (Genome Research Institute, 2023). Fortunately, at the ends of each DNA there is a protective device known as a telomere. The telomere is a region of repetitive DNA TTAGGG sequence, which is an extremely long stretch of a specific DNA sequence that repeats on itself hundreds if not thousands of times. At the end of the telomere repetitive sequence is a T-loop which stops the chromosome ends from all sticking together (Genome Research Institute, 2023). The theory is, every time a cell divide, some of the repetitive telomere gets cut off, thus there are only so many times a telomere can get cut off, before there is nothing left. This limit, ineffectively renders the chromosome defenceless leading to cell damage and ultimately cell senescence. It is this cell death that is thought to lead to ageing and age-related disease.

The limit of replication before senescence is commonly linked to The Hayflick theory, created by Leonard Hayflick in the early 1960s. His work became an extension of Nobel prize winner Alexis Carrel`s work on tissue culture and replication. Hayflick, studied the normal cycle of cultured cells over three stages he termed Phase 1 – primary culture, phase 2 – proliferation and stage 3 – senescence. The results of his cellular research found; a cell can only undergo mitosis approximately 40-60 times before a cell will enter a phase of senescence. Similar research in this field suggests cellular division can take place anything between 40-100 times before senescence (Suram & Herbig, 2014).

1.2.2 Cellular senescence

When cells reach their final stage phase, they can no longer divide and enter senescence. Senescence is an irreversible cell cycle arrest driven by a variety of biological mechanism (Florido, Tchkonia & Kirkland, 2011). Senescent cells are typically characterised via, 1) permanent cell cycle arrest, due to blockages (Krenning et al., 2014) 2) senescence-associated secretory phenotype, which encompasses the synthesis and release of proinflammatory chemokines, cytokines, growth factors and metalloproteinases (Martinez-Cue & Rueda, 2020), 3) altered mitochondrial function and morphology linked to oxidative stress, 4) changes in cellular metabolism and 5) DNA damage that alters chromatin structures (Martinez-Cue & Rueda, 2020).

Cellular senescence can exert both positive (programmed) and detrimental (accumulating) influence over cells. For example, programmed cellular senescence holds positive contributes to, embryo development (Dominguez-Batista, Acevo-Rodriguez & Castro-Obregon, 2021) regulates embryonic skeletal development and controls bone growth/acquisition during childhood (Liu & Wan, 2019). However, in contrast, cellular senescence also becomes detrimental as cells stop dividing and accumulate with age (Regulski, 2017), Moreover, additional changes are postulated to both increase production and decrease removal of senescent cells (Karin & Alon, 2021), with senescent cells accumulating in tissue that promote degeneration and malignancy (Ovadya et al., 2018), age related disease (Regulski, 2017), oncological change (Regulski, 2017) and neurodegenerative diseases such as dementia (Behfar, Zuniga & Martino-Adami, 2022).

1.2.3 Stem cell exhaustion

Stem cells can self-renew in undifferentiated state and to differentiate (specialise) into many types of cells with specific functions upon receiving appropriate triggers (Oh & Choo, 2011). Typically characterized based of their potency and differentiation potential, stem cells fall into 5 categories. Firstly, Totipotent stem cells (TSC) can differentiate into all cell types in an organism. Typically found during sexual reproduction, they hold potential to develop into a fully functioning embryo and then a fully functioning organism (Loya, 2014). Next, pluripotent stem cells (PSC) can self-renew indefinitely while maintaining the ability to become almost any cell type in the human body (Zhu & Huangfu, 2013). Multipotent stem cells (MPC) are the next category and like other stem cells are undifferentiated cells that have the ability of self-renewing. MPC`s have the ability of differentiation into multiple lineages playing an active role in development, tissue healing and defence within the body (Sobhani et al, 2016). Following on, Oligopotent stem cells (OSC) are cells that reside in tissue and can self-renew and differentiation only into closely related cell types (Ilic & Polak, 2011). Finally, Unipotent stem cells (USC) how slightly different characteristics as whilst they have an ability to self-renew, USC typically differentiate into a single cell type (Loya, 2014).

A new model to understand stem cell changes during biological ageing focuses specifically on a type of stem cell called hematopoietic stem cells (HSC), which are cells present in blood and bone marrow, capable of forming red blood cells, platelets and white blood cells and characterised by their exponential ability to self-renew and pluripotency (capable of differentiating into many cell types)

(Bernitz et al., 2016). Research suggests that as we age biologically, ageing HSC`s show a decrease in the potential to not only differentiate into lymphoid lineage, but a compromised quality of myeloid cells (Mejia-Remirez & florian, 2020) which when broken down into basic terms infers an inability to recognise and create lymphocytes a type of white blood cell which includes natural killer T and B cells, inferring a lower white blood cells count, with the compromised quality of myeloid cells increasing the propensity for cells to inflict damage to innocent tissue such as, increasing the risk of cancer (Engblom, Pfirschke & Pittet, 2016). This reduction of HSC stem cells during the natural ageing process, provides further evidence of why the natural ageing process sees a reduction in the observable characteristics or phenotypes of an individual, be it reduced immune systems or an increased propensity to develop uncontrolled growth and division of cells that may result in devastating diseases such as cancer.

Interestingly, research to understand stem cell changes in ageing has also taken on a Darwinian-like natural selection theory to explain stem cell loss. Goodell & Rando (2015) created a fitting model of stem cells over the life span, which outlines that stem cell activity during development, growth and adult reproductive years is highly shaped by natural selection, as these phases cover survival and reproduction critical to the propagation of the species (Goodell & Rando, 2015). However, when humans peak and natural selection is not an external pressure, there is a significant decline in stem cell activity in most tissue. Of further interest in this field is the use of heterochronic transplantation, to understand how stem cells age under exposure to different systematic environments (Conboy et al., 2005, Villeda et al., 2011). For example, in a study by Villeda et al. (2011) they were able to provide evidence that blood-borne factors in systemic milieu can inhibit or promote neurogenesis in age-dependent mice. Young mice (peak condition) which were exposed to plasma from old mice developed a significant decline in synaptic plasticity, impaired fear conditioning, spatial learning and memory. Similarly, Conboy et al. (2005) were able to find a reverse effect to ageing, via parabiotic pairings between young and old mice. Old mice which were exposed to the serum of young healthy mice, were found to have restored activation of notch signalling (conserved signalling pathway allowing communication between two adjacent cells, elicits downstream responses, maintenance and proliferation (Tang et al., 2012), in addition to proliferation and regeneration capacity of the aged satellite cells (Conboy et al.,2005), thus suggesting age related cell change, in animal models at least, is a feasible factor that can be modifiable, and a potential target of future research to modify the natural ageing process in humans.

1.2.4 Mitochondrial dysfunction

Mitochondrial DNA (mDNA) is DNA located within mitochondria, with the primary function to generate large quantities of the energy-carrying adenosine triphosphate (ATP) (Britannica, 2023), with ATP using chemical energy obtained from the breakdown of food molecules, to fuel multiple cellular processes within the body (Britannica, 2023). Moreover, mitochondria store calcium, that is used for cellular communication, excitation, and cell growth/death, with this calcium-based modulation maintain a level of homeostasis within cells (Giorgi et al., 2012). It is proposed that mitochondrial dysfunction in ageing, derives from a link between ATP synthesis and reactive oxygen species (ROS). The normal processes of ATP converting energy to fuel cell turnover converts on average up to 4% of all oxygen into superoxide free radicals (Melov, 2006). Given the damaging effects of free radicals in the body, eukaryote cells have evolved to create superoxide dismutase, that can detoxify any superoxide’s that are produced (Melov, 2006). However, the problem arises when ATP processing is altered, disrupted or halted, which can lead to a build-up of reactive oxygenated species (ROS), which in turn induces oxidative modifications in oxygen species, proteins or lipids resulting in cell damage and death (Wu & Caderbaum, 2003). It is suggested by Melov, (2006) that when the ROS take hold of ATP synthesis, organs such as the heart and brain are most affective, with ataxia, stoke and progressive dementia being the most prevalent changes.

1.2.5 Epigenetic alteration

A key contributor to genomic stability and function in humans derives from epigenetic mechanism. Epigenetics regulate normal gene expression via 3 distinct paths, namely DNA methylation, histone modification and non-coding RNA. Firstly, DNA methylation is a gene expression regulator that either recrates proteins involved in gene repression or by inhibiting the binding of transcription factors to DNA (Moore, Le, Fan, 2012). In normal circumstances, methylation turns genes off and demethylation turns genes on (CDC, 2023). Histone modification, encompasses the turning on and off of genes, via how loosely or tightly packed together histones are (CDC, 2023). Finally, non-coding RNA are functional ribonucleic acid (RNA) molecules that regulate gene expression at the transcriptional and posttranscription level, that exhibit cell/tissue/developmental specific expressions and functions that promote and maintain tissue identity (Bertrand-Lehouillier, Legault & McGraw, 2019). Moreover, it is thought that non-coding RNA can recruit proteins that are able to target and modify histones, that in turn can turn genes on and off (CDC, 2023).

The natural ageing process sees a shift in epigenetics, with your epigenetics at birth being different to your epigenetics during adulthood or old age. For example, Heyn et al. (2012), evaluated DNA methylation concentrations in babies and centenarians via Whole-genome bisulfide sequencing (WGBS). Sequencing data found that centenarians DNA had lower DNA methylation content with a reduced correlation in the methylation status of cytosine, phosphate, and guanine, throughout the whole genome, compared to that of babies, who maintained homogenously methylated DNA (Hayn et al., 2012). It is suggested that reduced levels of DNA methylation can increase risk to multiple biological changes including chromosomal rearrangements, increase cancer formation and progression, influence neurological and immunological disease (Verma et al., 2003).

Epigenetic changes to non-coding RNA have additionally been found to be involved in neurodegenerative diseases such as Alzheimer’s (Gao et al., 2020, Wang et al., 2018 & Khodayi-Shahrak et al., 2022). For example, in a review paper examining the mechanism of non-coding RNA in the pathogenesis of Alzheimer’s, Khodayi-Shahrak et al. (2022) outlines how RNA changes during ageing influence the human brain via pathological procedures, with specific focus Long non-coding RNA (lncRNA) a large group of RNA, highly expressed in the brain, playing an important role in inflammation, oxidative stress, apoptosis, immune response and proliferation to name a few (Eptaminitaki et al., 2021). Their review found lncRNA increased the production of Aβ over expression, reduced the ability of neurons to respond to DNA damage, Increased the production of amyloid precursor protein (APP) and increased tau hyperphosphorylation. It is believed that this increase in Alzheimer's pathology is linked to a natural reduction and dysregulation in non-coding RNA numbers and their proliferative potential during the ageing process, leading to a reduced development and maintenance of the regulatory systems (Pereira-Fernandes, Bitar, Jacobs & Berry, 2018). Furthermore, Fernandes et al. (2018) suggest age related disturbances of lncRNA can change the genomic and epigenetic regulatory landscape of neurons, thus such affecting neurogenesis and synaptic plasticity.

Interestingly, of the many biological processes that change over the ageing process, epigenetics shows some reversibility in response to behavioural or environmental factors. McCarthy et al. (2018) we able to provide evidence for epigenetic changes due to giving up smoking. DNA methylation patters from blood samples were taken from current smokers in response to dose and duration of smoking, along with the effects of smoking cessation on DNA methylation in former smokers. Finding from this study suggest, smokers have less DNA methylation than non-smokers, with the difference greater for heavy/long term smokers. Individual who quit smoking, began to develop an increase in DNA methylation at the AHRR gene, with the ability to reach methylation level of those who have never smoked (McCarthy et al., 2018). Thus, suggesting our environment and behaviour can produce measurable epigenetic change, which in turn provides an opportunity to change our behaviours at a younger age to facilitate healthy ageing for the future.

1.2.6 Loss of proteostasis

Proteostasis is the homeostasis of maintaining the proteome (a complete set of proteins expressed by an organism), by regulating protein synthesis, trans locational, post translational modification, folding and degradation of toxic oligomers into benign and less toxic aggregates (Verma, Verma, Chaphalkar & Chakraborty, 2021) and is imperative to preserve physiological processes within cells (DiDomenico & Lanzillotta, 2022). The proteostasis network is particularly important as it suppresses aggregation of protein, which in turn stops the accumulation and clumping together of protein aggregates (Labbadia & Morimoto, 2015). The beauty of proteostasis functionality means that when misfolded or aggregated states cannot be restored to their original state, proteostasis is able to use chaperones in the form of proteasomes or lysosomes to help redirect misfolded and aggregated cells towards degradation pathways, that can further support the turnover of healthy processing (Labbadia & Morimoto, 2015).

Leading evidence suggests however, that the ageing process leads to a decline in active proteostasis, which cascades into unstable transgenic proteins and an accumulation of protein aggregates (Verma et al., 2021, Labbadia & Morimoto, 2014, Kaushik & Cuervo, 2015, Hipp, Kasturi & Hart, 2019) due to external and endogenous stress that occur over a lifetime (Hipp et al., 2019). It is believed that loss of proteostasis is a leading contributor to pathologies such as Alzheimer’s and Parkinson’s, which coincidentally are known as proteinpathies (Kaushik & Cuervo, 2015). The development of such debilitating neurodegenerative diseases is thought to be exacerbated via an accumulation of misfolded and aggregated proteins, which favour targeting postmitotic cells such as neurons (Hipp, Kasturi & Hartle, 2019). Proteostasis in neurodegenerative diseases is thought to be linked to 4 distinct proteostasis changes including dysregulation of molecular chaperones, disruption of protein degradation pathways, stress response pathways and spreading protein aggregates. Whilst a full explanation into these changes is beyond the scope of this paper (see Labbadia & Morimoto, 2014 for full outline), leading research suggests that these changes are a consequence of increased neurotoxic protein aggregates of proteins such as amyloid, tau etc. Moreover, Ubiquitin in particular a post-translational protein thought to influence protein fate and function (Harris, Jasem & Licchesi, 2020) is believed to further exacerbate degeneration via homeostasis alterations, malfunctioning receptor trafficking, and altered DNA response, which in turn may lead to inflammatory response, autophagy and alterations to mitochondrial energy metabolism (Harris et al., 2020, Schmidt, yan Gan, Komander & Dewson, 2021).

Investigations into proteostasis in ageing are however progressing. Animal models are providing positive results when monitoring the effects of pharmacological intervention on the proteostasis network in in neurodegenerative diseases. For example, in a review paper by Labbadia et al. (2014), it was postulated that 19 compounds including, but not limited to Radicicol, Arimoclomol, clonidine and dexamethasone are able to influence the effects of disease. The effects of such compounds were able to, delay aggregation, suppress motor neuron death, suppress photoreceptor neuron degeneration, and suppress aggregation. Whilst this research is still in early development, it provides evidence that medical interventions in the future may be able to facilitate protein homeostasis during the again process, that in turn may reduce the devastating impact diseases such as Alzheimer’s have over a person.

1.2.7 Deregulated nutrient sensing.

Humans are dependent on nutrients we feed our body, to facilitate metabolic function. Moreover, multiple physiological process that occur in the body additionally require nutrients such as glucose, amino acids, and lipids to maintain a level of homeostasis, that allows components such cells, proteins, DNA to communicate information, suppress aggregation, facilitate cellular differentiation and regenerate our body to keep it at optimal functioning. For example, the pancreas requires sensing glucose to secrete different hormones to stimulate the brain and gut to increase or decrease food intake (Sung, Yu & Han, 2023), similarly the amino acid arginine increases t-cell production that ensures a healthy immune system (Geiger et al., 2016). Moreover, lipids such phospholipids are the main building blocks of mitochondrial membranes (Paradies, Paradies, Ruggiero & Petrosillo, 2019). Nutrient sensing has been showed to be a key regulator of epigenetics and enhance autophagy (Mandhair et al., 2021) and metabolic regulation in stem cells (Ochocki & Simon, 2013) that can minimise the production of reactive oxygen species. Nutrient sensing is particularly noted via genetic manipulation that alter signalling in mTORC1 essential for cell growth, biosynthesis of macromolecule organismal growth (Ben-Sahra & Manning, 2017) and IGF-1 and insulin-based growth factor.

The process of nutrient sensing to enhance, maintain and repair physiological processing does however diminish with age, which may contribute to altered cellular response to nutrition and regulated metabolism/energy production, specifically via the failure of pathways to sense nutrients that in turn hinder the process to which cells grow and repair (Tomtheelnganbee, Sah & Sharma, 2022). For example, insulin sensitivity has been noted to be in decline in the ageing population, with tissue having a reduced ability to uptake and use insulin (Barzilai & Ferrucci, 2012). The outcoming of such change may increase the development of diabetes, which can create a cascade health effect that influences vision, weight, altered kidney homeostasis and reduced infection healing. Similarly, nutrients such as vitamin D are shown to decline in aging (Berridge, 2017). In a paper by Berridge (2017), It is outlined that Vitamin regulates ageing via controlling autophagy, mitochondrial dysfunction, oxidative stress, inflammation, calcium signalling, epigenetics, and DNA disorders. The basis of this paper thus suggests that individuals with Vitamin D deficiency have increased risk of irreversible damage to cells and DNA, which increases the probability of developing age-related disease such as Alzheimer’s.

With regards to irreversibility, It is postulated that dietary / calorie restriction models and a specific diet may be able to some extent, increase longevity and protect the body from premature ageing and age related disease (Mitterberger, Mattesich & Zwerschke, 2014, Aunan, Watson, Hagland & Soreide, 2016), due to the ability of Calorie restriction and diet to elicit a hermetic response that boosts and regulates metabolism, thus supporting healthy physiology and cellular function (Tomtheelnganbee, Sah & Sharma, 2022). For example, Speakman & Mitchell (2011) suggest that calorie restriction can reduce oxidative stress to cellular physiology. Similarly, Finkel, (2015), suggests calorie restriction helps remove visceral fats, which in turn stops the development of inflammatory and diabetogenic activity. Moreover, Calorie restriction is thought to support autophagy, which allows for optimal stem cell activity and transformation of cells to malignancy (Galluzzi et al., 2015, Tomtheelnganbee et al., 2022). Similar results have been found with intermittent fasting and time restrictive feeding. Shannon et al. (2021) are quick to point out however, that it is not specifically calorie restriction that facilitates ageing, it is the healthy foods that we eat, I.e. Mediterranean diet.

Shannon et al. (2021) outline, that key dietary aspects of the Mediterranean diet (i.e., nuts, olive oil, vegetables, polyphenols, red wine, fruit, folate oily fish) can reduce oxidative stress, DNA damage, with those who stick to a high Mediterranean diet associated with longer telomere length and activity.

1.2.8 Intercellular communication

Intercellular communication is the different ways through which cells are able to communicate and transfer information (Fafian-Labora & Loghlen, 2020). Cellular communication can come in many forms including ions, metabolites, receptors, junction proteins, integrins proteins, ligands etc, with some molecules supporting structural cellular interactions, whereas ligands such as hormones, chemokines and neurotransmitters facilitate cell to cell communication (Armingol, Officer, Harismedy, 2021). Moreover, cells can also communicate within themselves using intracellular signalling (Fafian-Labora & Loghlen, 2020).

An exemplar to understand cellular communication derives neurotransmitters, of which humans have 40 neurotransmitters in the body. These are a substance, that use neurons to communicate with each other and with a target tissue in the process of synaptic transmission (Ken hub, 2023). As information arrives at an axon terminal an action potential takes place, this changes the polarisation of a cell via the influx of Ca^{2}. Synaptic vesicles, which store various neurotransmitters are released into the synapse cleft, where they then bind to receptor proteins in the cellular membrane of the target tissue (Ken hub, 2023). Once cellular information is passed to the next cell the tissue can act in one of three ways; 1) excitability, meaning information transfer can continue, 2) inhibited or 3) modified. A full detailed account of neurotransmission is beyond the scope of this paper, for a full account see Hyman (2005).

As noted previously, neurotransmitters are only one of multiple means of cell communication that facilitate information transfer, but what if the intercellular communication fails. There are many plausible causes such as; losing signal, not reaching a target, target being ignored, excitotoxicity, cellular breakdown leading to uncontrolled cell growth and disease interventions. A good representation of intercellular communication failure is a stroke, which are common in older adults due to cardiovascular changes and other co-morbidities. A stoke in basic terms is a brain attack, where part of the brain loses blood supply (Stroke UK, 2023). Immediately after the stroke takes place, cells in that area of the brain begin to die off. Following this there is a high influx of calcium ions through the NMDA receptors, which tigger overactivation of extracellular glutamate concentrations that rise abruptly, stimulating the GlN2B containing DMDAR in the extra synaptic sites, that triggers excitotoxic neuronal death (Lai, Zhang & Wang, 2014, Hazell, 2007). Similar concepts of excitotoxicity have been also been found in age related diseases such as Alzheimer’s (Wang & Reddy, 2017, Hynd, Scott & Dodd, 2004).

Age related changes to cellular communication are also linked to inflammatory reactions that increase with age. Moreover, as inflammatory reactions increase, monitoring of pathogens and premalignant cells decline, which in turn alters the cellular environment (Lopez-otin et al., 2013), becoming a leading cause of cellular senescence. More worrying, is recent evidence that suggests cellular communication via age related inflammatory change, can become contagious, in that senescent cells induce senescence in neighbouring cells via ROS (Lopez-Otin et al., 2013) that rapidly influence disease fighting T cells. This cascade effect of cellular death, inflammatory markers, and t cell changes, ultimately has a detrimental effect on the ageing process leading to diseases such as cancer and stroke. Most interestingly, recent evidence suggests, T-cell communication changes may also influence neurodegenerative diseases (McManus & Heneka, 2020) via infiltration into the brain, which may exacerbate disease progression (Ferretti et al., 2016). This is however, research of the cusp of development, with more research need to understand the mechanism of action.

1.2.9 Genomic instability

Genomic stability is an imperative feature that not only preserves genetic material it also transmits genetic information between generations in families or from one somatic cell to another (Kovalchuk, 2021). Preservation of genetic material can include, but not limited to, features such error free replication of DNA/RNA and correcting of replication mistakes (Kovalchuk, 2021) which are imperative for cell function and DNA, as noted above in the epigenetic section.

Similarly, preservation of genetic material is key to theories such as that of Hayflick, and the number of times a cell can divide before programmed death or apoptosis, (noted above in the telomere section). As such, it should not come as a shock that the natural ageing process and the accumulation of genetic damage that has been collected through our lives, alters homeostasis within our genome and able to produce instability. Genome instability, in its most basic terms defines genetic change that can include base pair changes, inversion and deletions in genetic algorithms, inversions and through to larger scale alterations that can impact translocation, duplication of genomic section and whole chromosome annihilation (Weinert, Kaochar, Jones, Paek & Clark, 2009, Anzalone et al., 2021, Auton et al., 2015).

Disease that are commonly linked to genomic instability, particularly during the ageing process are cancer (Kovalchuk, 2021), Alzheimer’s (Hou et al., 2017), cognitive impairment (Meramat, Rajab, Shahar & Sharif, 2015) and cardiovascular ageing (Abdellatif, Rainer, Sedej & Kroemer, 2023). Cancer and genomic instability research for example has shown genomic instability can develop following an inactivation of BRCA, BRCA2 or BRCA3 genes, which as a result, cancerous tumours that are growing rely on error prone repair, and accumulate mutations and chromosomal alterations, which in turn, can accelerate cancer progression and drive therapy resistance (Morris et al., 2022, Turner, Tutt & Ashworth, 2004). Moreover, it has been found that melanomas and bladder chancers are extremely genomically unstable with high mutation rates (Walker et al., 2018), along with Hodgkin lymphoma (Wienand et al., 2019). More worrying, recent evidence is suggesting that instability of chromosomes can be a driving force in tumorigenesis and cancer evolution, which is shaping the genome of cancer cells, that can maximise the cancer cell survival, giving cancer a survival advantage against possible treatments (Lee, Choi, Kwon & Park, 2016).

As with Cancer, genomic instability is intrinsically linked to Alzheimer’s disease (see Hou, Song, Croteau, Akbari & Bohr, 2017 for full overview). There are many ideas of how Alzheimer’s and genomic instability are linked, with the lead cause suggesting that unscheduled and incomplete DNA replications destabilise the genome in the brain, thus causing cell death, accumulation and clumping (Lourov et al., 2011). Moreover, it is suggested, the number of brain cells with abnormal chromosome, are increased at a rate of 2 folds in Alzheimer's disease (Yurov, Vorsanova, Liehr, Kolotii & Iourov, 2014), particularly chromosome 21, which is known to be the location the gene linked to amyloid precursor protein (APP), a component of the amyloid plaques found in Alzheimer's disease (Potter et al., 2019, Yurov et al., 2011). Support for the theory of genomic instability facilitating Alzheimer's development and progression derives from individuals who live with the genetic disorder, Down syndrome. This support derives from two routes, firstly, the link between the abnormal chromosome found in those with Alzheimer's disease on chromosome 21 and the third copy of chromosome 21 in those with down syndrome. Secondly, research has shown, those with down syndrome are at greater risk of developing Alzheimer's disease, and deemed very high risk for early onset dementia (Fortea, Zaman, Hartley, Rafii, Head & Carmona-Iragui, 2021). This supporting research, whilst brief in overview, provides a hint of evidence that genomic instability, weather being born with a disease, or via age accumulated, Is able to provide mutations and alterations to our genome that facilitate the development and progression of disease, neurodegeneration and a plethora of epigenetic alterations.

1.2.10 Compromised autophagy

Autophagy, whilst originally encompassed in the hallmark "altered proteostasis", have been given its own hallmark category, due to the regulatory mechanisms held over a plethora of ageing traits, namely, DNA repair, nutrient sensing and metabolism (Kaushik & Cuervo, 2018). Autophagy is the formation of autophagosomes by membrane wrapping part of the cytoplasm, organelles and proteins that need to be degraded in cells. Autophagosomes are fused with lysosomes to form autophagolysosomal, which degrade content of inclusions, to achieve cell homeostasis and organelle renewal (Cao, Li, Yang, Cao, 2021). Autophagy is also imperative for removal of misfolded or aggregated proteins and eradicating intracellular pathogens (Glick, Barth & Macleod, 2010), whilst imperative for balancing sources of energy at critical times in development, as a response to nutrient stress (Glick et al., 2010). Autophagy are characterized by 3 forms; Macro, chaperone-mediated and micro, and can facilitate degradation via bulk load of selective (for a full overview of autophagy see (Cao et al., 2021, Wong, Kumar, Mills & Lapierre, 2020).

Whilst we know autophagy is imperative for cellular homeostasis and preservation of genomic integrity and function (Caponio et al., 2022), we also know that the natural ageing process creates a decline in autophagy, rendering it compromised, that can contribute to the development of chronic disease and neurodegeneration (Fang et al., 2019, Leidal, Levine & Debnath, 2018). Compromised autophagy for example has been linked to the development of Alzheimer's, due to the link between autophagy-lysosome deficits occur relatively early in Alzheimer's pathogenesis (Zare-Shahabadi et al., 2015). When autophagy is compromised, cells that are responsible for removing the protein aggregates of amyloid cannot work efficiently, causing a cascade effect repeated production of proteins that spread through the brain. Similarly, studies such as that by Sun et al. (2014), found that the protein mTOR and its associating upstream molecules, enter a hyperactivation, which can produce a longstanding autophagy inhibition, rendering the autophagy compromised, which induces the production of plaques and tangles to spread through the brain.

Support of this notion that compromised autophagy pathways influence AD, can be found in animal models, particularly via the introduction of knock out mutations. For example, Rocchi et al. (2017) disrupted BECN1-BCL2 protein binding in mice and were able to activate autophagy. Furthermore, mice with Alzheimer's which already carry this mutation in their genes anyway, showed significantly lower amyloid plaques and cognitive impairment, thus providing a link between not only compromised autophagy, but a possible means to reactivate homeostatic autophagy function. Moreover Nilsson et al. (2013) suggesting knockout of Atf7 in amyloid precursor protein mouse models could enhance and reactivate efficient autophagy activity and enhance the secretion of amyloid beta. Notions such as that of Rocchi et al. (2017) and Nilsson et al. (2013) are now being used as models to create therapeutic strategies that may in the future help treat Alzheimer's. Currently mTOR inhibitors such as rapamycin and tat-BECN1 peptide are under review.

1.2.11 Microbiome disturbances

The human microbiome is a vast and diverse group of microorganisms. Trillions of microorganisms such as bacteria, archaea, fungi, protozoans and non-living viruses are found both inside and on our body. This group of microorganisms, called microbiota, are completely individual to the person and are determined by an individual's DNA, with first exposure to microorganism at the moment of passing through the birth canal and first drinking breast milk, though to later life where exposure to the environment and diet can reflect how the organisms work. Interestingly, the largest numbers of microorganisms are found in the gut, with approximately 30-400 trillion gut bacteria, both good and bad, which do not require oxygen for growth, as it is anaerobic. The microbes that are houses in our bodies can be symbiotic which is beneficial to the body or pathogenic, which may promote disease. Fortunately, both pathogenic and symbiotic microbes work together to maintain a level of homeostasis, that is until there is a disturbance, such as via illness, diet, and prolonged use of antibiotics to name a few, thus rendering the body more susceptible to disease. It is not commonly known amongst the general population, but microbiota stimulate the immune system, and aid the break down toxic food and compounds that are ingested, thus if we do not have the homeostasis maintained in the body, we could potential be increasing our risk of a multitude of age related diseases such as gastric cancers, cardiometabolic alterations, inflammation and more interestingly, a link between gut microbiome and the promotion of the formation of amyloid bundles in the brain linked to Alzheimer's.

The link between gut microbiome and age-related disease is still up for debate amongst the medical and research communities. However, there are around certain systems within the body that that researchers believe are altered during the ageing process. Buford (2017), sets out 6 prominent health conditions linked to gut dysbiosis, that include; nervous system (Parkinson's, Alzheimer's and multiple sclerosis), Musculoskeletal (fragility, osteoporosis, rheumatoid arthritis and gout), pulmonary (cystic fibrosis), digestive (IBS, Crohn`s), Cancer (colon) and cardiometabolic (obesity and diabetes). Researchers such as Belkaid & Hand (2014) and Buford (2017) suggest that as individuals are relying on the use of antibiotics and not sticking to a healthy diet, there is a depletion in symbiotic microbes, which in turn is leading to chronic activation of the immune system and a startling spike in inflammatory markers. Inflammatory markers such as lipopolysaccharides (LPS) which form cell wall components of gram-negative bacteria are under normal conditions restricted to how they move via intestinal epithelial and mucosal layers, however, when gut microbiota are disrupted and pathogenetic bacteria takes over the gut, movement of LPS is not restricted and can leave the intestinal barrier and enter into circulation through the body (Ghosh et al., 2020). The cascade effects as a result of such release of LPS can activate inflammatory cytokines, leading to inflammatory changes throughout the body (Janssen et al., 2017), hence the link to Alzheimer's, cardiovascular and cancer pathologies (Bander et al., 2020). For a full overview of this see (Bander et al., 2020)

1.2.12 Splicing dysregulation

The principles of human biology outlined that all genetic information is encoded in DNA and then transcribed into RNA, which is then translated into a protein. Splicing occurs at the point when genetic information is altered while in RNA form by removing introns, leaving only protein coding regions called exons at the intron/exons borders at point 3 and 5. Spliceosomes bring exons of either side of the intron close together where a loop is created and they are prepared to be cut. Spliceosomes cut away the intron and RNA and join the exosomes back together. The intron and RNA that have been release now hold complete instructions for a protein (Jurica & Roybal, 2013) For a full, detailed overview see Clancy (2008). As, we age, the functionality and reliability of splicing decreases. It is believed that approximately a third of splicing factors, present with age-related transcript expression changes (Holly et al., 2013). More worrying is the splicing change in approximate exons with age in human temporal cortex (Tollervey et al., 2011). Tollervey et al., 2011, analysed changes to transcript levels and splicing in the temporal cortex of those who were cognitively normal, suffered with frontotemporal lobar degeneration (FTLD) or Alzheimer's. The results found approximately 1174 splicing changes in cognitively normal individuals. It was additionally found that these changes were present in 95% of individuals with FTLD and Alzheimer’s, independent of age. Such changes were believed to be linked to an age-related increase in polypyrimidine tract binding protein (Tollervey et al., 2011).

1.2.13 Altered mechanical properties.

Mechanical properties of a cell are imperative to cell functioning as it allows cells to adapt to match the surrounding area. Mechanical properties have been shown to influence cell adhesion, migration, polarisation, differentiation, with the addition of organelle organisation and trafficking in cytoplasm (Wu et al., 2018). It is not known exactly why, but mechanobiological changes are prevalent through the natural and pathological ageing process. Cellular mechanobiology has been shown to influence, cell mechanics (stiffness, Elasticity, reduced sensitivity), Cellular force (hypertension, sagging skin increase, reduction in mechanotransduction), nuclear mechanics (Mutant Lamin A altered chromatic, deformability), mechanosensitive signalling (Increased inflammation signalling, decreased focal adhesion), cytoskeleton (decreased sensitivity, remodelling) and extra cellular matrix changes (Increased crosslinking, Increased fibre fragmentation and decreased stiffness) (Bajpai, Li & Chen, 2020, Hoeijmakers, 2009, Philip et al., 2015).

As human progress through the ageing process, altered mechanical property changes have been linked to Stroke (Zielinski et al, 2022), Alzheimer’s disease (Hall, Moeendarbary & Sheridan, 2020), cancer & cardiovascular disease (Bajpai et al., 2020) For example, when an individual suffers a stroke, there is a lack of blood supply to the brain, which in turn leads to oxygen and glucose deprivation. It is believed, that when this happens, the damage the surround tissue to where the stroke takes place, also change the functioning on cells, due to the ability of cells adapting to the surrounding area (Wu et al, 2018, Zielinski et al., 2022), thus altering cell properties. Similarly, brain cells in those with Alzheimer’s disease have been shown to have altered mechanical properties, due to an inability to readapt. Hall et al. (2020) note that the altered mechanical properties of

Alzheimer’s brain tissue hinder regeneration of new synaptic connections, which ultimately leads to a gradual impairment in cognition.

1.2.14 Inflammation

The natural ageing process sees a high proportion of older adults develop inflammation throughout the body, or inflammageing, as it has recently been termed, presenting with elevated blood inflammatory markers. The complications of inflammation derive form the link to disease and death. There are many mechanisms that are believed to be causes of changes to inflammatory markers including, genetic susceptibility, obesity, gut permeability, microbiota composition, cellular senescence, oxidative stress, immune dysregulation and so forth (Ferrucci & Fabbri, 2018), The list of possible mechanisms is by no means complete here, there is an extensive list of mechanism at play throughout the body, but what is common amongst such mechanism is the increased risk factor for cardiovascular disease, cancer, diabetes, sarcopenia and dementia to name a few.

1.2.15 Biological hallmark summary

It is clear from the hallmark research presented, that ageing is associated with biological changes that they can influence health, behaviour and contribute to disease development and progression, whilst influencing a range of system from the smallest of cells to the brain. Some hallmarks individuals may not easily be able to influence to promote healthy ageing, but some we may be able to change via behaviour and healthy option interventions. Research should also consider how the brain plays a defining role in ageing, particularly memory, attention perception and gait, when addressing biological changes during ageing. There are ways that we can maintain healthy brain function, but individuals cannot avoid all brain changes. It is important to note, like the biological hallmarks, the brain of everyone goes through similar brain morphology changes during the natural ageing process, however, there is a large degree of individual difference.

1.3 Changes in the ageing brain (morphological)

Changes to the brain are widespread and have multiple aetiologies. Physical changes can result from grey matter reduction (Giorgio et al., 2010), dendritic arbour, spines and synapses alterations (Morrison & Baxter, 2012), white matter changes via demyelination (Bennett et al., 2010) tissue atrophy (Firbank et al., 2007), accumulation of amyloid plaques and hyperphosphorylation (Fforest et al., 2021), brain volume decrease (Raz et al., 2010), Cortical density (Raz et al., 2010), neurotransmitter changes (Lee & Kim, 2022), ventricle enlargement (Hubbard & Anderson, 1981, Jin et al., 2018, Lee & Kim, 2022). The long-term impact of morphological changes to the brain, contribute to progressive cognitive decline, that influence memory, attention, perception and other high level cognitive function, which will be discussed later in this chapter. The next section of this chapter will focus on providing an overview of the morphological changes the brain goes through during the ageing process. Furthermore, it will provide evidence of how such morphological changes influence executive functioning and gait, to provide support for the research presented in this thesis.

1.3.1 Grey matter reduction

Grey matter contains high concentrations of neuronal cell bodies, axon terminals and dendrites (KenHub, 2023). Grey matter facilitates tasks via small granule cells, acting as intra cortical interneurons and large pyramidal cells, efferent projection neurons traveling within the cerebral cortex (Snyder, Hagan, Bolon & Keene, 2018). Formed during foetal development, grey matter volume continues to increase until an approximate age of eight years old but continuing to increase in density until the age of 20 (Taki & Kawashima, 2012). As grey matter increases, the sulci and gyri that form grey matter within the brain allow expansion of the brain area, causing folds and wrinkles. (Cleaveland Clinic, 2023). This expansion of grey matter allows for exponential growing in thinking and reasoning, sensory perception, movement, language (Farokhian et al., 2017) speech, Memory, and movement (Mercadante & Tadi, 2023) to name a few.

The ageing process however, is characterised by extensive grey matter atrophy, which declines in tandem with cognitive functioning (Ramanoel et al., 2018). Imaging techniques, provide an exciting way to monitor and track grey matter changes. For example, Ramanoel et al. (2018), analysed age-related grey matter changes in normal adult brains. One group of middle-aged adults and another older aged group, underwent magnetic resonance imaging (MRI) and voxel-based morphometry (VMB), whilst cognitive tests were administered to assess cognition range. Results found, older adults, compared to middle age, had smaller grey matter volume in several cerebral and right cerebellar regions, that may be the contributing factor to reduced language and executive function. Similarly, Farokhian et al. (2017) found an extensive reduction in grey matter volume in the frontal insular and cingulate cortices. Moreover, a longitudinal study by Taki et al. (2011) found over the course of 6 years, older adults, particularly women, showed a greater rate of percentage change to their grey matter ration. As presented, these studies suggest that as individuals progress through age, there is a positive correlation between age and grey matter loss. Moreover, observations of grey matter reduction correlate with cognitive loss, thus providing evidence that the mechanisms underlying cognitive decline in older adults. The repercussions of grey matter reduction can be found in memory function, perception, attention and motor function.

1.3.2 White matter changes via demyelination

White matter, a large network of nerve fibres in the brain, facilitate information exchange and communication between all areas of the brain (Cleavland Clinic, 2023). White matter is protected by myelin sheath, which acts as a insulation to the axons of a neuron, with the goal of increasing velocity of electrical signals (KenHub, 2023), via rapid action potentials and separation of axons from interacting with surrounding extra cellular components. As with grey matter, white matter is found in the brain and spinal cord, and situated beneath the grey matter and is made up of three specific axons associations; fibres, commissural fibres and projection fibres (KenHub, 2023).

Age related white matter changes are ubiquitous amongst the ageing population, progress over time and characterised by loss of myelin, axons and oligodendroglia cells (Xlong & Mok, 2011). White matter changes are linked to vascular change, depression, cognitive change and dementia (Wharton, Simpson, Brayne & Ince, 2015). Analysis of white matter changes in elderly has provided some interesting morphological change to the brain including tract length, lesion atrophy (Vernooij et al., 2008, Ouyang et al., 2021 & Leeuw et al., 2002). For example, Leeuw et al. (2002) used MRI to scan for white matter changes in 1007 randomly sampled subjects, aged between 60-90. Analysis confirmed that the proportion of white matter lesions increased with age, whilst being more prevalent in women. Similarly, Ouyang et al. (2021) used a range of imaging techniques to track white matter in 58 adults split into a younger group and a middle-aged group. Analysis found, that middle aged adults had a significant change to white matter compared to young, with white matter tract fibre length, correlating with age. Lastly, Vernooij et al. (2008) used fractional anisotropy and Diffusion Tension Imaging (DTI) to monitor white matter in 832 older adults, aged 60 plus. It was found, with increased age, comes a significant increase in white matter atrophy and lesions.

As noted above, the decrease in white matter is ubiquitous in older adults. The influence this has over white matter function can be seen in the ability to inhibit efficient connections in the brain and spinal cord, thus stopping nerves and axons connecting and passing on information. As a result, there is an increase in lesions, atrophy, and fibre length, which produces a cascade effect throughout the brain including cerebral damage, age related cognitive decline (e.g., attention / inhibition) and vascular disease.

1.3.3 Cerebrovascular change

Vasculature of the human brain consists of two blood supply systems. The internal carotid artery, is the main supply, accounting for 70% of cerebral blood flow and the vertebrobasilar system accounting for the final 30% of cerebral blood flow (Yang, Sun, Lu, Leak & Zhang, 2016). Union of both the blood supply systems in the subarachnoid space, is commonly referred to as the circle of Willis.

Branching from the main blood supplies are branches of varying length, that take blood through the whole brain. Cerebral blood flow is achieved through metabolic regulation, cerebral autoregulation, and autonomic regulation. If the co-ordination of mechanism is functioning efficiently, individuals regardless of age should maintain a healthy cerebral flow (Bolduc et al., 2013), although cerebral vascular ageing is part of the normal ageing process, regardless of health, fitness, and lifestyle.

As with other hallmarks of ageing noted in this paper, the ageing process does have an impact on the morphology of the cerebrovascular systems, with an increased possibility of stroke, brain bleeds, oxidative stress, inflammation, artery stiffening and vascular dementia (Sonntaj et al., 1997). For example, older adults are at increased risk of arterial stiffness, which consequently influences blood pressure, with the possibility of increased systolic pressure and a decrease in diastolic pressure. Moreover, when blood flow mechanisms are altered, mechanosensitive genes can influence the morphology of cerebrovascular, such as vascular wall change and oxidative stress (Li et al., 2023. Moreover, Jellinger (2013) notes that the ageing population may develop deposits of atherosclerotic plaques, which facilitate cardiovascular/cerebrovascular disease via laminal narrowing or precipitating thrombi that obstruct blood flow, leading to heart disease, ischemic stroke, and peripheral vascular disease (Bentzon, Otsuku, Virmani & Falk, 2014).

The most notable of vascular changes in older adults is the development of vascular dementia, caused by a reduced blood and oxygen flow to the brain (LaDecola, 2013). Vascular dementia develops in one of seven subtypes: multi-infarct dementia (cortical vascular), small vessel dementia (subcortical vascular), strategic infarct dementia, hypoperfusion dementia, haemorrhagic dementia, hereditary vascular dementia and Alzheimer’s with cardiovascular disease (O`Brien & Thomas, 2015). The most common causes pathological changes imaging techniques pick up on to establish a diagnosis of vascular dementia include cortical infarcts, extensive white matter lesions, demyelination, gliosis, lacunes and amyloid angiopathy (O`Brien & Thomas, 2015). Similar to that of other neurodegenerative diseases, symptoms include, but not limited to; planning, and understanding problems, concentration, language and memory problems, disorientation, behaviour change, gait and balance abnormality and incontinence (NHS, 2023).

1.3.4 Brain shrinkage

Brain shrinkage during the ageing process is unavoidable. Healthy older adults and those with pathological changes, have smaller brains and thinner cortices even when accounting for individual difference and rate of change. As noted in Blinkouskaya et al. (2021) the brain may shrink due to sulcal widening, ventricular enlargement and cortical thinning. Similarly, as noted above, grey and white matter loss can additionally shrink the brain (Ramanoel et al., 2018). Jack et al., (2004) suggests that healthy individuals loose approximately 0.4% of volume each year. In terms of neurodegenerative diseases, shrinkage rates rise exponentially due to atrophy, with a rate of between 1.4%-1.9% a year, dependant of disease severity (Blinkouskaya et al., 2021).

1.3.5 Neurotransmitter changes

The human nervous system consists of numerous transmitters, which can be inhibitory, excitatory, modulatory or neurohormonal (See Sheffler, Reddy & Pillarisetti, 2023 for full overview). In terms of importance, regardless of age, it is suggested that Acetylcholine (Ach), Glutamate (GL), Gamma aminobutyric acid (GABA), Norepinephrine (NE), Dopamine, Serotonin and Histamine are the key transmitters (KenHub, 2023), given their functionality. Neurotransmitters are used by neurons to communicate with each other and with a target tissue (e.g., within the brain), via synaptic transmission. Synthesised in nerve endings, transmitters are released into the synaptic cleft, before they bind to receptor proteins in the cellular membrane of the target tissue creating information exchange. The passing of information can be inhibitory, excitatory, or modified to pass on a message (KenHub, 2023). For example, GL the main excitatory and abundant transmitter in the nervous system, gets released from sensory neurons, this in turn regulates CNS excitability and can facilitate learning processing, memory, and mood regulation (Pal, 2021).

There can be significant age-related changes to neurotransmitters in the brain, particularly, Ach, dopamine, and serotonin, (Lee & Kim, 2022). Given cholinergic pathways influence cognitive processing and behaviour, cholinergic changes during the natural ageing process can have a lasting effect. A reduction in these transmitters can result in changes to cognition, motor performance, and altered inflammatory markers (Sheffler, Reddy & Pillarisetti, 2023).

Equally important, but frequency overlooked in ageing, are neurosteroids, which when synthesised in the brain modulate neuronal excitability via interacting with membrane receptors and in ion channels such as GABA (Akk et al., 2009, Reddy, 2011). Moreover, neurosteroids are implicated in cognitive change, neuroprotection, and neurotoxicity (Partinen, 2009). In addition, given steroid hormones control influx of glucose levels to cells (Lee & Kim, 2022), alterations to neurosteroids in the ageing process have the capacity alter glucose homeostasis in the brain, thus can infer the development of diseases such as diabetes (Alonge, D`alessio & Schawrtz, 2020) and gut microbiome disturbance (Howard, Lan & Duca, 2022), which as we know for the hallmarks of ageing set out above, can increase the risk of inflammatory cytokines travelling through the body.

1.3.6 Brain morphological changes and gait in ageing

Age-related brain morphological changes can influence gait in older adults. For example, Le floch et al. (2021) found that older adults who were prevalent to falls, had larger grey matter sub volumes in the caudate nucleus, and area known to facilitate visual information processing and control movement. Similarly, Bauchet et al. (2016) found that individuals who were prone to falls had altered sub volumes of the Somatosensory and hippocampal regions, compared to those who ae non-fallers. Moreover, in a 12-month prospective study, Hsu et al. (2016) found older adults who were “fallers” had lower volumes of grey matter, subcortical regions and cerebral white matter. Furthermore, cholinergic neurotransmitter changes in older adults have been found to be linked to changes to gait characteristics (Pelosin et al, 2016). The consensus of research agrees that brain morphological changes associated with ageing, disrupt neural integrity of the motor outputs, thus reducing the efficiency and performance of gait control, that ultimately leads to slips, trips and falls in elderly.

1.3.7 Pathological ageing

It seems prudent to include that for some older adults, the natural ageing process becomes abnormal, and individuals develop age related disease and severe brain morphology changes. Such brain changes speed up and exacerbate illness and disease. In terms of gait, pathological ageing increases risk of falls exponentially. Whilst this is beyond the scope of this thesis and its supporting research, participants that researchers test on can have, and will have pathological changes to the brain that we cannot see or measure, which unfortunately, can be in the form of disease. As such, a short overview will be presented.

Individuals who live with age related pathological change, see the brain morphology change at an increased rate, be it via changes such as volume, inflammation, or an increase in the prevalence of amyloid plaques. Pathological ageing, defined as the presence of age-related disease / illness, independent to that linked to normal age, can present in a plethora of ways including neurodegenerative diseases such as Alzheimer's, Multiple sclerosis, Parkinsons or rare form such as corticobasal degeneration (Armstrong et al., 2013). Moreover, and not typically linked to ageing in the normal context is the extremely rare Gilford Progeria Syndrome (GPS). GPS is a genetic condition that from a young age (approximately 2) sees innocuous changes to the skin such as wrinkles skin fragility and hair loss, as well as physiological altering cardio vasculature, nuclei instability and skeletal strength change. An individual with GPS ages around 10 times, resulting in old age peaking at 15 -20 years of age (Sickles & Gross, 2022).

In relation to dementia, Alzheimer's is the most prevalent and provides an interesting overview between normal and pathological ageing, particularly due to the brain morphology, thus the next section will provide a brief overview of Alzheimer's and the changes that occur. Alzheimer's, is a progressive disease characterised by wide spread brain shrinkage, neuronal death, via an inability to communicate, metabolite and repair (Demetrius & Daver, 2013)and the ubiquitous amyloid plaques and Tau tangles.

Amyloid plaques

Amyloid Precursor Protein (APP) plays a role in cellular functions such as, synaptogenesis and synaptic plasticity (Gralle & Ferreira, 2007) and can promote growth in cells and nutriogenesis in post Milotic neurons (Gralle et al., 2007). However, in the case of Alzheimer's, APP can have a neurotoxic effect, in the form of amyloid peptide deposits. Amyloid plaques/deposits in the brain are derived by proteolytic cleavages of APP accumulation, along with glial and neutric debris (Bazan et al., 2012). The Dense amyloid plaques initially accumulate in the cerebral regions with high metabolic energy activity rates (e.g. Hippocampus, entorhinal cortex), before engulfing the neo cortex, brain stem and finally the cerebellum (Hampel et al., 2021). It should also be noted however, that amyloid deposits, do not always signal the presence of Dementia. Cerebral Amyloid Angiopathy (CAA) is a cerebrovascular disorder characterised by amyloid accumulation in leptomeninges and small/medium blood vessels, which weaken cells walls leading to risk of bleeding, inflammation and cognitive impairment (Kuhn & Sherman, 2023). This is not directly dementia/Alzheimer's, but a disease using the same pathways.

Neurofibrillary tangles

In a healthy neuron, Tau influences microtubules via binding and stabilisation. However, in pathological disease such as Alzheimer's, changes to brain chemicals promote Tau to detach from microtubules and stick together, which over time clump to produce pathological aggregates or misfolded and hyperphosphorylated proteins (Brack & Tredici, 2010). Most Tau filaments tend to twist into a spiral or helix formation, and are found in neurons in the hippocamps and neocortex, with a small number in the cerebrum and brain stem (Xu, Brunden, Trojancouski & lee, 2010) Unlike amyloid plaques, Tau protein in Alzheimer's, do not spread to the whole brain and initially develop in the locus coeruleus and brain stem nuclei (Brack et al., 2011).

Amyloid plaques and hyperphosphorylated Tau proteins in Alzheimer's, detrimentally influence cognitive processing, for example, memory (Younan et al, 2020), attention (McDonough, Wood & Miller, 2019), spatial awareness (Jacus et al, 2022) processing speed (Amieva et al., 2019) language (McDonough et al., 2019) and perception to name a few. As the disease progresses, as does the severity of cognitive decline. Judgement ability, (O`Shaughnessy et al., 2021), personality change, typically in the form of aggression or introversion (NHS, 2023). Unfortunately, Alzheimer's disease ultimately renders the individual incapable of processing the basic everyday tasks such as eating, drinking and maintaining control over bowel and bladder. Motor control also declines, leading to the individual being bed bound.

Neuroinflammation

Whilst amyloid plaques and Tau tangles are the key characteristics of Alzheimer's. neuroinflammation, which was originally believed to be a bystander, has recently being found to play and equal role in this devastating disease. Some researchers have suggested that the contribution of neuroinflammation in Alzheimer's disease may play a greater role than others (Heneka et al., 2015). In basic terms, Neuroinflammation is the activation of cells such as microglial and astrocytes, creating subsequent production of inflammatory markers, thus contributing to the progression and severity of plaques and tangles (Monteiro et al., 2023). The mediators of neuroinflammation come in many forms (see Heneka et al., 2015 for full overview), with the basic contributors as follows. 1), Cytokines, pro inflammatory and uses αβ deposits to drive neuroinflammation. 2), chemokines, regulate microglial migration to areas of inflammation, thus increasing inflammation in that area. 3) Caspases, are key modulators of apoptosis and inflammation, they inhibit the immune system response by releasing pro inflammatory cytokines (Fernandez & Lamkanfi, 2015). 4) Proteinoids & Neuroprotectant DI. 5) compliment system, components of this system alter vascular flow, increasing vascular permeability and inflammatory rates. 6) Nitric oxide and reactive oxygen species (ROS). 7) Inflammatory change of neurovascular unit. It should also be noted that environmental factors such as obesity and brain injury have also been shown to drive inflammatory rate in Alzheimer’s and normal ageing.

Understanding morphological changes during the ageing process are important to this research as those with cognitive impairment for example due to the ageing process are at increased risk of falls and poor gait than those who are younger. Moreover, given attention, a focus of this thesis forms a large part of cognition, there is an even greater reason to understand morphology-based research to guide how we develop our research methodology.

1.4 Age related cognitive change.

The natural ageing process can show a variety of changes with respect to cognitive integrity, which in turn affects the degree to which the brain performs and functions. Whilst there is individual difference associated with cognitive decline such as; brain morphology, disease, genetics, lifestyle, educational attainments, emotional factors, health and economic status (Baghel, Singh, Srivas & Thakr, 2019), there are still commonalities amongst humans. All individuals will see a decline in executive function, memory, attention, and processing speed. It is important to understand cognitive change, as cognition perfects and drives performance. Moreover, falls as researched later in this thesis, are believed to be influenced by cognition, via lack of attention control, spatial memory and goal directed behaviour.

1.4.1 Executive function

Executive function (EF) are high order complex processes that are primarily controlled and modulated via the frontal lobes (Sereno, Babin, Hood & Jeter, 2009). EF facilitates working memory (WM) inhibitory control, cognitive flexibility, reasoning, planning, organising and problem solving (Menon & D`Esposito, 2022). EF allows humans to adapt to a current situation, maintain control over how we interact with the environment, and facilitate goal directed behaviour (Cristofori et al, 2019). Moreover, EF allows voluntary and automatic inhibition of irrelevant stimuli rapidly and unconsciously, whilst holding an ability to use thoughts and emotions to guide behaviour. Developmental trajectory of EF begins in early infancy and by the age of 3, most individuals have sufficient skills to facilitate healthy cognition (Fiske & Holmboe, 2019). Some researchers, suggest EF peaks in performance around 12 years of age (Anderson, 2002), however, contrasting evidence suggests that EF may improve until 20-29 years of age, thus suggesting EF is a prolonged developmental function (Zelazo, 2014). What is agreed on however, is that EF encompasses several functions that peak at different times, in addition to individual difference.

Age related EF performance decline varies, with the consensus of researchers agreeing that increased age, predicts faster rates of decline in all cognitive domains (Zaninotto, Batty, Allerhand & Deary, 2018). Comparisons studies of young v older adults are ubiquitous in the literature and those aged 65> show statistically reduced abilities. For example, Idowu & Szameitat (2023) ran a cross-sectional study to examine inhibition, shifting, updating and duals tasking in young and older adults. Results found; age related difference was found in all measures. Interestingly, it was also found that of all the measure, in older adults, inhibition to irrelevant stimuli showed the greatest decline. Similarly, Buczylowska & Petermann (2016) examined age related difference to an array of EF, with the greatest decline was age dependant, with older adults performing worse in cognitive abilities such as mazes, planning, and categorisation. Of interest, although age related decline was found, letter fluency, word generation and judgement decline less that other measures. Furthermore, Souchay & Isingrini (2004) examined age related difference and found older adults compared to young, were significantly worse at readiness-recall tests with older adults showing reduced memory performance.

In contrast to presenting evidence, Verissimo et al. (2022) favour the notion that whilst some executive functions decline, others improve. 702 participants aged 58-98 were tested for alerting, orientation and inhibition. Results indicated, whilst alerting ability decreased, orientating and executive inhibition efficiency increase up until around 70 years old, favouring the notion of variability in executive function. In support of this Goh, An & Resnick (2012) found that some components of EF decline, where others remain or even improve with age. A large sample of older adults were taken from the longitudinal Baltimore study of ageing and assessed over a 14-year period. The end of the 14-year period of testing found, there was decline in inhibition, manipulating, semantic/phonological rehearsing, as opposed to abstraction, capacity, chunking, discrimination and short term memory, which in most part were either stable or improved (Goh et al., 2012). This paper suggests that EF is not uniform, neither is it sable or consistent. Each component of EF has individual changes that should be factored individually, as opposed to an umbrella term for a complex and multifaceted control system. This is an important factor of the research undertaken in this thesis as individual difference needs to be accounted for and observed, to understand the true context of our results.

In relation to neuroanatomy, EF is believed to focused in the pre-frontal cortex, more specifically the dorsolateral pre frontal cortex (DLPFC), anterior cingulate cortex (ACC), and the orbitofrontal cortex, with some researchers suggesting the cerebellum (Koziol et al., 2012) also playing a defining role. For example, VanVeen et al. (2001) evaluated the contribution of the DLPFC and ACC to EF, via an fMRI study with task switching Stroop paradigm. Analysis found that the DLPFC contributes to strategic function and the ACC playing an executive role. Similarly, Shen et al. (2019) used MRI to understand the structure of the executive control network. White matter tracts, structural tracts that interconnected with executive control networks were also measured. Analysis found, a structured EF network of 1) interhemispheric frontal connections, 2) fronto-parietal subnetworks and 3) fronto-striatal connections between right DLPFC and right Caudate (Shen et al., 2019). Interestingly, some researchers consider EF does not reside in a specific place, rather numerous domain general processes, distributed across the whole frontal region acting in synchronicity to facilitate EF.

1.4.2 Memory

Memory is the most recognised cognitive change associated with age and made up of multiple memory subdivisions (See figure 1). Memory decline is common amongst older adults, with a large degree of individual variability. There is a normal decline and does not infer a link to neurodegenerative disease and there are memory related diseases. Alterations to memory can be found by at least the 5th decade of life (Albert et al., 1987), with the most noticeable changes being, losing keys, forgetting names or a password for email. The nature of memory decline in older adults is not a straightforward decline, rather the brain is made up of a highly complex system that facilitates memory, with multiple subdivisions, attributed to different memory processes (See Camina & Guell, 2017 for full review). In relation to this thesis, memory is a key variable that facilitates gait performance. Different components of our memory influence gait speed, how we walk and spatially navigate our environment and so forth. Equally important, walking helps preserve memory (Sng, Frith & Loprinzi, 2019) and cognition, thus providing a direct need for older adults to remain active and walking. It should also be noted that memory drives attention.

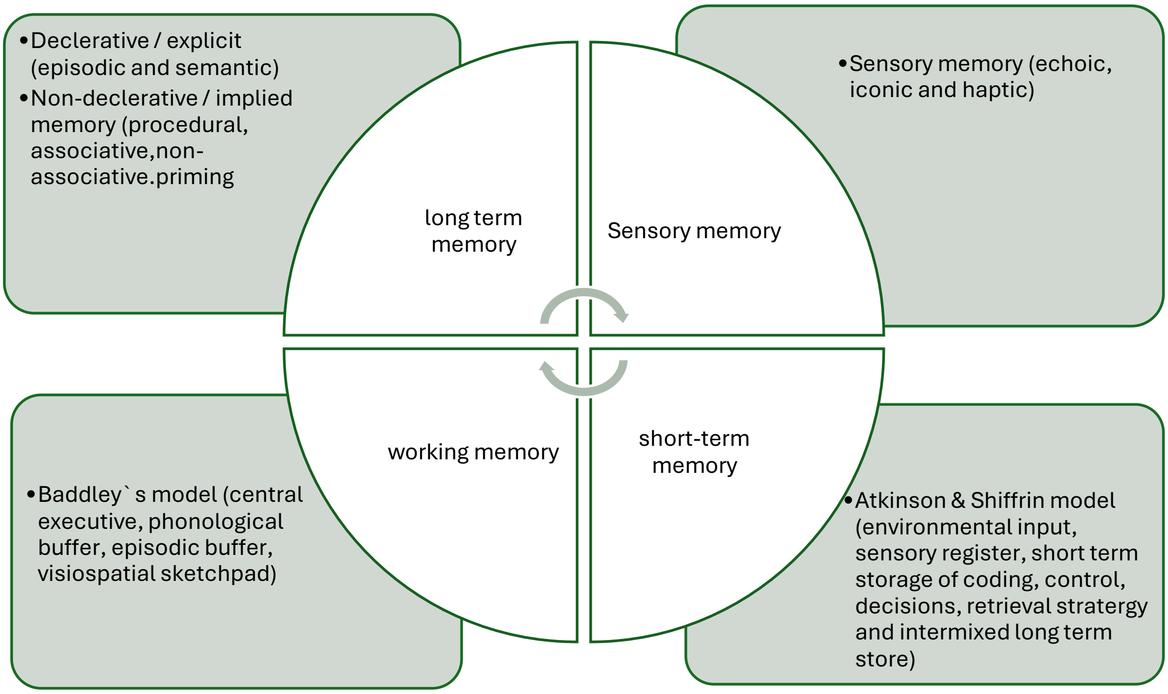


Figure 1 Age related change to memory components in older adults. (Image created by author of paper, 2023).

1.4.2.1 Sensory memory

Sensory memory is made up of three subtypes; echoic, iconic and Haptic, and is a mental representation of how environmental events look, sound, feel, smell and taste (Cowan, 2008). This automatic form of memory has a duration of a few seconds, and uses long term memory to recognise sensory information, remaining outside of conscious awareness. In terms of sensory memory, research is still growing in this field, however, EEG studies (I.e. Mismatch negativity) are finding encoding of sensory stimuli is preserved during the normal ageing process. However, maintenance of sensory memory may be impaired (Ruzzoli, Pirulli, Brignani, Moiloi & Miniussi, 2012).

1.4.2.2 Short term memory

Short term memory (STM) defines a system that provides the retention of information for a limited period of time, typically seconds, that is no longer present in the sensory environment (Dungan & Vogel, 2015). As a point of interest, STM is commonly linked and written about interchangeably with working memory (WM), however, this is not specifically correct. As such, they will be written about as separate identities, given the role WM plays in multiple cognitive processes, for a longer duration that that of STM and can facilitate manipulation of information. STM as a single identity, is probably most notable via the infamous “magic number” 7+/-2 which is believed to be the capacity of short-term memory (Miller, 1956); however, research has progressed. When the magic number of STM was created, there was no account for the size of each number slot. Cognitive processing tool such as chunking, and rehearsal have been shown to increase the amount of information that is held in STM. As I write this, I find humour in being able to retain a colour pattern of 42, via chunking in my STM, which is six times the original magic number.

In consideration of the ageing process, evidence suggests, STM abilities decline with age, as a constant decline with increase age, with comparative studies between younger and older adults are repeatedly providing evidence for this notion (Cepukaityle et al., 2023) For example, Mitchell et al. (2006) used fMRI to compare source memory judgement with old/new judgement. Results found, the DLPFC in younger adults had significant immediate activation to new judgement, even after a delay, compared to older adults who have decreased activation in the DLPFC region to new judgement making. Similarly, Castel et al. (2002), evaluated young v older adults for their ability to remember words. Over 4 experiments it was expected that participants were to remember words, of increased difficulty, measured via a point system. During the first 3 experiments, younger adults had greater recall, however, it was found during the final experiment that older adults recalled less words, but the words they did recall were of higher value than younger adults. Moreover, Cepukaityle et al. (2023) evaluated contextual spatial memory in younger and older adults. Analysis found, STM decline was significantly decreased in older adults, with increased errors rates. Thus, providing evidence that the ageing process influences memory, via a decline over the course of a lifetime.

1.4.2.3 Working memory

Working memory (WM) encompasses a system in the brain that facilitates temporal storage and manipulation of information needed to complete cognitive based tasks (Camina & Guell, 2017). The basic model of WM, still used in present research, was created by Baddeley, (1986). This model proposes a central processing centre, the central executive, with 3 support systems: the visuospatial sketchpad, episodic buffer, and phonological buffer. This was later updated in 2002, to include the role of additional memory input (See figure 2).

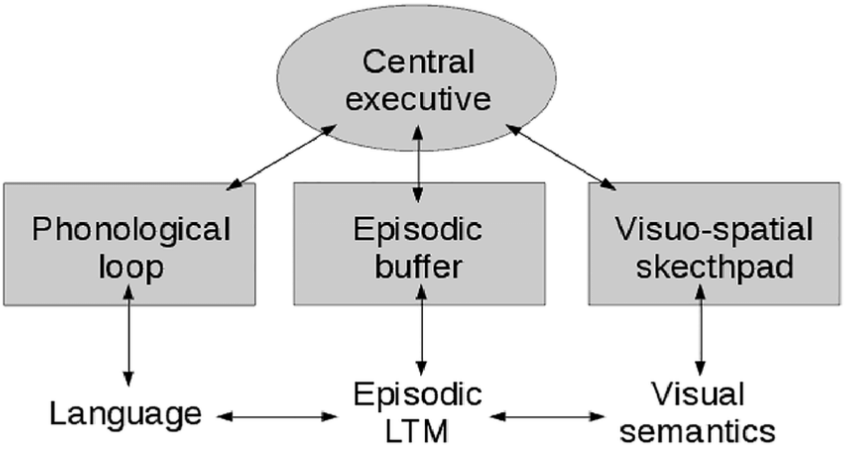


Figure 2 image from Golosio et al. (2015).

The visuospatial sketchpad (VSS) holds visual information, short term information that is ready for manipulation. It is proposed that the VSS is autonomous, in that it has its own storage of WM and can work efficiently without affecting other components of the WM model (Denis, Logie & Cornoldo, 2012). Logie, (1995) suggests the VSS has further subdivisions that facilitate performance via a visual cache and inner scribe. The cache being the form and colour information and the scribe, spatial and movement information. Moreover, it is suggested that the scribe can release information in cache and transmit this information to the central executive (Salthouse & Logie, 1995). The VSS is highly dependent on attention, with attention being the active maintenance of the sensory representation. This is of importance to this thesis as attention and memory working fluidly influences sensory input, which in turn will influence attention control and gait.

The phonological loop (PL) is a component of WM that facilitates speech and sound processing. Consisting of 2 parts, the loop firstly acts a short-term phonological store with auditory memory traces, and secondly, an articulatory rehearsal process that can revive memory traces (Hou & Chen, 2021). An example of the PL would be remembering a phone number. As we repeat a number, the information circulates and is released into WM for a period before rapid decay.

The episodic buffer (EB) is a multimodal storage that is temporary and limited to WM. First outlined by Baddeley (2000), this buffer integrates incoming information with long term memory, chunking information via prior knowledge, facilitating efficient storage and retrieval. The EB is accessed by the central executive via conscious awareness (Baddeley, 2000).

The central executive (CE), if theory is correct, is the most important component of the WM system. The CE co-ordinates activity in the system and has been linked to switching of retrieval plans, dual tasking, selective attention, activation of long-term memory, task switching and inhibition (Morris & Jones 1990).

Whilst there are alternative models to WM (Cowan, 2005, D`Esposito & Postle, 2015, Barrovillet et al., 2004), each model postulates that the natural ageing process sees a decline in WM performance, with older adults performing poorly compared to younger adults (Nissim et al., 2017). For example, Klencklen et al. (2017) studied working memory decline via demand and cognitive workload increases. Performance was measured via a young v old comparison, over a battery of memory tests, colour and spatial information. Results indicated a decline in WM for older adults, with WM decline increasing according to workload level. Interestingly, no spatial memory decline was found. Similarly, Klencklen et al. (2017) evaluated decline via changes to allocentric spatial WM in a aged comparison study. Analysis found, older adults performed significantly worse than younger adults on all tests, with the greatest decline being for WM. It is suggested that age related decline is linked to anatomical age-related changes to the brain, specifically, medial temporal lobes and the pre frontal regions (Deselaar & Cabeza, 2013).

1.4.2.4 Long term memory

Long term memory (LTM) (See figure 3) is the transfer of STM into LTM storage. LTM is unlimited and can endure over a lifetime (Hall & Stewart, 2010). Formation of LTM is achieved over 3 stages: acquisition, consolidation and retrieval (Hawk & Abel, 2010). LTM is complex and multifaceted, however, there is an agreement in research that LTM covers two main memory categories, each with a subtype. A full overview of the purposed LTM system is beyond the scope of this thesis (see, Camina & Guell, 2017 for full review), but below will be an overview of the system and subdivisions, along with changes during the ageing process.

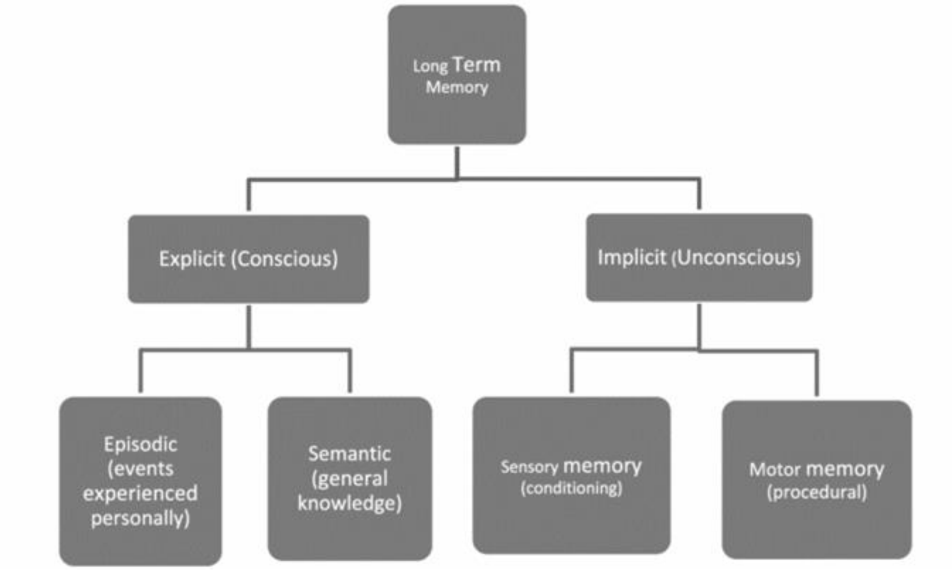


Figure 3 Example our long-term memory components, Image taken from Oyigeya (2021).

Declarative / explicit memory

Declarative memory can be consciously evoked by an individual via episodic memory, which hold personal experiences and semantic memory, that provides the factual information to a memory (Camina et al., 2017). Further differences in declarative memory are the mechanism of action of episodic and semantic memory. Episodic memory occurs via connections between the neo cortex and Para hippocampal regions and hippocampus, with the hippocampus being the primary modulator (Jawabri et al., 2023). Semantic memory on the other hand begins in the visual cortex, before converging in areas such as the inferior parietal lobe and the lateral frontal temporal lobe (Jawabri & Cascella, 2023).

Non declarative / implicit memory

This form of memory remains unconscious and used automatically. Non declarative memory types allow unconscious procedures and behaviours to facilitate how we interact with and attend to the environment around us. The first form of non-declarative memory is procedural memory. Procedural memory encompasses motor and executive skills needed to perform a task. It is thought to be facilitated not by repetition alone, but behaviour also. Fitts & Posner, (1967) suggest procedural memory is achieved via a cognitive phase, associative phase and autonomous phase. Completion of each of these stages facilitates perfection and accurate judgement of tasks. Next there is associative memory (conditioning). Associative memory is achieved via classic conditioning and operant learning of behaviour and outcome. Furthermore, LTM includes non-associative memory (habituation). This form of memory is formed via repeat exposure to a stimulus. Alonson (2008), suggests non-associative memory is in two forms, sensitisation and habituation, which habituation defined as repetition and sensitisation as an increase in response to a stimulus. Finally, there is priming. Over exposure to a stimulus allows or may influence, how we unconsciously respond to a subsequent stimulus via a semantic modality (i.e., doctor / nurse).

In relation to ageing, LTM is relatively consistent compared to the loss of STM/WM. LTM components such as semantic, procedural and priming, in disease free ageing remains optimal with some decline in episodic memory. For example, Mitchell, Brown & Murphy (1990) had younger and older adults name pictures, and consecutively tested 1,7, 21 days later. Results found, whilst older adults showed some decline in episodic memory, procedural memory showed no age-related difference. Similarly, Lovden et al. (2004) measured changes in semantic and episodic memory performance over a five-year period in older adults. Analysis found; the stability of semantic memory remained with episodic memory decreasing slightly. Moreover, in a review paper by Ward & Berry (2013) they outlined the preservation of implicit memory.

Concerning memory, there is not one distinct answer to what will decline and when, purely as individual difference and environmental contributions play such a defining role. However, through theoretical and research frameworks and hypothesis testing, there is a consensus that during the natural ageing process, LTM, namely, semantic, procedural and priming remain relatively intact through most of a person life. Memory loss to STM/WM and episodic memory to an extent shows decline for around the 6th decade of life onwards.

1.4.3 Attention

A critical component of cognitive function which is open for decline over the course of ageing, is attention, defined as the ability to concentrate and focus on a specific stimulus (Harada, Netelson-Love & Triebel, 2014). There are different components of attention, such as divided and selective, that each play a significant role in how we interact with the environment. Attention as a component of cognitive change in older adults is a key facet of this thesis due to the link between attention relocation and falls, as such this extremely brief outline of attention was placed in this chapter for recognition not information. Attention will be covered in detail in a later chapter.

1.4.4 Information processing speed

Performance speed is highly influenced by the ageing process, with older adults having reduced speed executing mental operations to complete a task

(Ticha et al., 2023). Salthouse (1996) created a theoretical frame work to explain the decline in performance speed in older adults called the “processing speed theory”. It is proposed, increased age in adults hood is associated with a decrease in speed, where many processing operations cannot be executed, thus creates a decrease in speed, which in turn creates impairments in cognitive function due to limited time mechanics and simultaneous mechanisms (Salthouse, 1996). Interestingly, researcher such as, Parking & Java (2005) further extend the model proposed by Salthouse (1996) to include perceptual speed and reasoning, which they postulate are far superior to EF, thus rather than being a subsidiary, perceptual speed and reasoning drive EF. This statement has however been found to be highly unlikely, given EF goes beyond the scope of cognitive measure such as perceptual speed. EF drives nearly all processing in the brain.

The consequence of performance speed decline in ageing has been measure in a multitude of tests and theoretical frameworks, all of which agree older adults perform significantly worse than younger adults (Albinet et al., 2012, Eckert, 2011). For example, Albinet et al. (2012) evaluated processing speed during the ageing process to understand to what degree change takes place. In a comparison study 28 younger and 39 older adults took part in a battery of test to assess inhibition, updating and shifting, with processing speed measured via experimental and psychometric tests. Analysis found; each measurable processing speed component was significantly decreased in older adults. Moreover, age related performance speed declined quicker than other components such as inhibition. Similarly, Caplan & Waters (2005) ran a study addressing age related change to performance speed, WM and language. Older adults performed significantly worse than younger adults in processing speed, with sentence processing on language tests also showing a decrease in processing speed. A plausible explanation for this form of decline in older adults has been linked to myelin integrity change (Lu et al., 2011), default mode network (Staffaroni et al., 2018), fronto-cerebella grey matter change (Eckert, 2011) and white matter integrity (Gunning-Dixon et al., 2009). This is important to understand for this thesis due to our data collection of RT information and the influence it may have over performance.

1.4.5 Intelligence

The concept of intelligence changing in older adults is important amongst research, particularly in the form of crystalised and fluid intelligence, originally proposed by Raymond Cattell (1963). Fluid intelligence is believed to peak at around the age of 20, before starting to decline at a rate of -0.02 SD per year (Elias & Savaer, 2014). Fluid intelligence encompasses problem solving, reasoning and is independent of learning. Moreover, it is an individual's ability to learn, solve, attend and manipulate the environment. Crystallised intelligence, increases gradually and remains stable. It is thought to improve at a rate of 0.02/0.005 SD each year until around the 6th, 7th decade of life (Salthouse, 2012). Crystallised intelligence encompasses skills, ability knowledge and is well predicted and familiar (Harada et al., 2014). An example of crystalised intelligence is vocabulary. Intelligence is particularly important in research as academic levels are believed to influence cognitive abilities.

1.4.6 Age related cognitive change subsection summary.

Cognitive changes during the age process encompasses a broad spectrum of change. Memory, attention and executive function in particular maybe the leading cause of falls in elderly, due to the loss of attention control, perception and communication between brain regions. Moreover, if older adults do not have the tools to facilitate environmental navigation, gait will remain perturbed as attentional resources will always be taken away and redirected to other sensory or cognitive modalities.

1.5 Sensory change

Sensory decline such as hearing loss, visual change and tactile perception are common with ageing. This is of utmost importance to this thesis as our hypothesis is based around auditory attention. Audition in particular guides attention, memory and executive function, which facilitates how we interact with the environment. Understanding the degree to which auditory functions may change over the ageing process, defines the reliability of results. As such, it is a variable that is measured at a later period in this thesis.

1.5.1 Somatosensory

The somatosensory system is a neural network that facilitates the perception of touch, thermoception and proprioception. Somatosensory perception begins when something touches the skin, or perceived to touch the skin (see phantom limb), which then awakens receptors to send signals to the spinal cord and brain via action potentials. The primary somatosensory cortex is located in the parietal lobe, behind the central sulcus, receiving input from the ventral posterolateral sulcus of the thalamus, via the internal capsule and corona radiata (Raju & Tadi, 2022). As outlined in McIntyre et al. (2021) there are key changes to though during the natural ageing process. 1) reduced skin elasticity that influences tactile skin receptors, 2) axonal loss and demyelination alters timings of tactile signalling, 3) ageing induces somatotopic reorganisation and 4) touch sensitivity declines.

1.5.2 Taste

Taste, also defined as the gustatory system, is responsible for the 5 basic tastes (sweet, sour, salty, bitter & savoury) or the perceived toxic tastes that alert humans to possible danger. Taste interacts with the somatosensory, to recognise hot food and drink and the olfactory system to perceive an associated smell. Nomaksteinsky et al. (2013) outline that the taste centre of the brain resides in the anterior insula and frontal opealim. Findings from Methven et al. (2012) suggest there is a decline in taste intensity and perception in the older population. Moreover, there is a decline in the number of taste buds available.

1.5.3 Smell

Smell or olfaction is a specific sense that allows humans to pick up on the smallest of scents in our environment. Olfaction can also pick up on pheromones from the opposite sex, inducing attraction. When we smell, incoming odour binds to receptors in the nasal cavity and sends information to the olfactory system (Trimmer & Mainland, 2017) found in the uncus of the temporal lobe. The sense of smell is also paired with memory and emotion, which facilitate the pairing of meaning to a smell. The natural ageing process sees a natural decline in olfactory neurons in the nasal cavity, reduced activity in the olfactory cortex and decreased cellular turnover (Kondo et al., 2020).

1.5.4 Vision

Vision or visual perception allows humans to view and scan the environment to actively and accurately interact with the surrounding environment. The primary visual cortex or V1, is located at the calcarine sulcus of the occipital lobe, extending posteriorly from the parieto-occipital sulcus to the occipital pole (Lee et al., 2016). Changes in vision are ubiquitous amongst in older adults with alterations including, cataracts, glaucoma, macular degeneration and diabetic retinopathy (Swenor & Ehrlich, 2021).

1.5.5 Hearing

Hearing or auditory processing, which will be outlined in detail in a later chapter, allows humans to perceive the environment by changes to sound levels, frequencies and tones. Understanding our environment is accomplished through and exquisite, highly complex system that uses tonotopic organisation to piece together and organise incoming sound waves, to specific regions of the cochlear, to create a sound representation. This representation interacts with memory, smell etc, to create a picture of our environment from pre stored information. The primary auditory cortex is located in the temporal lobes and transmits, relays and combines information from multiple area of the brain. Gradual hearing loss is extremely common in older adults, with common symptoms of hearing loss including, struggling to hear conversations, turning the television up and asking people to repeat conversations (NHS, 2023). It is believed that 70% of individuals aged 70 or greater have hearing loss, with approximately 14.2 million older adults predicted to have 35dB of greater hearing loss by 2035 (RNID, 2023). Interestingly, hearing loss is the most modifiable risk factor for the development of dementia.

Each component of the sensory system that is noted above, is important to this thesis. Whilst the primary focus is auditory input, each sensory system, whilst individual, work in harmony to create a full sensory perception of the environment.

1.6 Musculoskeletal system

The musculoskeletal system facilitates a range of locomotion, balance, and support within the human body. The musculoskeletal system also works in collaboration with the senses, particularly vision and audition, to facilitate interaction with the environment. Similarly, this system interacts with multiple brain regions to facilitate motor movement. Furthermore, the musculoskeletal system is heavily influenced by cognition. For example, attention processing can influence gait performance, which is something that will be discussed in greater detail later in the thesis. There are joints, ligaments, muscles, nerves, and tendons that support limbs, the neck and the back. Moreover, this system supports and binds connective tissue to hold our organs in place (i.e., cardiac muscle), (Ken Hub, 2023). Ageing however, is characterized by a progressive decline in muscle mass, function and widespread change to bone density and strength (Azzolino et al., 2021). Common musculoskeletal decline in older adults includes, arthritis, osteoporosis, osteomyelitis to name a few, that increase prevalence of falls which in turn increase prevalence of sprains, fractures and breaks.

1.7 Plasticity of the brain as a compensatory mechanism

This chapter to date has provide a relatively bleak outlook for individuals as we transverse through life. It has shown that the hallmarks of ageing have a devastating impact on ageing at a molecular, cellular, microbial and brain morphological level. Moreover, the widespread loss of white matter, grey matter and neurotransmitters has a devastating impact on cognition, particularly memory, attention and executive function. However, regardless of age, and considering individual difference, there is a tool that the brain can use to counter act decline, namely plasticity, which may be a key factor in reducing falls in elderly via training and remodulation on motor networks .

Brain plasticity, also termed neuro/neuronal plasticity, is the ability of networks in the brain to grow and regenerate in response to intrinsic and extrinsic factors (Mateos-Aparicio & Rodriguez-Moreno, 2019). Until recently, it was believed that plasticity was something that we lose as we age, however, it has been noted by Pauwels et al. (2018) that evidence is mounting for plasticity being a lifelong tool that can be enhance, particularly via training and practice performance, in that the more we train our brain, feed our body, the increased change of plasticity taking place. Moreover, it is suggested that in addition to neuronal plasticity, practice and brain training can influence structural changes to the brain in the form of white and grey matter increase (Zatorre et al., 2012). Whilst plasticity in older adults is still up for debate, there is a consensus that brain training creates a neuroprotective factor (Taybert et al., 2010). This is of importance to this thesis as brain training provides a tangible intervention to reduce falls. Furthermore, in the above hallmarks of ageing, preventative measures can also be used to induce plasticity to epigenetics (McCarthy et al., 2018), and nutrient sensing (Shannon et al., 2021), each of which will reduce the risk of cardiovascular disease, inflammatory disease and onset of pathological ageing. This is dependent on individual difference.

1.8 Precision medicine as an aid to ageing and gait research

Understanding the biological, anatomical, cognitive, sensory and musculoskeletal is extremely important to this research, as if a person is purely looked at as a participant number and a mean P-value, individual difference, a important component of research is ignored. Moreover, with the older adult population growing exponentially, more older adults are developing multimorbidity in disease that can affect quality of life, life expectancy, treatment burden and care co-ordination (NICE, 2023). Precision medicine is an exciting and emerging approach, aimed at disease treatment and previsions that considers individual variability in gens, environment, and lifestyle. (NHS, 2020). Diagnosis in research is not a one-size-fits-all. If research is able to look at multiple measures such as cognition, sensory, locomotion and external influence such as medication a bigger picture is able to be created. This can inform a more predicative, personalised and goal directive management of disease (NHS, 2020), or a predisposition to disease in the future. An example of the precision medicine technique can be seen in Chapter 5 of this thesis. To understand a true representation of how environmental sounds may influence gait, cognition, hearing, polypharmacy, balance and attentional control measures were taken.

1.9 Summation

The neuronal, physiological, genetic and cognitive changes, as set out above, are the key hallmarks and elements that facilitate the drive in the ageing process, be it natural or pathological. Whilst disease and genetics play a role, individual difference, maintenance via diet and healthy lifestyle, exercise, cognitive training and socialisation, each impact the brain and body, facilitating a heathy ageing, with enhanced plasticity or increased risk of developing disease. Similarly, the sensory system should not be underestimated in the influence it holds over cognition and motor movement in older adults. This overview has highlighted the links and potential causality between ageing, changes to the musculoskeletal system, attention, sensory processing, cognition and increased risk of falls in older adults, which later in the thesis will help with the overarching aims of this PhD.

Chapter 2 – Sound and the auditory system

Summary of chapter aims and context.

This chapter provides a detailed description of the anatomical and functional organisation of the auditory system. Emphasis will be put on how sound waves are converted as they travel through the auditory system in a tonotopic form before reaching the auditory cortex. Evidence will also be presented for the influence noise has over the auditory system, particularly how loud noise can induce plasticity changes, influence source localisation, integration of auditory spectral cues, and alter physiological processes for a short time. A full outline of the auditory system and how sound is produced, was of importance to this thesis as it provides context for the implications of noise on human function (e.g. visual processing, attentional capture). For example, The World Health Organisation (2023), produced a report outlining environmental noise had some form of adverse effect on nearly all measures, physiological, cognitive, or mental health. Such report outlines the need to evaluate sounds, particularly environmental sounds in as much detail as possible. This thesis will be combining the World Health Organisation report outline with the detailed anatomical and functional organisation of the auditory system, to provide evidence for later studies in this thesis including environmental sound perception, environmental sounds and attention control and the influence of incoming environmental sounds on gait.

2.1 Introduction - What is sound?

In any given moment, humans are presented with a plethora of sound related to many different things in our surroundings, which occur in parallel and sequentially with different frequencies and amplitudes. Humans rely of selective attention, a process of focusing processing resources to a restricted number of sensory stimuli, whilst ignoring or suppressing others (Bater & Jordan, 2020), to help focus on sounds that are relevant to our behaviour or goals. Sound that we hear in our environment can be extremely quiet or loud, with humans typically hearing sounds between 0-130dB, although it is suggested that 80dB is a healthy level. It is easy to take for granted the birds chirping, the builders drilling or having a conversation with someone, without acknowledging how the sound is perceived and how we selectively attend to only certain sounds at will or automatically. The overarching aim of this PhD is to examine attention control and gait, under silent and environmental sound conditions to understand the link with gait and falls.

Before we discuss these factors, it is important to define what sounds is and how it is produced, detected, perceived, how it can affect other processing and how it might be affected by other things . In its most basic term, sound is a vibration that travels through the air and other mediums (i.e., water) which is then detected by the complex auditory system, and processed to allow us to perceive sounds in our environment, interpret, recognise, and respond or ignore them. However, sound information processing is highly complex.

2.2 Perceiving sound

The first step in the process of how the human auditory systems work, begins with a sound wave (see figure 1). Within our environment, the constant motion of atoms and molecules create a static pressure on any material that it makes contact with, typically due to the repetitive bombardment of billions of air molecules at any given time (Plack, 2018). If the air is disturbed by the movement or vibrations of an object, fluctuations in density will occur. As objects moved out, air molecules are pushed away and squeeze together increasing density and pressure, creating a condensation period. As objects move in, air molecules move in, air molecules spread out to fill space, which creates a decrease in density and pressure, creating a rarefaction period (Plack, 2018). It is the condensation and rarefaction alternating that make up a sound wave in its most basic form (See figure 4), which travels at an approximate speed of 343m/s in air. Sound regarding volume is measured via Decibels, which is the measure of ratio between two intensities (flow of acoustic energy in a sound field), specifically 10 times the natural logarithm of the intensity ration. As a note, sound intensity, (the flow of acoustic energy in a sound field) is proportional to the sound amplitude squared.

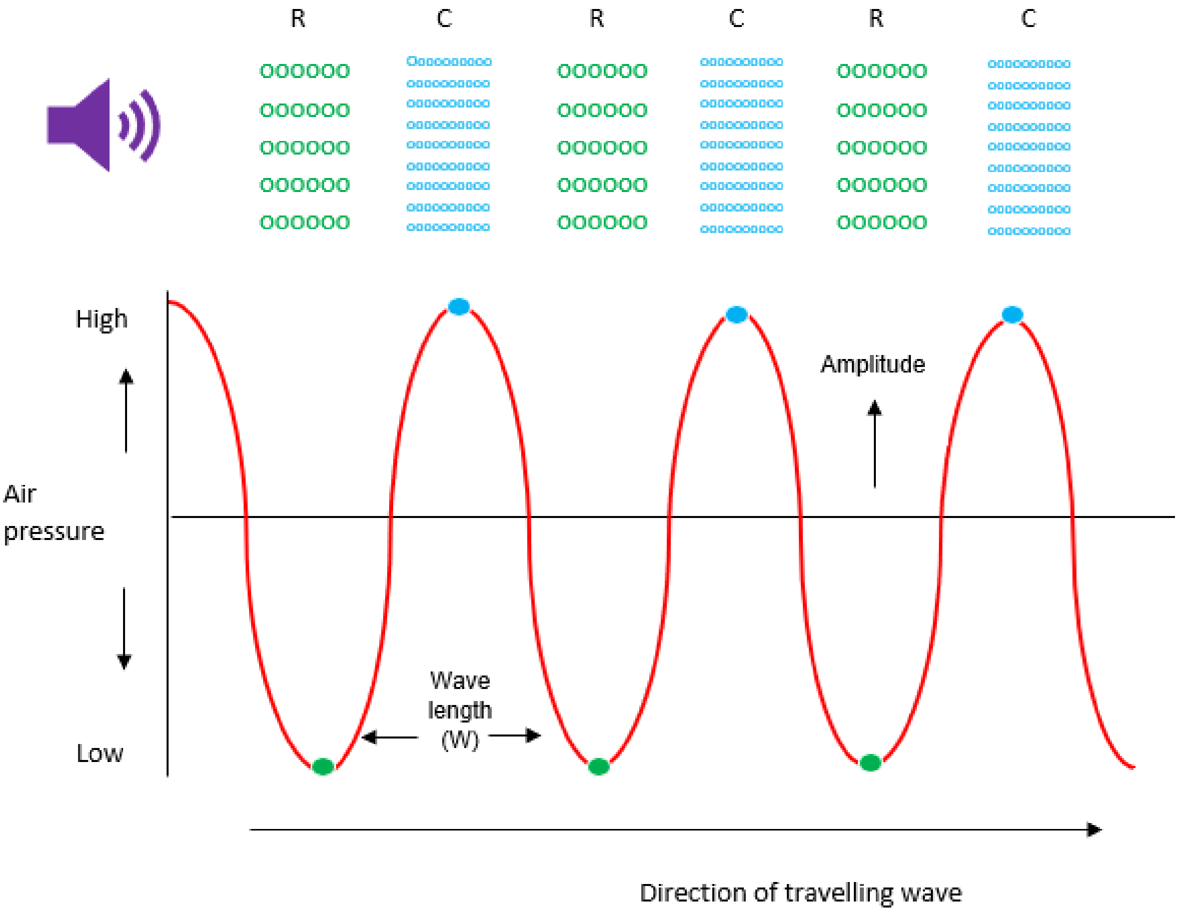


Figure 4 Example of a travelling wave and the components that make it up. Image created by author of this paper, based on research and diagrams of Plack (2018)

The simplest wave form is that related to pure tone, defined as a sound with a sinusoidal vibration in pressure over time (Boyd, 2003). The basic characteristics of a sound wave include frequency, period, wave length, phase, amplitude and intensity, with each characteristic collectively representing important components of the environment, that can be studied collectively or in isolation and which are detected and processed by specific aspects of the ear/ auditory system. Sound frequency, measured in Hertz (Hz), refers to the number of repeats of cycles of a pure tone, occurring at a given location, during a given length of time (Plack, 2018), corresponding to the number of ties in each second, air pressure changes from high to low and back again. A period of a sound wave is the antithesis of a frequency. It is a length of time taken or a tone to complete one cycle of alternating condensation and rarefaction (Plack, 2018). Next, the wavelength, refers to the distance between corresponding points of two consecutive waves (Britannica, 2022), with corresponding points being a reference to points on the same phase. The phase, as noted by Plack (2018) is the point reached on the pressure cycle at a given time. Phase covers 2π radians or 360° for one cycle of a wave form. Finally, the amplitude and intensity, references the magnitude of pressure variations, in relation to deviations away from atmospheric pressure (Plack, 2018).

The features and components of sinusoidal waves that the ears detect, provide a basic description of a smooth repetitive wave, however, in the everyday environment rarely do sounds come in singular form. Sound waves are complex due to the constant bombardment of environmental sounds. Sound waves are therefore more likely to be made up of waves that interact together, created via multiple sound displacements. Unsurprisingly, when more than one wave makes contact, known as interference, the resulting amalgamation creates a new wave. Described via principle of superposition, when two waves meet from individual sources, the created wave is the sum of two waves that would be produced by the respective sound source if each was presented alone (Gunther, 2019). These waves are typically larger and have bigger troughs and peaks. Like sinusoidal waves, the pairing of two sounds remains relatively simple, given the waves interact and line up perfectly. Rarely in the environment do waves line up well, thus creating complex waves. Complex waves are typically waves of different phases, which was previously described as the point reached on the pressure cycle. The changes in phase do not allow peaks and troughs to line up, resulting in magnitude of the resultant wave, being less than the magnitude of the interfering waves (Howard, 2022).

The auditory cortex is a highly tuned system which can detect and process different patterns and attributes of waves and provide a detailed analysis of each feature of a sound wave. Moreover, the cortex can decode the smallest details of spectral and temporal information embedded in sounds (Concina et al., 2019), whilst separating out frequency components of sound, thus allowing the detection, perception and understanding of our sound environment. Moreover, there is an interaction with visual information processing and with other areas of the brain related to attention and cognition. This is of particular interest to this thesis as environmental sound processing is believed to be a leading cause of falls in older adults, which will be discussed in later chapters.

2.2.1 How the ear processes different components of environmental sounds

The ability to separate of frequency components, or frequency selectivity is an imperative functional property of how we hear, namely by the ears ability to separately determine the various frequencies that enters the auditory system (Plack, 2018, Manley & Van Dijk, 2016).

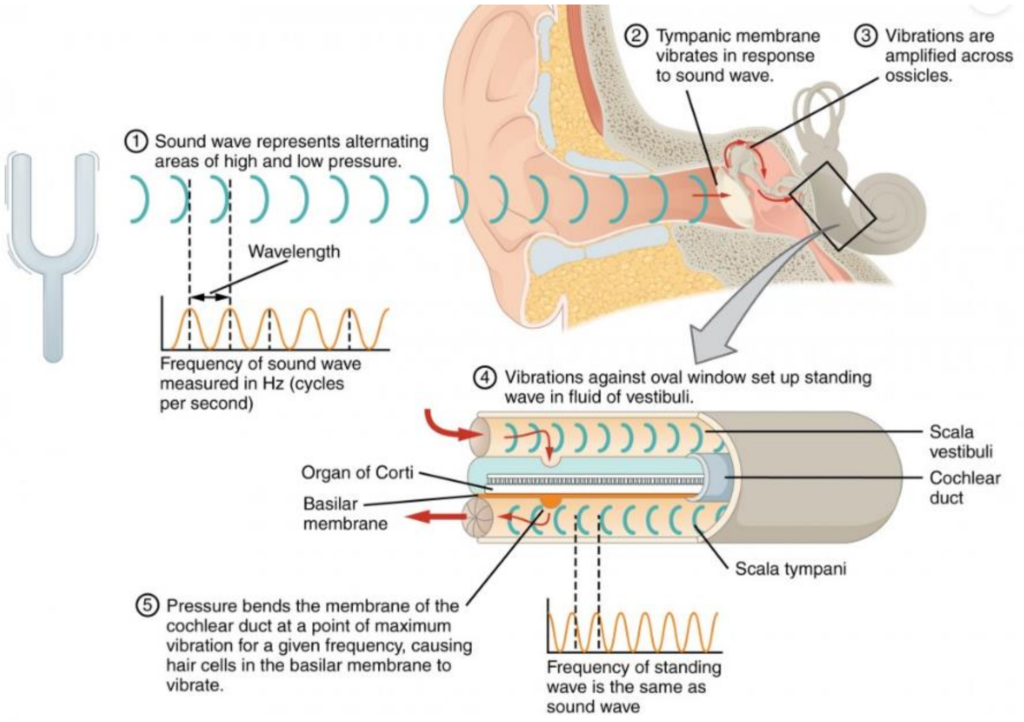


Figure 5 Transmission of incoming sound waves. Image taken from Lumenlearning (2024)

Afferent sound waves travel through the components of the ear (outer/middle/inner) to the basilar membrane housed in the cochlear (see figure 5). The basilar membrane is a highly tuned tonotopic tune structure that processes different frequencies at different locations of its structure, over a range of around 200Hz at the apex and approximately 20,000Hz at the base. The incoming sound wave travels along the membrane until it reaches a designated place that corresponds to its maximum vibration frequency. Similarly, it is on the basilar membrane where the complex waves of multiple phases travelling inwards can be separated out from multiple complex wave forms to singular frequency, before information gets transmitted through to the primary motor cortex (A1). Interestingly, frequency selectivity research as noted in Plack (2018) suggest, that the base of the basilar membrane in particular is nonlinear, as such, frequency selectivity has to compensate for 1) suppression, the reduction in response to one frequency component when another is added (Plack, 2018) and 2) distortion which can produce a change to a wave form, producing combined tones.

To this point, sound wave creation and movement have been discussed. This is by no means a full detailed account, that would require a thesis on its own, it does however include everything that is relevant to auditory processing in humans for the purpose of this thesis. A full account of sound wave formation and distribution in the auditory system in specific detail can be found via Plack (2018) and Moore (2012). Next, we shall discuss the auditory system. There will be an overview of the auditory system including, anatomy and connectivity.

2.3 The auditory system

The auditory system is a specialised system containing multiple, neurons, connections, cortical loops and interconnected anatomical regions that facilitate information exchange and thus hearing, executive function, motor function, sensory integration and language comprehension. Whilst complex, the auditory system is exquisitely and compactly divided into two distinct systems, the peripheral and the central. To understand how auditory processing occurs, the next section will provide a detailed account, from a sound wave entering the ear through to the cortex, through processing and the descending pathways. The peripheral auditory system (PAS) is divided into 3 distinct components. The outer ear, middle ear, and inner ear (See figure 6).

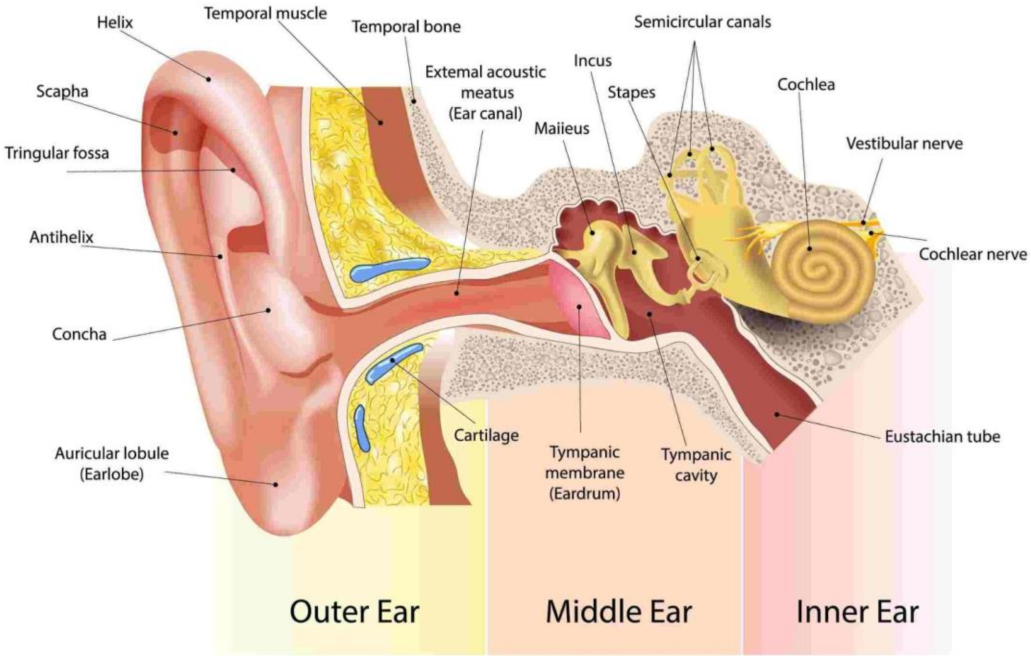


Figure 6 image of hearing system. Image taken from audiology research (2022)

2.3.1 The outer ear

Incoming sound waves enter the ear at the pinna, a large cartilaginous projection portion of the outer ear and the auditory canal. The pinna modifies incoming sound particularly at high frequency, which is important for our ability to locate sound. The auditory canal is the narrow passage that projects from the pinna, through to the ear drum. Approximately 2.5cm long, and shaped like a “S”, the auditory canal is engulfed by fibrocartilaginous tube in the initial 1/3 of the canal, with the later medial 2/3 surrounded by bone (Moore, 2003). An incoming sound wave enters the pinna and is directed down the auditory canal, where the eardrum (also known as the tympanic membrane) begins to vibrate with the incoming sound wave (Moore, 2003).

2.3.2 The middle ear

The vibrations on the ear drum are then transmitted through to the air-filled middle ear, where incoming sound waves are converted and transmitted. Notable features of the middle ear include the tegmen tympani, tympanic canaliculus, aditus, pyramid, stapedius muscle, tensor tympani muscle, shrapnel`s membrane and the auditory ossicles (see Marchioni, Molteni & Presutti, 2011 for full anatomy). Although the middle ear is filled with multiple features, it is the auditory ossicles that are of interest to this paper, given their role in carrying acoustic vibrations from the ear drum through to the cochlea (Plack, 2018), via synovial articulation. The auditory ossicles, malleus, incus and stapes are the smallest bones in the body. The malleus, reaches height of around 8mm and width of 2.7mm, the incus 6.8mm x 5.3mm and the stapes approximately 3.5mm x 2.4mm (George & Bordoni, 2022). The anatomical structures of the 3 ossicles according to George & Bordoni (2022) are situated with the malleus attached to the ear drum at the handle, with the head of the malleus attached to the incus (incudo-malleolar joint), the incus then connects with the stapes (incudo-stapedial joint), with the stapes conversing with the oval window (See figure 7).

Transfer of sound into the inner ear depends on differences between sound pressures that are applied to the oval window. The middle ear magnifies pressure to the oval window via acting as an impedance-matching device or transformer. It is postulated that transfer of sound appears most efficient at a frequency of 500Hz-5000Hz (Aibara et al., 2001). Auditory transmission in the middle ear is supported via tiny muscles attached to the 3 ossicles, via a 4-step process, where muscles contract to aid sound transfer. The muscles attenuate sound levels via vibration dampening of the ossicles (Neergaard, Andersen, Hansen & Jepsen, 2009). Then on, the stapedius stiffens the attachment of the stapes to the oval window of the cochlea, the tensor tympani pull on the malleus, which then increasing tension of the tympanic membrane (Beebe & Schofield. 2020). More specifically, the muscles contract via a middle ear reflex. Mediated by neuronal centres in the brain, the middle ear muscles, function to reduce transmission of sound through the middle ear for frequency's <1.5Hz (Plack, 2018), this reflex protects damage to the highly sensitive cochlear & protect against impulse of sounds.

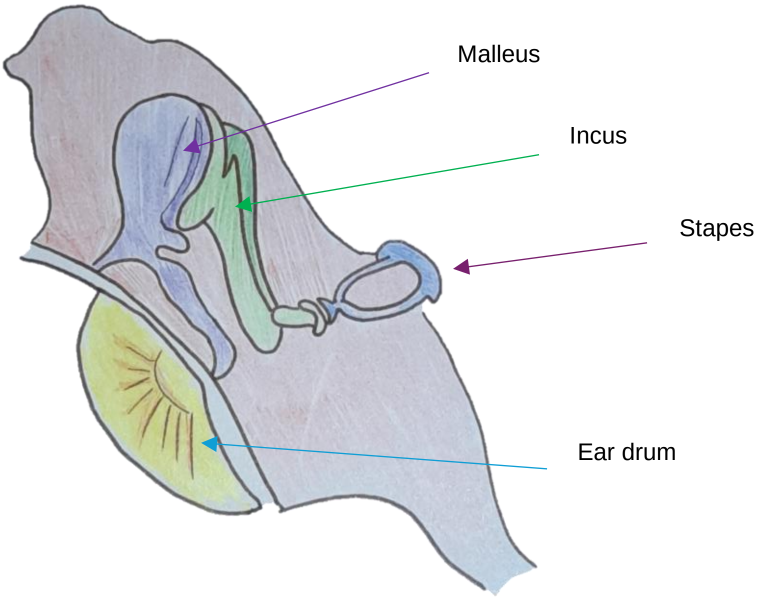


Figure 7, Anatomy of the inner ear, housing the incus, malleus, and stapes. Image created by author of paper.

2.3.3 The inner ear

The inner ear is a hub of mechanical relaying, where incoming sound waves convert waves into neuronal impulses via a process of transduction

(Alberti, 2001), that can be interpreted in the brain as a specific sound. Moreover, the inner ear is imperative for hearing, balance and allowing a level of homeostasis to balance when in motion (Swartz et al., 1996). The inner ear is made up facial nerves (V11), the vestibulocochlear nerve (V111) fibres spiral ganglia that communicate with stereocilia on the spiral organs of Corti, multiple vasculatures, namely the labyrinthine and stylomastoid artery. Most notably, the inner ear is made up of, the semi-circular canal, vestibules and the Cochlear. The semi-circular canal, at the apex of the inner ear, are a 3-component structure (superior, posterior & lateral), which form a base from the ampulla, that houses sensory epithelium, containing hair cells (Purves et al., 2001). The semi-circular canals use the mechanosensitive hair cells to facilitate the primary goal of movement analysis, specifically head rotations, that aid balance and orientation. The vestibules, a region between the cochlear and semi-circular canal and aids in maintaining locational position within the environment, allowing a sense of equilibrium (Treuting, Dintzis & Sellers, 2017). The vestibule converse with the semi-circular canals via the Utricle, and the cochlear via the saccule. When the head rotates or moves, the vestibule performs via activation of hair cells within the macula in the utricle, which signal the vestibular nerve, which then facilitates balance. Vestibule deterioration is specifically linked to balance and falls in older adults, via a reduction and deterioration of hair cells. The vestibule is sensitive to the ageing process (Rauch et al., 2006). Finally, the cochlear, the last of the 3 major features of the inner ear which will be described in full detail shortly, is a tonotopic sensory hub, imperative for transduction of sound waves into electrical energy and hearing. To understand how the inner ear facilitates sound transmission, transduction and the ascension of sound waves onto the auditory cortex, the next section of the paper will go into a more detailed anatomical and physiological account of the key role of the inner ear, starting from the cochlear, through transduction, onto the central auditory system ascending pathways to the auditory cortex, then to the descending auditory pathways, with a simplified auditory pathway diagram of the full system at the end.

2.3.4 The cochlear

The cochlear is a tonotopic, fluid filled tube within in inner ear (see figures 8 & 9), along with the semi-circular canal and vestibules. The cochlear tube is approximately 3.5cm long (Plack, 2018), with 2.5 turns from base to apex, with a width of 1cm and height 5mm (Pickles, 2015). The cochlear houses two membranes, the Reisner and basilar with the later housing the organ of Corti, an area of epithelial cells that facilitate transduction of sound waves into electrochemical signals (Hudspeth, 2014), which will be discussed later. The cochlear has 3 fluid filled subdivisions, namely the Scala vestibuli, Scala media & the Scala tympani. The scala vestibuli & tympani are connected by a small opening between the basilar membrane and the cochlear wall at the apex and house perilymph fluid, similar to that of plasma and cerebrospinal fluid. The scale media, is a separate division that contains a separate fluid, known as endolymph. Endolymph fluid at the scale media baths the sensory cells of the inner ear to facilitate normal function. The fluid maintains a positive electrical potential of 80mV and facilitates the endocochlear potential, an electrochemical boost for auditory sound waves to travel through hair cells (Ohlemiller, Kaur, Warchol & Withnell, 2018). More specifically, it is the potassium ion concentrations that excite hair cells and amplify the hair responses (Weiwei, Lei, Dengke, Wei & Shiming, 2014).

Anatomically, the cochlear is a compact area, that is somewhat sandwiched together. The scale timpani and vestibuli, form the top and bottom layers. Sitting on top of the timpani is the basilar membrane. Above the membrane sits the organ or Corti. The organ of Corti is a central hub of hair cells, supporting cells and nerve endings (Plack, 2018). Super specialised, the hair cells in this corti hub are 20 millionth of a meter in size and have rows of minute hair cells called stereocilia, being the extensions of the hair cell membrane. There is postulated to be one row of inner hair cells containing approximately 3500 cells and five rows of outer hair cells, containing approximately 12,000 cells (Moller, 2013). The tallest tips of the outer hair cells are embedded into the tectorial membrane and alter the mechanical property of the basilar membrane, and the inner hair cells that are not embedded are responsible for basilar membrane vibrations that transduce sound into neural signals via shearing of stereocilia. (Plack, 2018). Directly above the organ of Corti sits the tectorial membrane, that is encompassed by the scale media which is then topped by the Reissner membrane.

Before transduction of sound can take place, an important role is fulfilled by the basilar membrane, where it separates out the frequency features of a sound. This is achieved via the membrane’s slight variance in size. The placement of the basilar membrane near the oval window is narrow, where it picks out high pitched frequency features of a sound, whereas the apex of the basilar membrane is somewhat wider, are captures the lower frequency wave information (Plack, 2018). It is thought that the anatomy of the basilar membrane allows for a smooth movement of the vibrations down the length of the membrane (Polly et al., 2013), that can efficiently support the tonotopic organisation of the hearing system transverses multiple regions from the cochlear through to the auditory cortex. The mechanical separation of frequency components is dependent on a method similar to that of spectral analysis. If we were to envision how sound waves fall onto the basilar membrane, you would see a wave building up to a maximum height, the place on the membrane that resonations with the frequency of the tone (Plack, 2018), followed by a gradual decrease in the wave. The frequency of vibrations at each place on the membrane, is directly proportional to the frequency of the tone. It is important to note here that the motion of the membrane is highly dependent on the motion of endolymph fluid resonance and stereocilia (Moller, 2013).

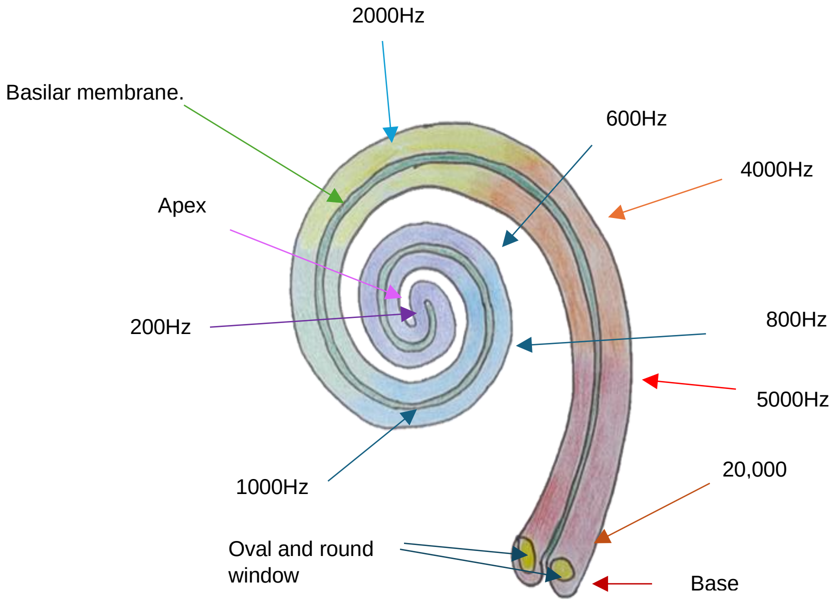


Figure 8 Example of tonotopic organisation of the cochlear. Purple area represents the apex, with lower frequency, and the base represents high frequency. Image created by author of paper.

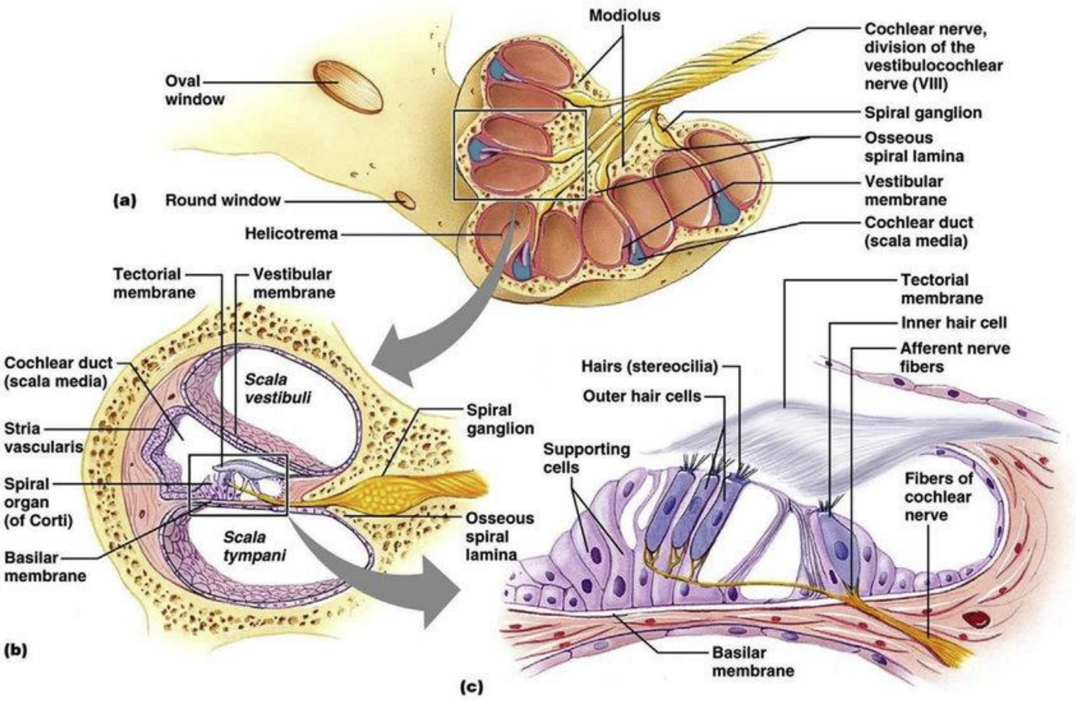


Figure 9 Complete anatomy of the cochlear. Image by Morrill, S., & He, D. Z. (2017). Apoptosis in inner ear sensory hair cells. Journal of otology, 12(4), 151-164.

2.3.5 Transduction

The cochlea, organ of Corti and the basilar membrane which have just been discussed, provide the basis for transduction. Transduction is a biochemical process where extracellular signals are translated from the sound waves into electrical impulses, which are forwarded onto the brain for interpretation. The stapes moves, thanks to a flexible round window, which is able to displace perilymph fluid sending sound vibrations through into the cochlear. When sound waves vibrate on the basilar membrane, hair cells rub on the tectorial membrane above. The shearing motion that occurs, causes stereocilia on the hair cells to sway from side to side, displacing hairs by around 0.3 billionth of a meter (Plack, 2018). Stereocilia are connected to a specific protein filament known as “tip links”, that allow potassium ions to enter hair cells from endolymph. when stereocilia bend towards the Scala media, “tip links” stretch. This shearing motion and stretching of hair cells causes stereocilia to all lean in the same direction to open mechanotransduction channels (McPherson, 2018), which allow potassium and calcium ions flow and increase the electric potential of the inner hair cell, which initiates the first phase of an action potential, known as depolarisation. Depolarisation, causes Glutamate, the main excitatory neurochemical in the body to be released into the synaptic cleft. When the neurotransmitters arrive at the receptor site information is sent up the vestibulocochlear nerve, and onto the ascending auditory pathways, where signals synapse on cells of cochlear nucleus.

It is important to note here that the transduction cycle is sensitive to the intensity of the sound that is entering the ear. It has been noted that movement of the basilar membrane, somewhat depends on sound. For example, Plack (2018) noted the greater the amplitude, the greater the movement of the membrane, which ultimately increases deflection of stereocilia, that opens more channels, which consequently releases more neurotransmitters, ultimately increasing activity along the auditory nerve (Plack, 2018). High frequency sounds produce maximum movement on the base, whilst low frequencies activate the apex of the membrane (Nuttall, 1999), following the spatial cochlear frequency map, with the spatial distributions of frequency called cochlear tonotopy, of a tonotopic map (Li et al., 2021).

2.3.6 Vestibular cochlear nerve

.

As sound information leaves the inner ear via transduction, sound information makes its way through to the central auditory pathway before entering into the brain. The vestibular Cochlear Nerve (VCN), a bundle of axons that synapse with the hair cells, has two components that amalgamate into one track, the vestibular nerve, responsible for carrying impulses for equilibrium (Waldman, 2009) and the cochlear nerve which innervates the cochlear to promote hearing (Kliegman, 2020. When neurons make connections with hair cells, the sensory receptors of the auditory system, hair cells are activated, that relay auditory signals to both portion of the nerve signalling neurotransmission release. The cochlear nerve has its origin in the bipolar cells of spiral ganglion of the cochlear, adjacent to the spiral lamina. The fibres pass through the foramen centrale into the outer portion of the internal auditory meatus with the vestibular nerve. Finally, the nerve travels through the subarachnoid space until it meets is cochlear nucleus (Waldman, 2009).

The firing rated of a neuron in the VCN is dependent on the magnitude of vibration that enter onto the basilar membrane, at the place where the frequency of the sound is connected (Plack, 2018). It is also characterising of this anatomy to find increased sound levels, increasing neuronal firing rates, via a spectrum of sound. For example, when low frequency stimuli are presented, neurons with low characteristic frequency’s, in the centre of the auditory bundle increase in firing rates. Similar with high frequency, neurons with high frequency characteristics near the periphery of auditory bundle will increase firing rates (Plack, 2018). This is called place coding, which by definition is where sound frequency is encoded by location of the neurons that fire during an auditory stimulus (Reyes, 2021). Nerve fibres also represent the characteristics of sound via phase locking, the ability of a neuron to fire potentials at a particular phase of an on-going periodic sound wave (Tollin, 2008) and temporal coding the representation of information in terms of temporal patterns of activity in the neurons.

2.4 The central auditory system

Auditory information enters the central auditory system, a complex ascending system, which includes nerve fibres, cell bodies, nuclei of the brain stem, mid brain and cortex (Fowler, Leigh-Paffenroth, 2007). Projections start at the cochlear nucleus, then travel to the superior olivary complex, the lateral lemniscus nuclei, the inferior colliculus, medial geniculate nucleus, before reaching the auditory cortex. It is important to note here that whilst there is research into the anatomy, cytoarchitecture and synaptic path ways of the central system, research is still limited, compared to that of the visual field for example. Moreover, research into the central auditory system is heavily reliant on animal studies (e.g. bats and rodents), as such, caution should be given when evaluating the evidence in humans.

2.4.1 The cochlear nucleus

The Cochlear Nucleus (CN) is the location all ascending information from the cochlear form synaptic connections with the auditory brain (Stefanescu & Shore, 2017). Divided into two streams, the dorsal and ventral, these streams are imperative for sound localisation, auditory features detection and adaptive filtering of self-generated signals (Stefanescu et al., 2017). The Ventral Cochlear Nucleus (VCN), part of the nuclei at the front of the brainstem, contains millions of neurons, who`s axons project mainly to the superior olivary complex on both sides of the head (Plack, 2018). The central part of the cochlear nuclei is covered by floccules and caudal fascicles of the idle cerebellar peduncle (Henkel, 2018). The ventral stream is further subdivided into the Posteroventral Cochlear Nucleus (PVCN) and the Anteroventral Cochlear Nucleus (AVCN) by the nerve root (Middlebrooks, Lee & Macpherson 2009). Histology of the VCN show that cells convey information via 3 distinct cells, bushy cells, stellate cells and octopus' cells, which play central roles in synchronisation of nerve fibres (Ferragamo & Oertel, 2006) and encoding the spectrum of sounds. The dorsal cochlear nucleus, towards the back of the brain stem, drapes over the restiform body, inferior to the pontomedullary junction (Henkel, 2018), project mainly to the nuclei of the lateral lemniscus and inferior colliculus on the opposite side of the head (Plack, 2018). Histology of the VCN shows, two key cells aid information transmission, namely the fusiform cells and giant cells, which collect and process auditory input.

2.4.2 The superior olivary complex

The Superior Olivary Complex (SOC) is the next hub of the auditory ascending pathway after the CN. When auditory information reaches the SOC, information from both ears gets combined and the nuclei respond to the sound perceived in both ears as a single piece of information. Divided into 2 components, the medial and lateral the medial superior olive (MSO) is sensitive to differences in time of arrival of sounds between the two ears (Plack, 2018). Interestingly, the MSO specifically detects the time lag between auditory signals entering the auditory system, via the impinging of acoustic signals on the contralateral dendrites (Hall &Hall, 2021). The Lateral Superior Olive (LSO) is sensitive to differences in sound, specifically with detecting the direction sound have originated from, which is postulated to be achieved via the difference in intensity of the sound reaching both ears (Hall & Hall 2021). Furthermore, Tollin (2008) suggests the LSO uses interaural level differences as a point of resources for location of auditory source. For example, a sound on the right side will arrive at the right ear, a moment before it arrives at the left ear, whilst a sound that is directly in front will arrive at the same moment in time (Tollin, Rutland & Yin, 2009).

2.4.3 Lateral Lemniscus Nuclei

Following the ascending pathways from the cochlear nuclei, into the superior olivary complex, the next hub of auditory processing is the Lateral Lemniscus Nuclei (LLN). The LLN is formed via a thick bundle of fibres, connecting the auditory brain stem with the auditory midbrain (Kandler, 2019). The nucleus is separated into 3 nuclei-based structures; the Ventral Nucleus of the Lateral Lemniscus (VNLL), The Intermediate Nucleus of the Lateral Lemniscus (INLL) and the Dorsal Nucleus of the Lateral Lemniscus (DNLL). Each nuclei express different neurotransmitters, synaptic and biophysical features, with the complexity of their input pattern increasing in ascending fashion (Franzen et al., 2015).

The VNLL according to Felmy & Meyer (2020) generates a temporally precise, broadly tuned feed forward inhibition, which reduces spectral splatter at the onset of a sound. The INLL, integrates sound frequency in auditory scenes that are complex, with the DNLL, providing long lasting inhibition that overpowers sound source information during reverberation acting as a temporal binaural filter (Felmy & Meyer, 2020).

2.4.4 Inferior Colliculus

The Inferior Colliculus (IC) is an important part of the auditory pathways, where most ascending nerve fibres synapse. It is a paired structure, serving as a relay point and is responsible for integrated sound localisation and identity (Plack, 2018, Driscoll & Tadi, 2022). Moreover, the IC, is the first site where cells carrying horizontal and vertical sound location from each ear converge. Interestingly, the IC plays a defining role in generating the auditory startle response, which will be discussed later. The IC additionally aids orientation of the body towards relevant stimuli and discriminating pitch and rhythm (Driscoll et al., 2022).

Mainly glutamatergic, cells in layer V & V1 of the auditory cortex, project principally to the ipsilateral IC, with main contribution of cortical information derived from layer V. (Plack, 2018). This allows for top-down modulation of IC response to frequency, intensity, duration and localisation (Plack, 2018). It is thought, some cells in the IC allow a response to contralateral visual field stimuli. The hypothesis is that this helps map the surrounding physical space with both modalities working in tandem (Driscoll et al., 2022). Plack (2018) further suggests that somatosensory information deriving from the spinal cord and cranial nerves, further facilitates the role of the IC in auditory processing. Efferent projections include the medial geniculate nucleus of the thalamus, in addition to lower-level processing nuclei and regions.

2.4.5 Medial Geniculate Nucleus

Part of the thalamus, the Median Geniculate Nucleus (MGN) is a complex nucleus that receives vast inputs from the inferior colliculus, serves as a synaptic relay station in the pathways for information reaching the auditory cortex (Greenlee et al., 2007). The MGN is subdivided into 3 distinct components, which each play a defining role in auditory processing. The Ventral Medial Geniculate Nucleus (VMGN), the Dorsal Medial Geniculate Nucleus (DMGN) and the Medial Medial Geniculate Nucleus (MMGN).

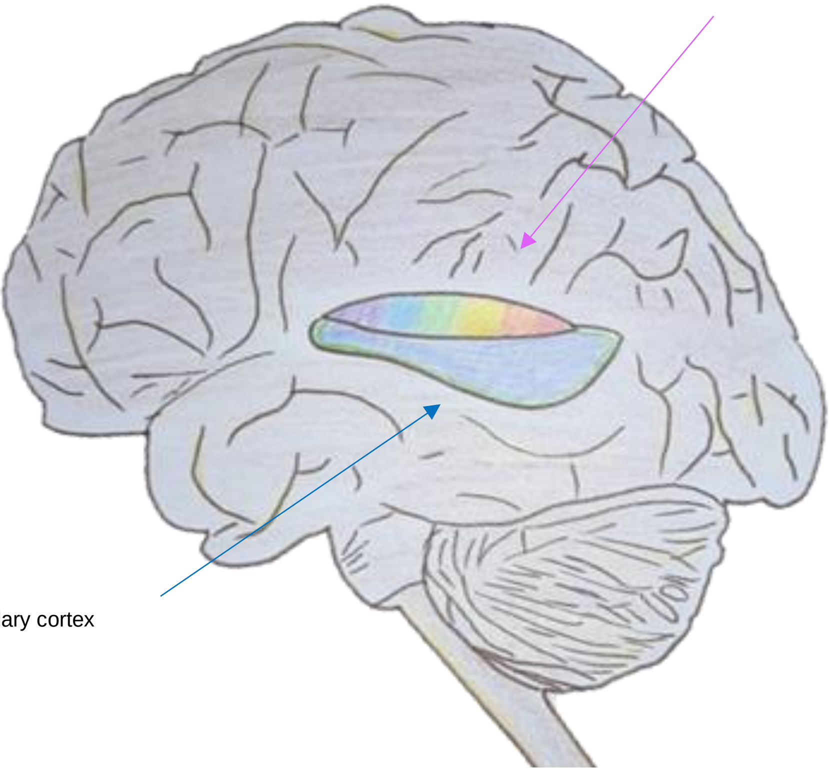
The VMGN projects mainly to the primary auditory cortex. It has a tonotopic organisation which relays frequency, intensity and binaural information to the A1. (Sheridan & Tadi, 2023). The DMGN, Receives input from the IF and other thalamic nuclei and projects to the auditory association cortex (Flint, 2021). The DMGN attends to acoustic and somatosensory information. Finally, the MMGN, projects to the A1 and some associated regions such as; amygdala, putamen and palladium, receiving input form the vestibular nuclei and the spinal cord. MMGN uses binaural interaction and plays a possible role in arousal to auditory intensity and duration (Flint, 2021). Tonotopic arrangement is unknown in this area, due to anaesthetics used in research interacting with MMGN cellular function, however, it is plausible that tonotopic arrangement exists, given the link to the A1 and how it receives sound information.

2.4.6 Auditory cortex

The exact anatomy of the auditory cortex remains under debate and can vary form one person to another (Moller et al., 2013). Based on current literature, evidence suggests nerve fibres from the MGP project directly to the auditory cortex, located at the top of the temporal lobe, hidden in a fissure in the cerebral cortex known as the Sylvian fissure. The auditory cortex consists of the Primary auditory cortex (A1) and the secondary auditory cortex (AC2) (See figure 10). The A1 is located on a raised area in the fissures of the cortex known as Heschel's gyrus. Approximately 85% of cells within the A1 are pyramidal cells, with the remaining proportion thought to be multipolar or stellate cells (Gil-Loyzaga, 2022). Whilst no consensus of the full macro-anatomy of the A1 exist, most researchers postulate an organisation including Heschel's gyrus, first transverse sulcus, Heschel's sulcus, planum temporale, superior temporal gyrus and superior temporal sulcus (Moerel, Martino & Formisano, 2014). These regions are compact and contain tonotopic representation where it is organised in columns, such that each column of a cell responds maximally to an acoustic stimulus of a specific frequency (Moerel et al., 2014) which is an exact replica of the tonotopic map of the cochlea (See Figure 6). It has a striped arrangement of binaural properties, with excitation of one stripe by both ears (EE cells) with the neurons in the next ear excited by one and inhibited by the other (E1 cells) (Purves et al., 2001). Sources of neurotransmitters are also abundant within the A1. Acetylcholine is thought to be involved in plasticity and tonotopic reorganisation (Ji & Suga, 2003), Glutamate as well as GABA acts on GABA-A receptors to modulate intensity and frequency responses of neurons in the A1 (Moore et al., 2012).

Normative computational and circuit models are also beginning to provide further knowledge in this field. For example, Park & Geffen (2020), evaluated the auditory cortex via a Wilson-Cowan model, which describes the dynamics of interactions between excitatory and inhibitory neurons, with a further introduction of tonotopy into the spiking model. Results found, the A1 inhibitory interneuron parvalbumin compensates for reduced somatostatin activity when the thalamic inputs are strong. There is plasticity within the synapse of the A1 and a seamless balance of inhibitory and excitatory currents. (Park & Geffen, 2020). Similarly, DePinho, Mazza & Roque (2006), use a computation model to reproduce auditory representations. Research found, during auditory classic conditioning paradigms, there was a retuning of neurons, inferring auditory plasticity, accompanied by expansion of cortical representations and properties of high tonotopic maps. Furthermore, computational modelling of the A1, allowed May, Westo & Tiitinen (2015), to establish that synaptic adaptation was ubiquitous in the A1 which facilitated suppression effects, particularly to respond selectively to tone pairs and complex tone sequences, as well as temporal integration. As a note of caution, Bray (2014) suggests, these models are framed under severe restrictive conditions and do not account for molecular uncertainty, specifically that are responsible for fine tuning and adaption. As such, accepting these models does come with some tribulation, regardless of the exponential developments in the research area they provide.

In addition to the A1, the auditory cortex has the further division, namely the AC2, which receives projections from the A1. This region engulfs the A1 and receives ascending information form the dorsal and medial MGN (Arslan, 2016). Current research suggests that the AC2 facilitates proper execution of learned action timing, with the additional function of transducing self-generated audio motor feed-back to control timing (Cook et al., 2022).



Primary Auditory Cortex (A1). Area follows tonotopic representation that is throughout the auditory system. Purple- apex, red- base

Secondary cortex

Figure 10. Organisation of the auditory cortex. Image created by author of paper.

Auditory pathway region	**Function**
Superior olivary complex	Locates the angle of the sound
Lateral lemniscus	Feed forward inhibition to reduce spectral distribution of sound and integrates sounds in complex scenes
Inferior colliculus	Localises the sound
Medial geniculate nucleus	Direction and maintenance of attention
A1 (Primary auditory cortex)	Hearing reception and sound perception processing. Relay station for distributing sound information throughout the brain for facilitate task appropriate behaviour

Table 1 Overview of what is processed in each area of the central auditory system and how it influences direction of attention to a sound source.

2.5 Descending auditory pathways.

In addition to the ascending pathways in the auditory system, audition has descending pathways that carry information form the A1/AC2 to lower centres, as far down as the cochlear nucleus (Plack, 2018), using a plethora of neurochemicals, namely, glutamate, GABA, glycine, acetylcholine, and dopamine (Schofield & Beebe, 2018) and cortical loops. Huffman et al. (1990) suggest, 3 parallel descending pathways connecting the A1, MGN and the IC, which are mutually exclusive and inform, parallel processing of auditory information. The connecting pathways set out in Huffman et al. (1990) are the A1 and the IC, the IC and the SOC, particularly to the source of olivocochlear efferent neurons, which descend to the cochlear, and finally the 3 branches of IC neurons connecting the AC2 and cerebellum.

It is also suggested that the descending pathways are involved in perceptual learning. For example, Plack (2018) notes signals from the high auditory cortex change the way neurons in the brain stem process sound, to enhance ability to extract relevant stimuli characteristics and adapt to changing conditions. Additionally, King & Schnupp (2007) noted the auditory thalamus as being an auditory hub, receiving descending projections, with four times more inputs arriving from the cortex than other pathways. It is thought though descending corticofugal axons may be involved in selectively filtering information in the mid brain and thalamus, which may enable attention direction to multiple aspects of the environment whilst inhibiting others (Plack, 2018). Furthermore, Terreros & Delano (2015), describe descending pathways from the A1 as the MGB, IC, SOC, CN and the SOC to the cochlear. Finally, Leach et al. (2013) suggest descending pathways influence plasticity or neuronal processing, via a cortico-collicular projection and a variety of cells types in layer V1.

2.6 Hypothesised model of ascending and descending pathways

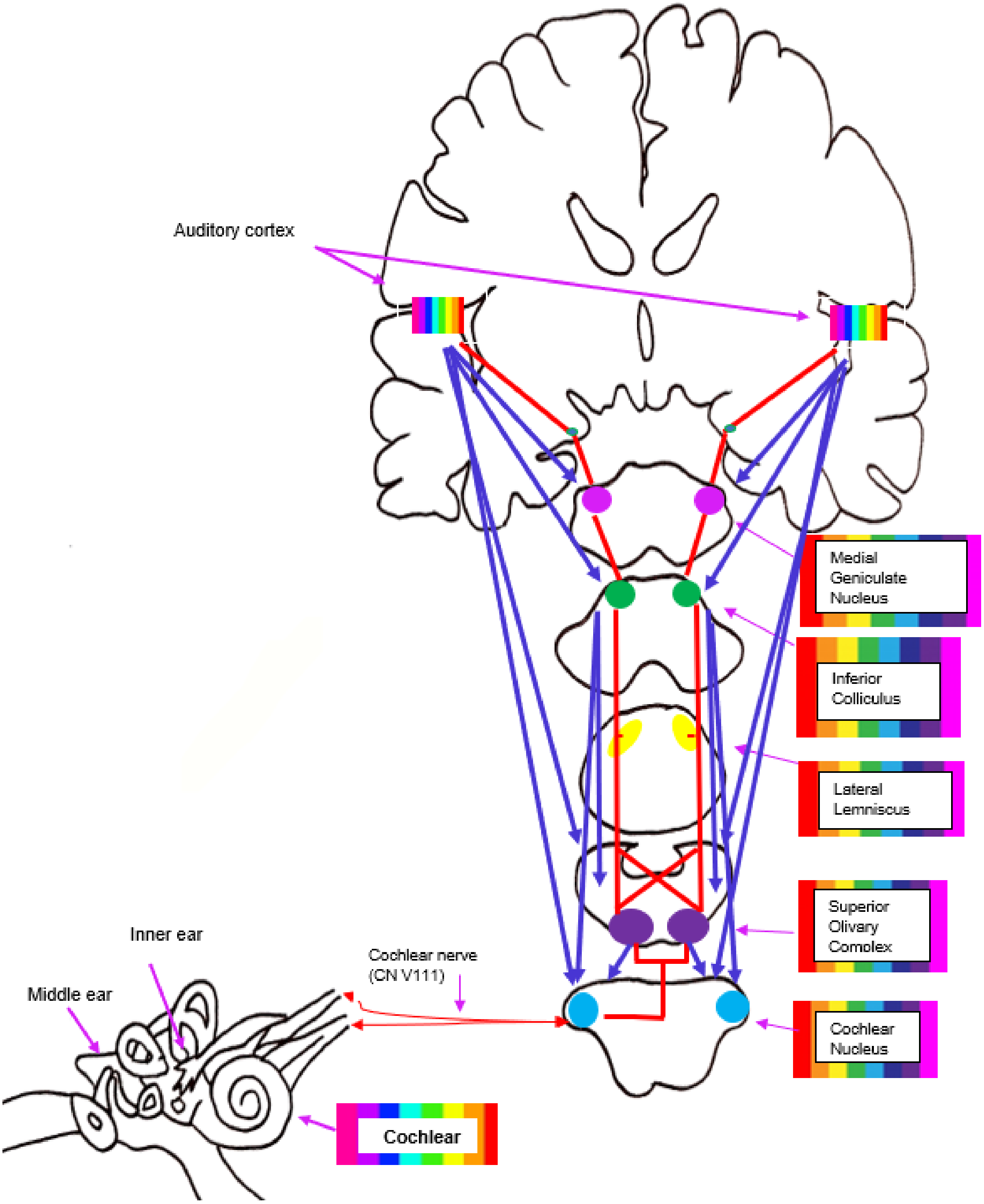


Figure 11, Hypothesised ascending (red) and descending (purple) projections of the auditory system. Note, rainbow boxes represent tonotopic organisation. A note of caution should be given as research in this area is a growing field. Current tonotopic hypothesis are animal model predictors for humans. Image created by author of this paper.

The hypothesised model of the ascending and descending pathways of the auditory system (See figure 11), provides a detailed visual representation of how sound waves get converted and distributed through the entire system. Organisation of some aspects of sound are processed automatically and require little cognitive processing, whilst some are high level processing (e.g., perception, speed) (De Santis, Clarke & Murray, 2007). Processing of sound be it automatically or high-level processing is an imperative feature of how we interact with the environment. The everyday environment is noisy and rapidly changes dependant on where we are. Moreover, how we process sound defines our behaviour and our walking. A later chapter will provide a detailed analysis of how sound, attention, cognition and behaviour are all interrelated, and hold a large degree of influence of gait and attention control. The next section will provide evidence of how sound impact the body, and the influence this may have over how we navigate and interact with our environment.

2.7 Environmental sounds and noise.

Noise in generalised layman terms is any unwanted sound and In terms of acoustic research, noise is a sound wave whose pressure varies in an unpredictable way, over time (Plack, 2018), with continuous distributions of frequency components. Humans generally hear around 50-80dB in a given day, but noise we experience in our environment, unexpected or not can reach in excess of 100dB, which is known to have long term detrimental effects on hearing loss and influence acute acoustic trauma such as tympanic membrane perforation.

The influence of loud noise and modulation on the basilar membrane has been reported to produce a reduction in amplitude with, phase lags recognised at multiple frequency sections of the basilar membrane organisation (Fridberger, Zheng & Nuttall, 2002). Similarly, reduction of basilar membrane velocity, post loud sound, has been linked to cochlear amplifications changes determined by the organ of Corti (Fridberger et al., 2002). Moreover, loud noise has a considerable influence over perilymph and endolymph fluid in the inner ear. Loud noise creates an aggressive fluctuation within the fluid, which in turn activates the basilar and tectorial membrane to shear and squeeze, which damages cilia via separation from the inner and outer hair cells, which in turn impact hair cells receiving information, becoming defective and have limited coding ability (Ding, Yan & Liu, 2019). Given hair cells are not able to regenerate, the effects of noise exposure on hearing are catastrophic, particularly when 50% of hair cells can be damaged for destroyed before noticeable noise induce change (CDC, 2022)

Relating to physiology, Loud noise has been linked to neuronal changes in the Inferior colliculus, particularly via diminishing dopamine receptor density, which can influence hearing loss (Wilson & Apawu, 2022). Animal studies have found loud noise exposure influences the auditory cortex via a reorganisation of the cortical tonotopic map which can cause hearing loss to part of frequency hearing ranges (Pienkowski & Eggermont, 2012). Furthermore Busceti et al. (2015) note hippocampus changes as a result of loud noise, as well as the reticular formation (Fornai et al., 2011) and cerebellum alterations (Uran et al., 2010). A study by Frenzilli et al. (2017) examining the role of noise exposure on DNA, neurotransmission and morphological damage found specific anatomical alteration in rats exposed to high noise. Loud noise was highly influential on the striatal, hippocampus and cerebellum, each with significant damage to DNA and neurotransmitter release. Dehmel et al. (2012), also suggest noise alters long term somatosensory-auditory processing in the dorsal nucleus, which may influence source localisation, integration of auditory spectral cues and high-level computation of sound source.

Interestingly, links are also found between noise and metabolic damage, which give rise to free radicals such as reactive oxygen species (ROS) being produced because of noise contracting cochlear blood vessels (Ding et al. 2019). Similarly, Ding et al. (2019) also acknowledge noise may alter Ca^2 channels that open, influencing how much Ca^2 gets to hair cells.

This influx can activate protease involved in processes such as cell mobility and cycle progression, which they suggest induces apoptosis of hair cells. In addition, Ohinata et al. (2000) found loud noise induces formation of vasoactive lipid peroxidation in the cochlear, with noise induced lipid peroxidation creating substantial morphological damage to the organ of Corti and substantial hair cell damage.

2.7.1 Noise and physiological changes

As presented, there is a growing body of evidence that suggests sound, particularly noise that we experience every day, can lead to anatomical changes, fluctuations in fluids that facilitate transduction of sound via hair cells and free radical production within the auditory system. Environmental sounds, defined as an accumulation of noise pollution or unwanted sounds, that interfere with normal activity*,* have also been shown to have a physiological effect on the body, including heart rate Munzel, Gori, Babisch & Basner, 2014, Lusk et al., 2004, Lu et al., 2018 & Babisch, 2003), skin conductance changes (Ellermeier et al., 2020) and respiratory intensity change and muscle activity. For example, studies have elucidated the relationship between noise and heart rate variability via increases in blood pressure, cardiovascular rhythm changes. Lu et al., (2018) exposed 30 participants to sounds of increasing dB level, with results finding an increase In systolic and diastolic blood pressure at 0.71mmHg/10dB. Similarly, Lusk, (2004) evaluated the effects of noise exposure on systolic and diastolic blood pressure in 46 adults. As with previous evidence, there was a significant positive association between noise level and blood pressure. Furthermore, Walker et al., (2016) evaluated cardiovascular response to short term noise exposure. Measurements included electrocardiogram, blood pressure and saliva collection, before, during and after noise exposure. Results found, exposure to low frequency noise has a significant impact on heart rate variability.

Possible explanations for the link between noise and heart rate variability include the release of catecholamines which include neurotransmitters adrenaline and dopamine (Babisch, 2003) and noise exerting a physiological effect via synaptic interactions and/or perception of sound (Munzel, 2014). Perception of sounds (distractibility or pleasantness), which this thesis will cover in a later chapter is of great importance as research suggest that pleasurable perceptions of sounds are believed to promote health, whilst sounds that are annoying or distracting impact health exponentially. Finally, an increasingly damning report by the European Environmental Agency (2020), further exacerbates the link between sound/ noise with a paper noting some 12,000 premature deaths and 48,000 ischemic heart disease were attributed to environmental noise pollution every year.

In addition to heart rate variability, the increase in our understanding of how noise may play an underlying role in physiological changes has also created an opportunity to explore noise and skin conductance changes. For example, Strukelj et al., (2012) eye movement and skin response to noise exposure during text comprehension. Results found no significant changes to eye movement, but an increased stress of participants via skin response to noise over 70dB. Similarly, Bradley & Lang (2000) monitored affective reactions to acoustic stimuli. Subjects were required to rate pleasure and arousal of 60 sounds, followed by a recall task. Autonomic and facial EMG was deployed to collect physiological measures. Results found, Electrodermal reactions (skin response) were increased for emotional arousing noise as opposed to neutral noise. Furthermore, Ellermaeier et al., (2020) evaluated short term noise annoyance and electrodermal response, under two conditions: 1) participating in a challenging non-auditory task with traffic in the back ground and 2) imaging relaxing at home in the absence of activity, with sounds played. Results found, across both experiments, skin conductance responses after the onset of noise increased significantly with sound level. Interestingly, a study by Tarpin & Siddle, (1979) found when participants are presented with sounds of increasing noise level, there was a skin conductance response habituation. Such that the increasing noise is diminishing in effectiveness.

Understanding the physiological response to sounds (environmental sound) is of importance as it highlights how sound influences wellbeing. Moreover, it helps create a greater understanding of the cognitive and behavioural response to the environment in everyday life (Masullo, Toma & Maffei, 2022). Moreover, sounds we hear in our everyday life are capable of creating an arousal and fight or flight response that may alter how we interact with or navigate the environment. Muscle become tense, attention control deteriorates, depletes energy levels and produces asymmetric gait (Goyal, Gupta & Walia, 2010, Reh, Schmitz, Hwang & Effenberg, 2022). If environmental sounds (regardless or noise level) are capable of such change, it is important to continue to research this field, particularly with respects to gait and attentional control/visual processing.

2.7.2 Noise and cognition

The effects of noise, particularly environmental sounds that we hear in our everyday environment are documented in literature for the influence it has over cognition. Environmental sounds, of varying degree in amplitude have been shown to influence writing abilities (Kabanski et al., 2014), reading and listening (Marchand et al., 2014). It is believed that impaired task performance is due to attention capture and the inability to filter out the irrelevant stimuli focus on the current task (Kabanski et al., 2014). The inability to filter out irrelevant environmental sound stimuli has significant impact in memory, reaction times and perception and given cognition is a behaviour, it can be affected by sound, which further supports the notion of this thesis that environmental sound can influence attention and gait. For example, Zeydabadi et al. (2018) examined the implications of environmental industrial noise on attention, reaction times and memory. Two groups, one noise levels of 85dB or greater and one with lower sound exposure of 80DB or less, were tested before and after a work shift. Selective attention, memory, response time, divided response time were significantly changed in the loud noise group compared to the lower amplitude group, with a decline in each measure's performance. Similarly, Bhang et al. (2018) found in educational system, noise has a detrimental influence over attention and academic performance (maths, vocabulary, response times etc).

Interestingly, low frequency environmental noises have been shown to have a similar impact on cognition. Pawlaczyk-Luszczynska et al. (2005), found that low frequency noises adversely affect visual function, concentration, continuous and selective attention. Thus suggesting, regardless of the noise level, the hearing system is capable of maintain a hold over attention and performance. Interestingly, Hidaka and Ide (2015) outline that sound can capture attention and a lower and faster threshold than any other sensory modality, whilst maintaining the ability to suppress other sensory modalities in favour of sound localisation. If sounds are capable of drawing attention and thus processing resources away from behaviour, then performance of that behaviour can be detrimentally impacted. This is something that will be addressed in later chapters (e.g. STAC test, gait study). A note of caution should be given. Individual difference needs to be acknowledged when looking at the link between sound and performance as not all research shows a detrimental effect of sound. Some show that sounds can have an alerting effect and improve performance under some circumstances. Moreover, different aspects of sound impact human performance differently (Dalton & Behn, 2008).

2.7.3 Context effect in environmental sounds processing

Whilst the aim of this PhD thesis is to understand the degree to which environmental sounds (e.g., industrial, nature, mechanical noise) influence attention control and gait, a note of interest should be given to sounds that hold familiarity and meaningfulness. Unfortunately, we could not measure such influence in this study due to COVID-19 restrictions, but it is important that this information is presented as it is an important component of everyday sounds, that we would like to review later.

An effective stimulus for capturing attention via familiarity and meaningfulness in our environment is calling someone by their name. The most notable research in this field derives from the “cocktail-party effect” Cherry (1953), in which a person who is engrossed in conversation, will be able to hear their name being called from somewhere else in the room. This auditory ability allows an individual to isolate and re-direct attention towards the sound source, whilst filtering out the irrelevant sound. The notion of an individuals name capturing attention has additionally been found in oddball paradigms where rare and unexpected changes to a sequence can break through attentional filters and alter task performance (Permentier, 2016). For example, Eichenlaub, Ruby & Morlet (2012) found that when an individual’s name was presented during an oddball sequence, an evoked potential measure was found at 300ms. Suggesting one’s own name is processed differently to task relevant and environmental sounds (e.g. sequence).

Familiarity of sound may also alter task performance via an emotional component (e.g., a common word spoken in a pleasant on unpleasant manner). For example, Chen, Lee & Cheng, (2014) created a research design to understand the emotional salient of voices in an odd ball paradigm. This study used magnetoencephalography to measure the magnetic counterparts of MMN and P3a, whilst the syllable dada was presented in a neutral, happy, or disgusted pattern. The results revealed that happy presentation could elicit strong cortical activity. Moreover, this paper addressed task performance during an emotional categorisation task during three separate conditions (emotional syllables, complex tones & simple tones). Evidence from the study found accuracy and response times we significantly improved during presentation of emotional syllables compared to other conditions. This study highlights the role of an emotional component of an incoming auditory stimulus. Furthermore, emotional salience should not be discounted as a variable when trying to understand how environmental sounds influence task performance or gait. Environmental sounds are likely to include both familiarity and emotional elements.

Familiarity and emotional elements of environmental sounds are somewhat of a challenging variable when trying to measure the influence environmental sounds have on attention control and gait. Firstly, metacognition, the ability to be aware of one's cognitive processes and regulate them, may influence how people respond to sounds (Fleur, Bredeweg & Van den Bos, 2021) Secondly, individual perception will influence people judgements on how they attach meaning to and interpret incoming auditory information. Finally, if familiarity and emotion context influence categorisation of sounds, how accurate are people's judgement. To overcome this, study 3 included sounds that older adults deemed pleasant and not distracting to our auditory folder for our gait study. We used these sounds to understand the degree to which perceptual judgement of categories were accurate, particularly for distractibility.

Research addressing individual difference and metacognition in auditory distraction is a growing field of research, with mixed reactions (Beaman et al., 2014, Bell, 2022, Parmentier & Hebrero, 2013). Some individuals indicate they have an awareness of how changing auditory stimuli influence their performance (Bell, 2022), whilst others outline auditory distractions undermine accuracy of metacognition monitoring, reduced confidence in response provided and increased propensity to withhold responses in free-reporting recognition (Beaman, Hanczakowski & Jones 2014). More research is needed to support the role of metacognition, distraction, and performance. However, what is clear is if individuals can use metacognition to be aware of how they perform, tools such as auditory cognitive training may be a beneficial tool to reduce the risk of falls and falling in older adults.

2.8 World health report and noise.

A summation of the detrimental impact of noise on humans, comes from a damning report by the world health organisation (2023), via identification of issues surrounding noise, specifically environmental noise the general population hear every day, at varying levels of volume/decibels. In 8 large systematic reviews, WHO looked at the influence of environmental noise on cardiovascular disease, sleep, annoyance, cognitive impairment, hearing impairment and tinnitus, adverse birth outcome, quality of life, wellbeing, mental health and metabolic outcomes. Each measure was the result of >1000 people across different qualitative and quantitative measures. Evaluation of the data found environmental noise had some form of adverse effect on nearly all measures, physiological, cognitive or mental health. Recommendations as a result of this study suggest; road noise >53dB (>45dB at night), Rail noise >54dB, aircraft >45dB, leisure noise >70dB all have significant adverse effects on the population, which elevate the risk of psychological, mental and cognitive problems, and reduce rates of efficient outcomes of illness (WHO, 2018).

This publication of this report has led to a resurgence of research in the field of environmental sounds/noise and the impact it may have on individuals. What was missing from this report is the detrimental impact noise has on walking integrity, particularly in older adults, giving increasing reasons why the studies in this thesis are important to this field of research. Maintaining walking integrity is of upmost importance in older adults as it allows for independence in living and healthy ageing. As such, this paper, as outlined previously will discuss sounds in the environment related to walking behaviour, to build on current knowledge, whilst further justifying the negative influence environmental sounds play in older adults, particularly via attention control and redirection.

2.9 Summary of findings and formulation of research question.

- Organisation of sound are processed either automatically or require little cognitive processing, whilst some are high level processing (e.g., perception, speed).
- The auditory cortex is a highly tuned system which is able to detect and process these different patterns and attributes of waves and

provide a detailed analysis of each feature of a sound wave and decode the smallest details of spectral and temporal information embedded in sounds (Concina et al., 2019), whilst separating out frequency components of sound, thus allowing the detection, perception and understanding of our sound environment.

- The effects of noise exposure on hearing are catastrophic, particularly when 50% of hair cells can be damaged for destroyed before noticeable noise induce change (CDC, 2022). The implications this may have on old adults can be devastating. Hearing loss can influence gait, balance, attention, social life, mental health. Moreover, Hearing loss has recently been found to be a defining factor in developing dementia in later life.
- Environmental sounds are capable of producing a measurable change to physiology (e.g., heart rate & skin response).
- Moreover, sounds we hear in our everyday life can create an arousal and fight or flight response that may alter how we interact with or navigate the environment. Muscle become tense, attention control deteriorates and depletes the body of energy and gait may become asymmetric.

Chapter 3 – Environmental sound perception

Summary of chapter aims and context.

The everyday environment is busy, loud and presents with unexpected auditory stimuli, which are capable of capturing and redirecting attention. This is particularly worrisome for older adults, who are at increased risk of attention redirection due the age-related changes to the brain and auditory systems. The unexpected nature of environmental sound can also influence gait and balance, leading to an increased risk of slips, trips and falls. As such, it is important to understand what kind of sounds within the environment do older adults find the most distracting and attention grabbing. This aim of this chapter is to provide an overview of environmental sound and how it may influence attention. Moreover, it will provide research taken from a study undertaken during this PhD, to understand how older adults specifically perceive and categorise sounds, via an auditory confrontation naming paradigm.

Environmental sound – An accumulation of noise pollution or unwanted sounds, that interfere with normal activity.

3.1 Introduction

An important component of our ability to successfully navigate and interact with our environment, is the brain's ability to direct in parallel its limited resources (attention) towards the processing of several behaviourally and situationally relevant environmental stimuli or events (Wu, Liu, Hallett, Zheng & Chan, 2013, Lindenberger, Marsiske & Baltes, 2000) and away from irrelevant but distracting information. Although individuals have some degree of endogenous control over such attentional allocation (Grubert, Fahrenfort, Olivers & Eimer, 2017, Kurtz, Shapcott, Kaiser, Schmiedt & Schmid, 2017), irrelevant but salient environmental stimuli, can automatically capture attention or some degree of it, thus directing processing resources away from current behaviour. Such attentional re-direction can lead to various degrees of failure in the ability to successfully perform a primary action and the capacity to dual task, (i.e., perform actions concurrently (Zukowski, Tennant, Lyigun, Giuliani & Plummer, 2021, Papegaaij et al., 2017).

Cognitive healthy ageing can be accompanied by a significant increase in falls (Lockhart, Smith & Woldstad, 2005) and it has been suggested that this may result, at least in part, from inefficiency in the ability to selectively allocate attention and thus resources or reduction in the availability of the resources *per se* required for initiating and maintaining walking. This inefficiency may be further exacerbated as a result of, age-related reduction in the ability to ignore distracting and irrelevant information, poor cognitive and motor performance (Brustio et al., 2017, Tsang et al., 2016, Nieborowska et al., 2018, Zukowski et al., 2021, Harris, Eckert, Ahlstrom & Dubno, 2010). Such factors can result in a detrimental influence over gait and balance and thus walking efficiency and safety. Particularly, when walking is performed in conjunction with another activity such as talking. (Berti, Grunwald & Schroger, 2013, Owsley & McGwin, 2004, Zukowski, Lyigun, Giuliani & Plummer, 2020), with such detrimental changes potentially contributing to the 30% older adults (65+) experiencing a fall each year, with around half of that figure continuing to have more frequent and life changing falls (NHS, 2021).

Such factors are also linked to fear of falling (Reelick, Van Larsel, Kessels & Rikkert, 2009) over exposure of visual perturbations which can cause a mismatch between actual and perceived gait (Osoba, Rao, Agrawald & Lalwani, 2019), and spatio-temporal changes that may impact problem solving and organisation of gait (Elboim-Gabyzon & Rotchild, 2017). Furthermore, if attention, selective attention, and dual tasking are already poor then people may not be able to cope with further resources being directed away from walking as well as walking and talking, by stimuli within the environment. Sound for example is very efficient at automatically capturing attention, as well as taking away resources to process the sound, thus leaving less for walking. Sound may also cause a startle reflex and thus people may react, jump, or fall over (Neshige et al., 2016).

Although the physical attributes of sound have been investigated in terms of attention capture and distraction, the potential influence of preference for a sound along with perception of its distractibility may also influence the impact on walking and will vary person to person. Our overall aim is to investigate the impact of various sound conditions on walking and gait, presented here is a prelude to this research, examining the various factors associated with sounds which may need to be accounted for in future work. This paper specifically addresses sounds as a subjective environmental distractor, as evidence suggests that it can be a highly powerful means of diverting processing resources from activities such as walking, particularly during dual tasking as the pre attentive processing of sounds is able to capture attention at a lower and faster threshold than visual stimuli, whilst suppressing visual perceptions. (Hidaka & Ide, 2015).

There are however examples of how sound can positively influence gait and walking activities, with rhythmic auditory stimulation rehabilitation in gait showing to be effective in Parkinson’s Disease, Multiple Sclerosis, and stroke (Murgia et al., 2018, Gomez-Andres et al., 2020). For example, Murgia et al. (2018) found the use of footstep sounds as a rhythmic auditory stimulation facilitated improvement in biomechanical and clinical measures of gait in Parkinson disease. Similarly, Gomez-Andres et al. (2019) found enriching and increasing the amplitude of footstep sounds was able to reduce asymmetry of stance and stride in chronic stroke patients. Likewise, Michnik et al. (2021) found that when metro-rhythmic stimulation is presented, the frequency of gait can also be influenced. The evidence of gait improvement linked to sound cues is highly relevant to this study as it provides a starting point as to how auditory processing is linked to motor function during research-based tasks.

Although there is some evidence of how sounds can capture attention whilst walking and thus contribute to falls risk (Zhang, Xu, Zhu, Tian & Kong, 2020), many studies fail to address the unexpected and variable nature of sound, particularly every day or environmental sounds and the potential for such effects to be related to individual variation in how the sound is perceived. Moreover, studies have failed to acknowledge whether the type/category of sound has different a different impact on gait, specific elements of gait and to what extend sound may be negative. Environmental sounds are important, as they are heard in an uncontrolled environment, and because they can be spurious, loud, highly unpredictable, salient, and arguably highly efficient at automatically capturing and/or dividing attention, thus reducing the resources required for walking making gait less effective, unstable and falls more likely (Shumway-Cook & Wollacott, 2000).

To examine the under-pinning research related to the subjective aspect of environmental sounds namely their distractibility and pleasantness. It is also important to determine whether there are significant individual differences in such subjective measures and therefore variance in what may be distracting in real life and how distracting may be related to whether a person finds a sound pleasant or not. Understanding such individual difference will facilitate personalised interventions to reduce the risk of falls in older adults. Gaining further information about individual differences relating to environmental sounds, will inform further research to determine what sounds are likely to be most distracting to people in general. It will also inform which sounds are used in the next study and at the individual level facilitate intervention training in response to such sounds to reduce risk of falls. Finally, at a personal level, people could be trained to become habituated to sounds they find extremely distracting/unpleasant so they are less impacted by them (e.g., so it does not affect gait as much as it might before training).

In the present study, two distinct components were examined (i) sounds in terms of perceived distractibility and pleasantness to understand if there is any relationship between the two, and how this/these may vary across individuals. and (ii) categorisation of sounds via confrontation naming, to understand if there are specific categories of sounds that are deemed more distracting than others. This data will be useful to researchers, as it will provide structure, organisation, and classification to health professionals to target auditory/attention and gait rehabilitation interventions.

3.2 Pleasantness and Distractibility

To evaluate the extent to which environmental sounds are subjectively assessed in terms of distractibility in older adults, this paper will explore environmental sounds via a combination of auditory confrontation naming, an adaption of the psychological test “visual confrontation naming”, where participants are required to identify images on demand and judgements of each sound presented on a Likert scale for distractibility and pleasantness. In line with auditory confrontation naming research set out in Marcell (2000), this paper will continue this form of research design, with the addition of a new variable “distraction”. As such, this paper will examine, how older adults rate environmental sounds as distracting.

It is hypothesised that the sound that will be deemed the most distracting will be industrial, transport or dangers sounds (e.g., things/sounds we have learnt to associate with danger and thus will be naturally more alert to) due to the repetitive, high-pitched sounds within the everyday environment Furthermore, it is hypothesised that sounds perceived to be most pleasant will be musical and nature sounds. It is hypothesised that the results will not be uniform, there will be some variation amongst the participants. It is hoped, that by understanding what sounds in the everyday environment are judged to be more distracting and pleasant, this paper will be able to provide evidence of sounds that may be a contributing factor slips, trips, and falls in the older adults. Moreover, it will provide evidence of preference importance (e.g., how is sound is perceived and judged) and understand other potential factors that should be consider at a later date. If we are not thorough with addressing all variables now, unknowing bias or influence may impact our results or introduce confounds later. Finally, this data can be used as a first step in possible intervention to reduce the risk of falls at home, in care homes or simply when older adults go shopping.

3.3 Categorisation

Visual confrontation naming is a standardised naming task with links to clinical language testing due its ability to detect impairments in word finding abilities such as aphasia. Moreover, visual confrontation naming has been used in temporal lobe epilepsy, memory and language, a diagnostic tool for semantic dementia and developmental disorders (Snodgrass & Vanderwart,1980, Raymer, 2017). Testing via auditory confrontation naming, as used in this paper, was revolutionaries by Marcell et al. (2000), who evaluated confrontation naming of environmental sounds in university students. Marcell (2000), asked university students to listen to 120 auditory clips, then on demand identify, name and categorise the sound they heard to develop a categorisation system to simplify and develop structure of human information processing in younger adults. Reaction times (RT), accuracy, familiarity, pleasantness, and complexity were also recorded. This paper is of significant interest as it is a step away from current research in this field such as frequency (Ballas & Howard 1987) and retention of sound (Leung, Smith, Parker & Martin, 1997) papers focusing on interpretation and learning of environmental sound, to a more generalised study of human perception, from a subjective view point, similar to that of Gygi, Kidd & Watson (2007) who evaluated the similarity and categorisation of sounds via a subjective acoustic similarity rating. The previous studies did not however examine sound categorisation in older adults, nor adults living in the UK or in respect of sound distractibility.

Categorisation of sounds across multiple fields or research, including distractibility in older adults, is important to this research as it will allow researchers to make sense of the noisy world, whilst facilitate communication between researchers evaluating sounds to optimise research. Moreover, categorisation will allow observations and organisation of sounds into concentrated groups to explain the everyday environmental sounds, which may be helpful to health care and medical problems (Vacher et al., 2004) as well as monitoring the environment (Green & Murphy, 2020) to assess where interventions can be placed to reduce falls.

It is hypothesised this research will produce a new distinct group of categories based around everyday life. If is also hypothesised that the categories in this paper will be somewhat different to that of Marcell (2000) as (i) the age group of the participants is significantly different and (ii) locational differences (UK rather than USA) may influence sound categorisation. As such, this research will produce a UK specific relevant index/categorisation of sounds, from which we can then look at perception of these sounds.

3.4 Methods

3.4.1 Developing the index (categorisation) of environmental sounds

Creating the index of environmental sounds used in this study required a considerable amount of detail. The sound clips needed to be short, as to resemble the way many sounds are heard in the environment, but also represent a broad category of environmental sounds that are often heard. The clips chosen for this study are a selection of sounds taken from Marcell et al. (2000). As noted in Marcell et al., (2000), there was a collection of 120 sounds, however this number of sounds did not suit the nature of this study and considerations were given in order to use the most effective environmental sounds clips following strict ethical procedures. Firstly, if all 120 sounds were used the study would last approximately 90 minutes, increasing the risk of participant fatigue, thus creating a decline in performance. Secondly, a large selection of the sounds that were used in the Marcell paper, were deemed unsuitable for this current study (e.g., sounds not commonly heard in UK). Thirdly, given the population of participants are

65+, and are likely to have served at some point in the military, sounds that were linked to warfare were removed to reduce the exacerbation or onset of PTSD, depression, and anxiety.

SOUND LABEL

- AIRPLANE
- BABY CRY
- BANJO
- BASKETBALL
- BIKE BELL
- BIRDS
- BLINDS CLOSING
- BLOWING NOSE
- BOAT HORN
- BOWLING
- BRUSHING TEETH
- BURP
- CAMERA
- CAR CRASH
- CAR HORN
- CAT
- CHEWING
- CHICKENS
- CHILD COUGH
- CHURCH BELL
- CLAPPING
- CLEARING THOAT
- COIN DROPPING
- COW
- CRUMPLING PAPER
- CUCKOO CLOCK
- CYMBALS
- DOG BARKING
- DOORBELL
- DRILL

SOUND LABEL

- DROPPING ICE IN GLASS
- DRUMS
- FLUTE
- FROG
- GARGLING
- GLASS BRAKING
- HAMMERING
- HARP
- HELICOPTER
- JACK HAMMER
- KETTLE WHISTLING
- KNOCKING
- LAUGHING
- LAWN MOWER
- MOSQUITO
- MOTORCYCLE
- OCEAN
- OWL
- PIANO
- PIG
- PING PONG
- POLICE SIREN
- WATER POURING
- RAIN
- SANDPAPER
- SAWING
- SCREAM
- SHEEP
- SNEEZE
- SNORE

SOUND LABEL

- SONAR
- SWORDS
- TELEPHONE
- THUNDER
- TOILET
- TRAIN
- TRUCK
- TRUMPET
- TYPEWRITER
- VELCRO
- VIOLIN
- WATER BUBBLING
- WATER DRAINING
- WATER DRIPPING
- WHISTLE
- WHISTLING
- WIND
- WIND CHIME
- YAWN
- ZIPPER

Table 2 sounds used in confrontation naming of sounds study.

3.4.2 Participants

59 older adults (60+ years) were recruited onto this study, with final data consisting of 41 complete data sets and 5 partial data sets, from the older adult's research volunteer database, at Swansea University. Participant requirements include; English speakers, normal or corrected to normal vision and hearing (via glasses and hearing aids), no psychological condition, not at high risk of falls or poor mobility. Exclusion criteria included clinical depression, and Post Traumatic Stress Disorder (PTSD). Requirements and exclusion criteria were checked via standard pre-screening questions. All participants were given an online auditory confrontation naming of environmental sounds task via Qualtrics

Ethical approval was granted by the Swansea University Department of Human and Health Science (Reference number 270320) and the study was conducted in accordance with the principles of the Declaration of Helsinki. Written informed consent was given by each participant, and all participants were debriefed after participation.

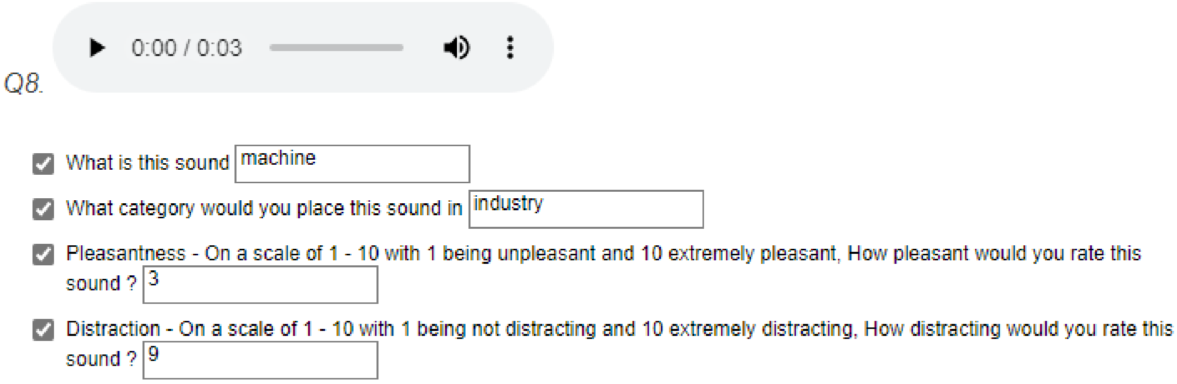
3.4.3 Design

This study used a within subject design. The independent variable (IV) was the environmental sound clip, with the dependant variable (DV) the ratings of pleasantness, distraction, sound labelling and categorisation.

3.4.4 Materials

Qualtrics software was used to design the online study. The study comprised of listening to 80 auditory clips of environmental sounds (duration 2-5 seconds) adapted from Marcell (2000). Audio clips were uploaded to

Qualtrics in an MP3 format. Audio clips were stored in a designated Qualtrics library. Each auditory clip was linked to four questions associated with pleasantness, distraction ability, a name label for the sound and a category (see Figure 12). Participants were required to make up their own categories.



Q8.

☑ What is this sound machine

☑ What category would you place this sound in industry

☑ Pleasantness - On a scale of 1 - 10 with 1 being unpleasant and 10 extremely pleasant, How pleasant would you rate this sound ? 3

☑ Distraction - On a scale of 1 - 10 with 1 being not distracting and 10 extremely distracting, How distracting would you rate this sound ? 9

Figure 12, Example of question asked for all sounds used in study

In relation to software, participants were permitted to use personal laptops, computers, tablets or mobile phones. Personal devices were required to be set to a suitable auditory level where sounds could be heard clearly. Participants were permitted to wear headphones should they choose.

3.4.5 Procedure

Participants were invited to take part in this study via an open invitation sent to their personal email addresses. Those who were interested were given an information sheet and pre-screened by the named lead researcher and author of this paper. Those who passed pre-screening were sent a link to an online consent form designed and stored on Qualtrics. Upon completion of the consent form, participants were sent a link to their person email with instructions. Participants were informed that the study they were going to participate in, could not be returned to at a later date and had to be completed in one sitting. Once participants clicked on the link in the email, they were automatically directed to the Qualtrics website and the start of the study. To remove external confounds, participants were required to enter a password to start the study, to avoid nonconsenting participants taking place. Finally, this study was programmed to stop a participant taking the study more than once via IP recognition.

Once participants had entered the password, they were directed to the first screen which outlined the study and what was expected. The next screen was used to provide an example/practice of what they will see during the study for each question (see Figure 1). Participants were given a sound and presented with 4 questions as set out in the main study. Participants were permitted to spend as much time as they needed looking at the example to be comfortable taking part in the study. Finally, the final screen before the start of the study explained that the study was about to start and the approximate duration of the study (approx. 50 min).

When participants started the study, they were presented consecutively with 80 environmental sounds. Each sound required the participants to press play on the sound icon then answer the 4 questions as shown in Figure 1. Participants did not have the option to go back, all participants had was an option to go forward, via a little blue arrow on the bottom right of the screen. The study kept moving forward until all sounds were played and questions answered. A progression bar was placed at the bottom of the screen to show participants how long was left of the study. When the final sound was answered, participants were directed to a debrief form that outlined the purpose of the study and how the data would be used.

3.5 Data analysis

All responses were stored on the Qualtrics software programme. Upon closing of the study, all responses were extracted and individually placed into an excel spread sheet. When all response data was collected, data points were placed into a final spread sheet that showed how sounds were rate for distractibility and pleasantness (see appendix 1 & 2). The mean and standard deviation of each sound was analysed with each sound response placed into a table, for both pleasantness and distractibility (See appendix 3). To understand how the participant labelled and categorised the sound, an excel sheet was created using factor analysis (see appendix 4)

3.6 Results

3.6.1 Distractibility

Once distractibility results were analysed and placed into a spread sheet (see appendix 1), the top ten distracting sounds were extracted, based of the mean distractibility score (see table 3).

	Average distractibility
Scream	Mean = 9.38, SD = 7.66
Jack hammer	Mean = 8.98, SD = 5.91
Police siren	Mean = 8.83, SD = 5.43
Car horn	Mean = 8.76, SD = 5.89
Mosquito	Mean = 8.71, SD = 5.59
Car crash	Mean = 8.68, SD = 6.56
Burp	Mean = 8.54, SD = 5.32
Telephone	Mean = 8.29, SD = 4.39
Glass breaking	Mean = 8.27, SD = 4.57
Snore	Mean = 8.02, SD = 4.32

Table 3. top 10 most distracting sounds, as perceived by older adults in this study

3.6.2 Pleasantness

Once pleasantness results were analysed and placed into an excel spread sheet (see appendix 2), the top 10 pleasant sounds were extracted based on the mean pleasantness score (see table 4)

	Average pleasantness
Birds	Mean = 8.73, SD = 5.36
Harp	Mean = 8.00, SD = 4.99
Owl	Mean = 7.98, SD = 5.20
Flute	Mean = 7.73, SD = 4.57
Piano	Mean = 7.37, SD = 3.83
Violin	Mean = 7.15, SD = 3.08
Cow	Mean = 6.71, SD = 4.13
Ocean	Mean = 6.70, SD = 2.53
Church bell	Mean = 6.63, SD = 3.24
Water pouring	Mean = 6.61, SD = 4.91

Table 4 Top 10 most pleasant sounds, as perceived by older adults in this study.

3.6.3 Categorisation

Perceptual categorisation is extremely important to the brain as it allows efficient processing of large amounts of information. By asking older adults to actively categorise sounds we can see how people actively perceive a sound, whilst also understanding how they feel the sounds should be represented. Moreover, categorisation is a great tool to understand if there are specific categories of sounds that are more likely to increase risk of falls than others.

To understand how participants categorise sounds, participants were asked to place each sound used in this study within a category (E.g., car = transport, cow = animal). Once the study was complete a matrix was created in excel, with each of the 80 sounds used in this study given a designated column. The categorical response that was given by participant for each sound were then place below the sound. Once all the response were in one excel folder, exploratory factor analysis was used to identity underlying common variable names and relationships between responses, to reduce the data to a smaller set of summary variables. This study was able to reduce 351 categorical names given into 18 distinct categories (see table 5)

As expected, individual difference in perception highlighted how different people place sounds in different categories. For example, the sound “car crash” was placed in to 5 distinctly different categories (industrial, mechanical, communication, transport & miscellaneous). Similarly, “airplane” was placed within 7 distinctly different categories (communication, mechanical, industrial, natural world, human, transport & lifestyle).

FINAL CATEGORIES
ARMY
HUMAN
MUSICAL
NATURE
INDUSTRIAL
MECHANICAL
ANIMAL
COMMUNICATION
DANGER
TRANSPORT
HOUSEHOLD/RESIDENTIAL
WARNINGS
LIFESTYLE
HYGINE + HEALTH
AGRICULTURE
MISCELLANEOUS
EMOTION + EXPRESSION
WORK

Table 5 visual representation of new categories of environmental sounds created in this study.

3.7 Discussion

The aim of the analysis undertaken in this paper was to increase understanding about the potential for environmental sounds to distract attention away from walking and thus contribute to the risk of falls. The Current data provides an in-depth descriptive analysis of sounds that should be considered when looking at slips, trips and falls in older adults. The response to each environmental sounds Is important for research as the results are taken from the perspective of older adults and the perception they have of a sound. This is something that has not been done previously. Previous, research has not taken the time to collect perceptions of environmental sounds from the people who take part in research. In relation to distraction and pleasantness it is clear from the data in this paper, that participants tend to find natural, animalistic, and musical sounds the most pleasant. Similar results were found by Medvedev, Shepherd & Hautus (2015) who established such sounds were regarded as positive in the environment and offered beneficial improvements to mood and cognition. With respect to distractibility, in support of the hypothesis, industrial, warning and transportation sounds were the most distracting. The variable nature of these repetitive, high pitched and attention-grabbing sounds corresponds with a pivotal study exploring what sounds can capture attention in a library environment by Fry (2002), who found, environmental elements such as motors, loud pumps and repetitive fan type noise are the most distracting. Coincidentally, all of which fall within the “industrial” type sounds.

In relation to categorisation, 18 distinct categories of environmental sounds were found via factor analysis of participant responses. This is somewhat different to Marcell (2000), who provides evidence of 27 environmental sounds categories. The 18 categories of environmental sounds found in this paper are believed to provide a good inclusive representation of environmental sounds, that are heard in the everyday environment. It is also believed that sounds not used in this study, would be easily placed within the 18 categories set out. Interestingly, when the sounds were cross referenced with the categorisation, the sounds fall not just in one category but multiple. For example, the sound “car crash” was placed in to 5 distinctly different categories (industrial, mechanical, communication, transport & miscellaneous). Similarly, “airplane” was placed within 7 distinctly different categories (communication, mechanical, industrial, natural world, human, transport & lifestyle). Interestingly, this variability was found for confrontation naming of categorises for all the environmental sounds used in this study. No single sound was categorised as the same for all participants. All sounds fell within at least 3 separate categorises, highlighting the importance of individual difference in perception.

To understand individual differencing in categorising, it is important to address possible causes that shape our perception of sound (experience/learning we`ve had in the past or previous environments, such as where we live/grew up). Firstly, acoustic variables and ecological frequency may alter categorisation as different sound constructions can result in different perceptual judgement (Chiu, Neel & Loux, 2021), particularly, when the duration or volume of the sound is limited, as it does not provide enough time to perceive what we are hearing (Ballas, 1993). Similarly, identifiability, the ease at which a person can form an image, recognise the familiarity and develop an associated stereotype, can produce variation within a sample (Ballas, 1993). Additionally, the constructs of interpreting and processing sound context via top down and bottom-up processing should be considered. Top-down processing within the auditory system is imperative to explain perception, as when information is received, this form of processing extracts information to create a quick hypothesis of what we are hearing, via previously stored experiences (Davis & Johnsrude, 2007). As such, if a person hears a sound that they may not experience often or not heard, top-down processing will not be efficient in creating a quick explanation of what has been heard. Similarly, bottom-up processing of auditory sound is limited to the ability to process, perceive, and interpret information in real time to form an auditory recognition pattern (Gibson & Carmichael 1966). If there is no previous sensory data pattern stored, processing will be hindered, hence creating variability in recognition.

Regardless of the many variables that may influence variation amongst the sample used in this study, one key factor stands out to explain variation, and that is perception. Perception is important as it is providing evidence that how one person perceives a sound may be different to the next (Wen et al., 2022). Auditory perception is important for recognition, processing, creating a mental representation of what we are hearing and is highly influenced by many cognitive facets, particularly previously stored information (Zimmermann, Moscovitch & Alain, 2016) and for this reason, variation will always be found as perception is a unique and subjective experience for everyone.

This paper contributes to a clearer understanding of what types of sounds can capture attention in older adults and how sounds may be categorised for future research in this field. The practical implications of this paper may contribute to providing novel techniques that may facilitate interventions to reduce slips, trips and falls in older adults. Knowing what sounds in the environment may influence or capture attention, can in theory, reduce the risk and incidence of falls. For example, older adults who have a high risk of falls, could be screened, and assessed to see if sounds within their environmental may influence falls. Similarly, those who do have limited attention capacity to filter out distracting environmental sounds, should be given access to gait, balance, and auditory training interventions to promote reduced falls and improving physical function. This would be particularly favourable for older adults who have increased risk of falls at home and follow several fall patterns set out in Connell & Wolf (1996), with the addition of perception being recognised as a contributing factor to falls as how we perceive the environment is unique and subjective, no two people are the same. Finally, as suggested by the National institute for Health Care Excellence (2021), education and information giving should be a key intervention for slips, trips, and falls. Educating carers, companies, and councils on the detrimental influence of environmental sounds of falls, may be key to preventing future falls, facilitation of environment adaption for older adults and acknowledging that auditory stimuli are equally disabling as broken curbs, pot holes and irregular surfaces to older adults.

3.8 Final summary of chapter

- Evidence of sound distractibility was taken from the perceptions of older adults, something that is new to this research field.
- Developed a new relevant list of sounds that are deemed distracting and pleasant,
- Developed a categorical index of environmental sounds that are relevant to older adult research.

- This data will be beneficial to researchers, as it will provide structure, organisation, and classification to health professionals to target auditory/attention and gait rehabilitation interventions.

Chapter 4 - Attention and sound.

Summary of chapter aims and context.

This chapter will provide an overview of attention and the components that are relevant to this thesis. Moreover, evidence will be presented for what is already known about how sound may affect attention during performance of a visual test. This study is unique as it will use environmental sounds, as opposed to generic sounds that may be used in other lab-based experiments. This chapter will provide research where older adults participated in a computer based, attention control task under two conditions, with sound and without. The environmental sounds will be played at 80dB. Subjective views were also collected from participants to understand individual difference and how the sounds were subjectively believed to influence attention. The hypothesis for this chapter is, the sound condition, where environmental sounds are played, will influence task performance more than, a silent condition. The final section of this chapter will present evidence for the auditory startle reflex which was noted in participants subjective views of the study. Evidence will provide an overview of what the auditory startle is and how it may influence task performance and gait.

4.1 Introduction

Attention is a multifaceted concept, with multiple meanings, across various research fields. The word attention is also ubiquitous in everyday conversation, but is associated with numerous different contexts (e.g., paying attention, attention grabbing & attention to detail). Moreover, it has been argued that “nobody truly knows what attention really is” (Hommel et al., 2019). For the aim of this psychology-based research, attention is defined as; the ability to focus to and interact with our surroundings via the direction of processing resources. Moreover, it is the ability to focus processing resources on a given stimuli or task, rather than wasting processing resources on attention grabbing/salient but irrelevant information, e.g., other visual / auditory information, thus prioritising current, relevant behaviour. Although attention is recognised as a specific brain function, with numerous specific and interactive components, it is associated with and interacts with many other aspects of brain function such as executive function, which interacts with perception (Rodrigues et al., 2015), Memory (Oberauer, 2019), sensory stimulation (Petersson Hilchey & Pratt, 2019) and emotion (Tyng, Amin, Saad & Malik, 2017). It is clear therefore that attention and other brain functions are highly inter-related and that this needs to be taken into account in attention-related research,

The brain's limited processing resources means that priority for information processing is mediated (at least in part) via a flexible, responsive but threshold-driven, attentional control system. This facilitates the processing of specific, behaviourally pertinent, information and inhibits or reduces the processing of irrelevant but distracting stimuli that may detrimentally affect primary behaviour (Carlisle, 2019; Prat-Ortega & De La Rocha, 2018, Van Moorselaar & Slagter, 2020; Knudsen 2018; Burgoyne & Engle, 2020. According to some reports, the functional integrity of various aspects of the attentional control system can be significantly impaired in older compared to younger adults, for example, an increased vulnerability to attentional capture and distractibility by task-irrelevant stimuli (Zhang et al 2019; Ferguson, Brunsdin and Bradform, 2021, Brustio et al., 2017). This has however been contradicted by research such as that of Lien et al. (2011), who found older adults are able to resist the influence of irrelevant stimuli.

Under laboratory conditions, typically employing psychophysics techniques, increased distractibility in older compared to younger adults appears to occur particularly under cross-modal conditions in which a primary visual behaviour (task) is performed in the presence of auditory distractors, typically resulting in reduced performance (e.g., slowed reaction time, RT and/or reduced accuracy). However, substantial study outcome variation exists, with some results indicative of preserved performance, i.e., continued resistance to distracting information in older adulthood (Kojouharova et al., 2020; Leiva et al., 2015, Brunsdin and Bradform, 2021, Leiva et al., 2021, Hidaka and Ide, 2015, Parmentier et al., 2022). Such outcome variability, at least in part, may be related to RT *per se* as a performance indicator, as it is recognised that significant within-group individual differences and thus high functional variation within older adult and other participant groups exist and can be related to interactions between demographic and methodological factors and morbidity (Basoudan et al., 2019, Phillips et al 2013., Kojouharova et al., 2020; Tales et al., 2002, Porter et al., 2010).

Nevertheless, outcome variability also appears to be related to methodological factors which may be acting independently of ageing or mediated by both ageing and other factors. Such factors include variation in the sensory modality of the task and the distracting information and whether a cross- or uni-modal sensory paradigm is employed; the task used (e.g., its processing requirements or difficulty), the presentation characteristics of the stimuli (e.g., frequency, expectancy, uniqueness) and participant-related individual differences in strategic processing (Kojouharova et al., 202, Cid-Fernandez et al., 2016), the functional integrity of other brain processes and motivation (Mahajan et al., 2020, Parmentier et al., (2022). Furthermore, study results may also be influenced by individual differences in participants' perception of how distracting or unpleasant a given environmental sound is, thus possibly rendering a given sound more distracting to some people than others. For example, some sounds, as outlined in chapter 3, are perceived to be more pleasant than others, with nature and music sounds perceived as most pleasant, with a reported positive influence upon mood and cognition (Alvarsson, Wiens &Nilsson, 2010, Medvedev, Shepherd & Hautis, 2015, Chen and Qu, 2015). Arguably therefore if highly unpleasant sounds detrimentally affect mood and cognition, they may similarly detrimentally influence attentional function, thus distractibility, thus walking.

Despite variable outcomes and contributory factors under laboratory conditions, in real life, increased distractibility in older adulthood (even just under specific conditions) may have significant consequences in terms of its detrimental effect upon behaviours, wellbeing and health. This is typified by detrimental changes in walking in older adulthood thought to be the result, at least in part, by a reduced ability to dual-task, i.e., to ‘share’ processing resources between walking and other behaviours such as talking or using a mobile phone whilst walking (Zukowski et al., 2021). Arguably, given the outcome of some studies (as described above), walking (a largely visual behaviour) may also, under certain conditions, be detrimentally affected by the capture of processing resources by salient, distracting environmental sounds. Given the high detrimental impact falls and falls risk can have on health and wellbeing (Jonsdottir and Ruthig, 2021) this warrants further investigation, and we have in preparation an ambulatory study examining the effects of real-life environmental sounds upon walking in older adulthood. This allows greater real-life naturalistic context and thus validity perhaps, compared to purely lab-based studies with no actual walking component.

4.2 Auditory driven attention processing

Visual attention has dominated research for a considerable time. It is an imperative component of attention functions, as it allows an individual the ability to prepare, select and maintain awareness of surroundings (Deyoe, 2002). Visual attention can be deployed to a target purposely, or automatically due to changes within the environment (Treve, 2005) and filtering out irrelevant information from our complex environments (McMains & Kastner, 2011). The domination of visual attention research as somewhat overshadowed the equally complex abilities of the auditory system to drive attention.

Auditory attention is the ability to actively attend to and understand sounds within our everyday environment, whilst actively or selectively inhibiting those that are not important (Makov et al., 2023). Auditory attention is important as sounds can capture attention at a lower and faster threshold than any other sensory modality (Hidaka & Ide, 2015). Moreover, audition can suppress visual information in favour of rapid auditory processing (Ersin et al., 2021). This evidence, together with some of the evidence from previous psychophysics studies (mentioned above) contribute to the study hypothesis that the performance of a visual attention control task (STAC) will be significantly poorer when performed in conjunction with sound stimuli compared to when no sound Is present. This is of importance to this thesis because if environmental sounds significantly affect a visual task performance, it may follow that such sounds may attract attention and thus processing resources away from a behaviour such as walking, thus having a detrimental effect up it. This may explain detrimental changes in gait and increased risk of falls in older adults (see next chapter for the next study examining this).

The influence of incoming auditory stimuli on cognitive performance is also of particular interest as research suggests that sound particularly loud sounds can redirect attention, thus impacting; learning (Clark & Sorqvist, 2012), reduce mental workload (Jafari et al., 2019), slower reaction times (LaPointe et al., 2007) and performance errors (Golmohammadi et al., 2020). For example, the influence of noise on attention and short-term memory was evaluated by Monteiro et al. (2018), in a study looking at 3 increasingly noisy conditions: normal room, noisy room and a noisy room with alarms sounding. Performance measures including serial recall, response inhibition and Stroop interference were measured during each condition. Analysis found, performance was significantly lowered, with increased errors, in noisy conditions. Similarly, Jarafi et al. (2019) examined participant mental workload and attention under varying levels of noise exposure. Analysis found that when incoming auditory stimuli peaked at around 95dB, there was a significant reduction in attention performance, in that attention was reduced. Moreover, EEG analysis taken from this study found that louder auditory stimuli altered brain frequency bands in occipital lobe, prefrontal, frontal and parietal regions, areas know to support executive functioning and perception.

Incoming auditory stimuli may be especially distracting to older adults who have a reduced ability to filter out task irrelevant stimuli. The inability to filter is associated with significant decline in cognitive and attentional performance. For example, Alain & Woods (1999) evaluated age related changes due to auditory stimuli processing. EEG recordings were taken during a visual discrimination task, with the deviant sound played sporadically. The introduction of the auditory stimuli induced a mismatch negativity wave that decreased with age. Similarly, using auditory event related potentials to investigate cortical inhibition of auditory processing, Stothart & Kazanina (2016) found older adults, compared to young require greater neuronal effort to inhibit irrelevant auditory stimuli. Moreover, monitoring brain activity during audio-visual tasks, Andres et al. (2006) found older adults are significantly more distracted than younger adults, with accuracy levels significantly decreased. Such evidence that older adults may have less flexibility in attention when trying to inhibit task irrelevant stimuli compared to young Passow et al. (2012). This limited flexibility means older adult require additional effort to complete a task, which further drain limited resources, thus in turn reduce cognitive performance.

In contrast, previous psychophysical studies outline that pleasant sounds improve stress recovery (Alvarsson, Wiens & Nilsson, 2010), improved mood state (Song, Baek, Kim & Song, 2023) and improve psychological wellbeing and cognitive performance (Luo, Wang & Chen, 2021). The influence of pleasant sounds on cognition is additionally supported by theories such as the attention restoration theory, which outlines that auditory stimuli found in nature may restore direct attention functioning (Van hedger et al., 2019). As a note, It would be of interest to understand how these studies chose sounds, do they account for perception, like measured in the previous chapter, during our confrontation naming paradigm.

The influence of auditory stimuli on cognitive performance can be seen as both positive and negative. Whilst some literature accounts for the variable (changing-state effect) and unexpected nature (oddball effect) of environmental sounds that individuals are exposed to in everyday life, such studies use artificial sounds. The study presented below, uses sound from the confrontation naming paradigm, using environmental sounds that have been rated and categorised, based on older adult perceptions, something not done before. It is not uncommon to walk through a city scape and hear construction, traffic, dogs barking and people shouting. These are the sounds that are capable of capturing attention and can capture individuals off guard.

Moreover, it is these sounds that this thesis believes are a leading cause of slips, trips and falls in older adults as older adults are less able to focus attention on task relevant stimuli (gait) and inhibit task- irrelevant stimuli (environmental sounds) (Hasher & Zacks, 1988).

To inform the design of our future ambulatory research in this PhD thesis, the aim of the present study was to determine the extent to which highly distracting environmental sounds influenced the performance of a visual task, namely Swansea Test of Attentional Control (STAC) task (Carter, N & Wood, R., unpublished). The STAC involves selective attention, task monitoring, and response inhibition components of attentional control, based on the supervisory attentional system model and thus simulates the natural and complex demands of continuous environmental monitoring and interaction, within a single test. The STAC test also includes the continuous presentation of stimuli which better represents real life environmental situations as opposed to delivering discrete trials in blocks that systematically vary task demands (Torrens-Burton et al 2020). As described in full within the methods section, the STAC test includes a flexible algorithm designed to track performance (Parameter Estimation by Sequential Testing, PEST), which calibrates stimulus presentation speed based on prior stimulus (target) responses times (RT) thus ensuring that the task is performed in accordance with an individual’s capabilities (too easy at the beginning, to being just right at the end). STAC test performance outcome/indicator is comprised of the final speed of performance (measured in symbols per minute; ‘spm’ performed by the end of the trial). Moreover, additional measures namely, motor impulsivity, late responding, recognition failure and false hits, will be measured during the task. Gender difference will also be accounted for.

In this study we investigated whether the performance of a demanding primary visual attentional control task (the STAC test) would be significantly detrimentally affected by the co-presentation of highly distracting and unpleasant environmental sounds. We used 30 sounds from study 1 (see chapter 3) which were universally named and categorised and perceived as distracting and unpleasant. The most distracting and unpleasant sound were chosen to provide the maximum test of distractibility on the STAC test?

4.3 Study 2 – STAC test. Materials and Methods

4.3.1 Ethics

Ethical approval was granted by the Swansea University Department of Human and Health Science (Reference number 270320) and the study was conducted in accordance with the principles of the Declaration of Helsinki. Written informed consent was given by each participant, and all participants were debriefed after participation.

4.3.2 Participants

Twenty-four participants (range 62 to 75 years; mean age = 66.625, SD=3.94; 15 females; 9 males), were recruited from the School of Psychology`s older adult data base at Swansea University. All participants were community dwelling and fluent English speakers, with self-reported normal or corrected-to-normal vision and hearing (e.g., hearing aids and glasses), no self-reported on going or history of significant psychological, neurological, psychiatric conditions or health conditions and good mobility, and none had consulted a general practitioner (GP) or memory services about concern about or change in their cognitive function. Medication could not be controlled.

4.3.3 Swansea Test of Attentional Control (STAC)

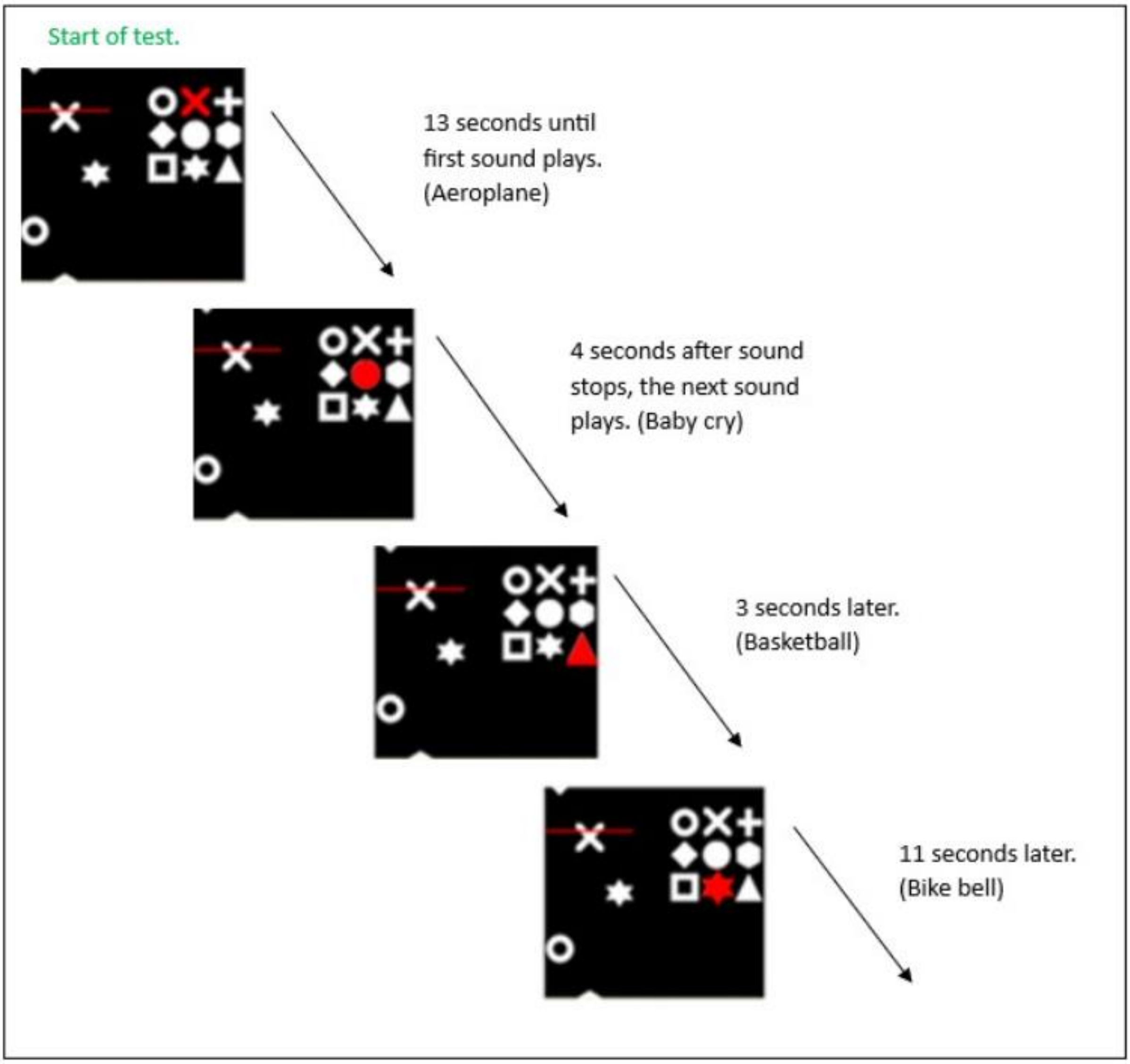


Figure 14 The STAC test. A visual representation of how the STAC test changes over time. The 3x3 matrix changes are represented with the shapes highlighted red. When the symbol on the left matches the red symbol, participants are required to press space bar. Time stamps next to the black screen images, represented the first 4 time change during the STAC test.

Symbols are 36.2 mm across, subtending 3.6 degrees of visual angle on a 19-inch monitor at 52 cm viewing distance. A target is identified within the 3 x 3 matrix of symbols (above). When a matching symbol appears amongst the three tracks of the search array, which scroll up the left-hand side of the screen, participants press the spacebar as the symbol crosses behind the red line (as opposed to before or after). The task is to identify the target within a 3 x 3 matrix of symbols on the right and search for matching symbols amongst an array of three tracks of symbols (On the left). The matrix target changes at regular intervals throughout the task such that participants must remain vigilant in order to consistently update their search criteria, while simultaneously monitoring the tracks to identify matching items and ignore distractor symbols. The target changes every 10s but is delayed if the current target is already present in the tracks (e.g., the target will not change to a different symbol if the current target is moving up the tracks). In such instances, the corresponding time lapse is added to the total run time (initially set to 390 s, resulting in approx. 9 target changes for all participants). Speed (measured in symbols per minute per column; abbreviated to spm) is adjusted to maintain accuracy around a commonly adopted 75% correct criterion, using the PEST algorithm. The task begins at a speed of 41 spm. After a minimum of 4 target changes (for the first block), speed is calibrated based on performance accuracy, increasing, or decreasing with a step-size between 20 and 60 spm. The participants' thresholds are the average speed at which the task is performed across the duration of the task. Participants are asked to try hard to keep up with the symbols, but not to be discouraged if they miss some of the targets as the task is supposed to be difficult. Participants are told that the symbols will move up the screen at different speeds during the test. They are also told that there is no feedback during the test, so they won't know how well they are doing. The environmental sound clips used in this study (N=30) were those commonly identified and universally perceived to be highly distracting and highly unpleasant by older adults in a preliminary study (see appendix 3).

A silent practice version to familiarise participants with the task was administered to each participant (approximately 3.2 minutes in duration). Following which the main test started. The main STAC test was presented twice (counter-balanced), once for the sound condition and one for the no sound condition with each presentation lasting approximately 6 minute 48 seconds, with approximately 4 minutes in between (to allow any visual disturbances, as a result of the symbol movement, to dissipate). For both conditions, there was a 13 second practice block (block 1) in order to reduce the ‘starting of the trial’

For the sound condition, the presentation of the sounds started after the 13 second test period and continued through the study at pre-specified times (e.g. after the first sound clip, the next sound is randomly played at 2,5,6, 9 seconds (considering the duration of the sounds themselves). Once all 30 sounds had been presented, the programmed sounds went back to the beginning of the audio clip list. We measured performance over 17 blocks (the first block is the no-sound for both conditions, within test practice period). To measure sound compared to no sound mean, performance was measured between blocks for each condition (block one was not included in overall spm performance analysis as it contained no sound in the sound condition).

4.3.4 Procedure

This study was conducted at Swansea University, under COVID-19 health and safety guidelines, as specified by risk assessment and the Welsh Government. Participants attending campus for this experiment were pre-screened for COVID-19 symptoms one day before attending and on the day of testing, temperatures were taken and again participants were asked if they had any symptoms of COVID-19 before being permitted to enter any buildings. Participants were required to wear face masks, asked to practice social distancing and sanitise their hands before, during and after testing. Participants began by reading over the participant information sheet and completing a consent form. Once participants had given consent, they were instructed on how to perform the STAC test (See figure 14) via a visual aid, which was verbally clarified by the researcher. Participants were then sat in front of a 17.3” HP Envy laptop with NVIDIA graphics processing unit featuring accelerated output to device display. Once participants were comfortable, they were given a practice run of the STAC. Participants were then given the opportunity to ask the researcher any questions before starting the main experimental runs. Immediately following the completion of the STAC test, participants were asked to freely describe if they experienced any differences when performing the task under the sound and no-sound conditions. Finally, participants were debriefed as to the nature of the study and asked if they had any questions.

4.4 Data analysis

Data collected form the STAC test, automatically gets saved as a excel file. Once all participant data was collected, our measures were separated (e.g. final speed) and the mean, SD and median scores were calculated. The data was also analysed in SPSS (version 22, IBM, New York), where t-tests were used to calculate the significance of the mean for groups.

4.5 Results

4.5.1 Performance over task

The performance measures for the sound vs. no-sound condition comprised of the speed of performance (measured in the number of symbols responded to per minute, ‘spm’ by the end of the study (final spm) whilst able to maintain an accuracy rate of at least 75%). (see figure 15).

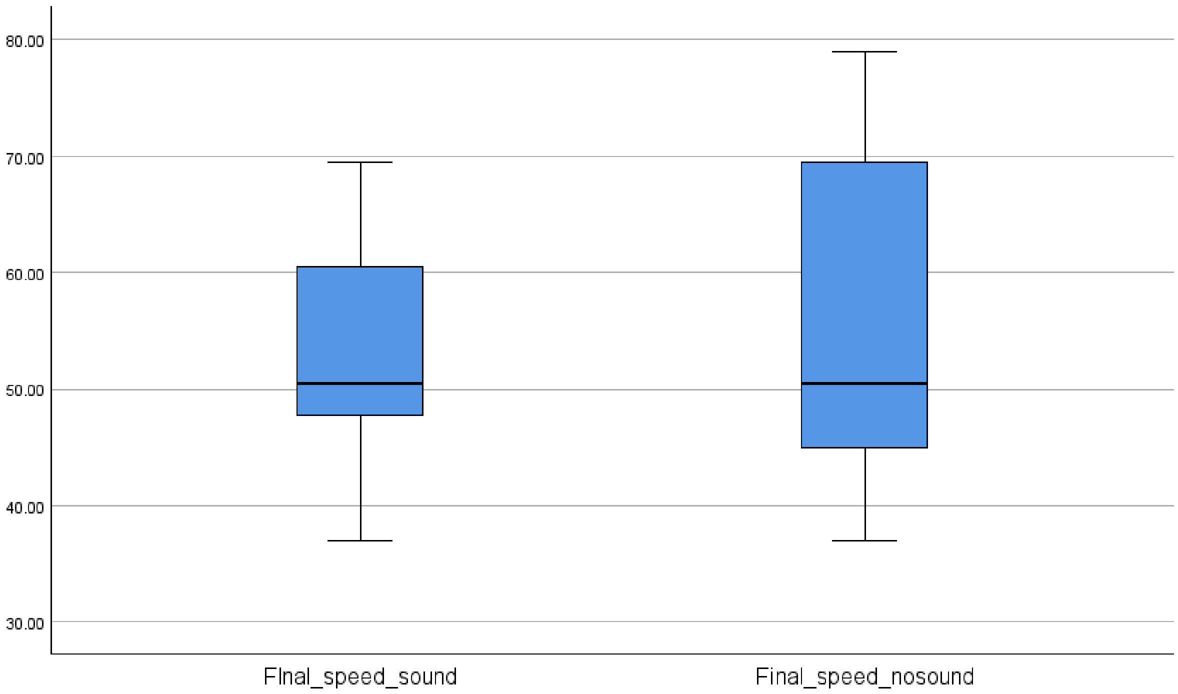


Figure 15 Mean SPM score per condition (sound v no sound)

The effect size was calculated via a Cohen’s d, to measure the strength of relationship between the two condition variables (sound v no sound). Cohen`s d = 0.168. A t-test revealed no significance in the main effect of final speed performance in sound / no sound conditions, t(23) = .622, p = .54.

4.5.2 cognitive measures taken during task

Analysis of our additional measure were calculated to further assess the degree to which sound may influence task performance (See table 6)

	Sound condition	No sound condition
Final speed (SPM)	Mean = 52.83 SD = 10.48 Median = 50.5	Mean = 54.83 SD = 13.21 Median = 50.5
Motor impulsivity	Mean = 8.83 SD = 7.16 Median = 7	Mean = 8.92 SD = 6.78 Median 8
Delayed/late response	Mean = 14.92 SD = 7.73 Median = 12.5	Mean = 16.17 SD = 6.57 Median = 17.5
Recognition failure	Mean = 10.29 SD = 4.1 Median = 9.5	Mean = 10.58 SD = 4.5 Median = 10.5
Inattentive random (false hits)	Mean = 5.33 SD = 2.67 Median = 5	Mean = 5.13 SD = 3.78 Median = 4

Table 6 Table with the results for all measures taken from the STAC programme. Analysis included for each measure was the mean score, the Standard deviation (SD) and the median score. Data is presented for both sound and no sound conditions.

4.5.3 Gender differences across STAC test

It was important to this research to understand the degree to which gender may influence task performance as it increases rigor, promotes discovery and expands the relevance of research. For each gender, data was analysed to provide a mean, SD and median score for final speed (See table 7).

Final speed male (sound)	Mean = 53.89 SD = 13.81 Median = 50.5
Final speed female (sound)	Mean = 52.20 SD = 8.84 Median = 50.5
Final speed male (no sound)	Mean = 51.50 SD = 13.68 Median = 50.5
Final speed female (no sound)	Mean = 56.83 SD = 13.45 Median = 50.5

Table 7 table outlining the differences in STAC performance across gender (male / female). As with the table previous, each measure presents the mean score, SD and median measure.

Mean scores for both male and female were extremely similar. A box and whiskers graph (See figure 16) was created to visualise the data represented in the table above.

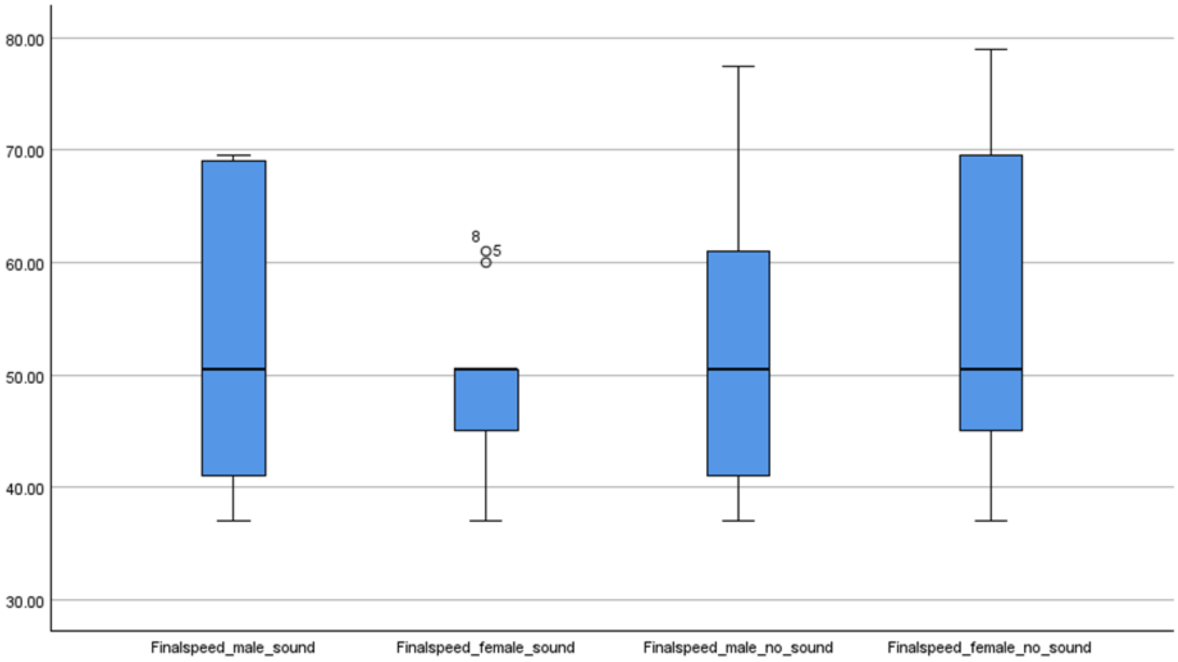


Figure 16 Visual representation of gender difference across the STAC test for final speed (SPM)

Performance across gender during the STAC test is relatively similar. The median score for both male and female remained the same at 50.5 (spm) for final speed. The mean scores for spm were slightly lower for females during the sound condition (6.69 spm), however, in the silent condition, females performed slightly better than males (5.33 spm). To understand if there was any significance in this difference, a repeated measures (sound/no sound) ANOVA, with the between subject's factor gender was performed. No statistical significance was found between the main effect of gender on STAC conditions., F(1,22) = 1.124, p = .301.

Although the STAC test was randomised (sound or no sound first) there is always a possibility of task order effect influencing results. To test if this happened with this data, participant data was split into sound and no sound conditions, as set out previously, with the additional variable measure of task order (did participants run test with sound first or silent first). A repeated measures ANOVA was administered to the data with the within-subjects factor sound or no sound and a between subject factor of task order. There was no significance in the data F(1,22) = .348, p = .561.

As less samples of data were collected than we originally proposed due to COVID-19 restrictions etc, post hoc power computations were performed. R and SPSS outcomes provide evidence that a between group sample size of 48 would hold statistical power at a significance value of 0.05. Given this was a repeated measures design, we have reached this number.

4.5.4 Subjective data

It was important to the results of this paper that participant subjective views were collected. Firstly, participants views were important to get an objective view of how the sounds influence performance. Secondly, we were interested in if any sounds were alerting or distracting. Thirdly, participants were asked if the sounds had any effect on them. As this study was run during strict COVID-19 guidelines, with distancing measures, participants were asked questions and the lead researcher (Leanne Richards) wrote down responses.

Data collected for participants subjective views of the STAC test (see table 8) showed a consensus that the onset of sound during the sound condition was able to create a “startle”, that re directed attention away from the task for a short period of time. Habituation to the sounds remained consistent across all participants. (See appendix 9 for full overview of results)

Recognised via participant	Explanation by participants
Startle response	• A startle to the environmental auditory clip was noted amongst most participants. Consensus saw startle remain for approximately the first 5 sounds.
Attention direction	• Attention was directed away from the task at onset of environmental sounds. Participants were able to regain attention after first few sounds had played. • Task performance felt hindered and reduced.
Attention*sound*workplace	• Sound that participants deemed distracting during the STAC test, were representative of job roles. (e.g., Midwife (crying, screaming, sirens) Steel worker (industrial tools).

Table 8. Data collected of participants subjective view of the test.

4.6 Discussion

There was no difference in final speed (SPM) between the no-sound and sound conditions across the whole test period. Although there were graphically some suggestions overall that SPM (the amount of information that could be processed whilst maintaining a 75% accuracy) was greater under the ‘no-sound’ condition, statistical analyses revealed that this difference failed to reach significance. Similarly, whilst it looked that there may be some significant gender differences in STAC performance, the ANOVA that was performed on data presented with no significance. It should be noted however, that there were different amounts of participants in each group (male / female). Due to the outcome of these results, we cannot accept our hypothesis that older adults will have reduced performance during the sound condition, compared to the silent.

Over the entire test period, there was no significant difference in the performance (final spm and accuracy) of this task when environmental sounds were played compared to when they were not. The ability to modulate activity to varying task resource demands whilst maintaining a high level of processing speed for a given accuracy of performance (attentional control) was not affected by the distracting sounds in older adulthood. Older adults appeared able to resist the capture of processing resources by distracting stimuli to maintain speed/RT performance of the primary visual task. These results contrast with the outcome of other studies which have shown significant attentional capture by a deviant auditory stimulus resulting in the significant disruption of a primary visual task (Vachon, Labonte & Marsh, 2016, Ersin, Gundogdu, Kaya, Aykiri & Serbetcioglu, 2021, Vasilev, Permentier & Kirkby, 2019). As noted at the end of the data section, we did not collect as many data sets as expected, however, comparable studies as outlined by Vachon et al. (2016) only have 28 participants in their research, a number not to far from our 24.

As this study was run during COVID-19 strict guidelines. To reach significance of 0.05 an post hoc power analysis suggests approximately 48 participants would be needed. As such, we may not have true effects, if any would be present in a large sample size. The reduce level of power associated with this study leave the interpretation of results open at present. Given we will run the STAC test a second time in the next study, with larger samples, a true representation of how environmental sounds influence attention control may be found.

The results of this study lead to the next question, how will older adults perform during the walking study that is planned during this PhD. It may be suggested that given the no significance found in this present study, older adults may not have any gait perturbation because of the unexpected environmental sounds that will be played to them. However, it may be argued that the STAC test and perception may not be fully resembled in active walking trials. The STAC was performed in a lab based, computer experiment. The walking study that we are going to run, requires additional attentional control, whilst environmental perception, navigation and monitoring to maintain an efficient walk during the long walking test.

4.7 Future studies and what unanswered question that remain.

It would be of value to administer the task for a range of durations to assess age-related or sound effects, under conditions of varying demands on sustained attention. When using this task paradigm to understand the influence of sound on attention, it may be beneficial to introduce measures such as event-related potentials (ERP) and heart rate variability (HRV) to assess the degree of physiological arousal, something which was a limitation in this study. Previous studies have evaluated the role of startle response on physiology. For example, Jarczewski et al. (2019) measured cardiovascular response to different types of stress stimulation, finding acoustic startle caused changes to heart rate variability. In a study evaluating the effects of auditory text alerts on attention and HRV, by Whiting & Murdock (2021), the startle of a notification alert was enough to reduce problem accuracy and reduce reaction times. Furthermore, in a revolutionary paper by Sonkusare et al. (2019) physiological change to auditory stimuli was measured via skin response and a new facial thermal imaging device to track heat changes. Post auditory stimuli onset, peaks in skin response increased between 5 – 10 seconds and gradually decreased back to based line shortly after. Furthermore, there was an increase in inter-beat heart intervals following auditory stimulus, and finally, a rapid decrease in facial temperature was found after an auditory stimulus at around 4-5 seconds, approximately 2 seconds following skin response change. The evidence provided seems to support the notion that the onset of auditory stimuli is able to produce physiological changes that are short lived, before returning to normal. Whilst only speculation it is plausibility that the onset of sounds had a similar affect upon attention control, namely a rapid capture of attention, followed by rapid habituation. Further support for this theory, is provided by this study.

4.8 A startle in response to auditory sounds used in STAC

The subjective views from participants, outlining that certain sounds elicited what they describe as a “startle response” was not something that was expected during this study, particularly as when the data was processed from the STAC test, there was nothing that supported this view. However, It is not implausible that there is a startle as sound has long been linked to activation of the fight and flight (Nozawa et al., 2006). Moreover, the onset of sound has been linked to by rapid eye blinking, movement of the limbs (Binder, Hirokawa & Windhorst, 2009) and a spasmodic movement of the head (Britannica, 2023). In terms of physiology, there is a change to heart rate (Holand et al. 1999) electrical brain activity (yang, Logothetis & Eschenko, 2021) and a variation in electrical characterisations of the skin (Sjouwerman & Lonsdorf, 2019). Given the environmental sounds used in this study will also be used in a gait and sound research design, it is important to understand more about the startle reflex, and the influence it may have over movement.

4.9 Startle reflex

One of the greatest acquisitions of human research, is the theory of evolution, and the changes in heritable traits over a generation. Charles Darwin stated “It is not the strongest of the species that survive, nor the intelligent, it is the ones that are most adaptable to change (Darwin, 1859). The trait of adaption allows humans to thrive and survive the most challenging of environments. Over time, adaptions become an inheritance regardless of individual difference, culture and gender. The most evolutionary and essential of all adaptions, is the ability to respond to possible threats or changes within the environment. One example of such adaption is the innate startle response, that serves to facilitate a rapid response to the changing environment, especially in hearing. The auditory response is capable of interacting with other senses, to place and individual on high alert to surroundings (Spence & Soto-Faraco, 2012) This startle reflex is primarily described as an adaption for benefit of human behaviour. However, in the concept of the research in this thesis evaluating attention control and gait, it may be acting as a detrimental input/effect.

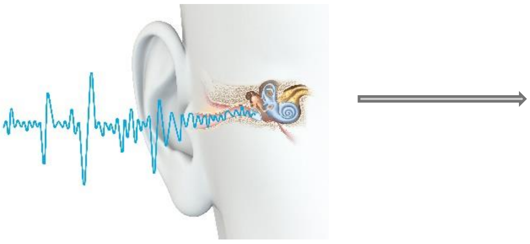
The startle reflex is an oligosynaptic, involuntary brain stem reflex, creating a fast and protective response to a highly salient, intense or unexpected stimuli, such as loud noise or a flashing light (Britannica, 2023). The Auditory Startle response (ASR) defined as a generalised motor reaction, triggered by an auditory stimulus inducing surprise or alarm (Brown et al., 1991) presents at an auditory stimuli level of 80dB, with the rate of response approximately 5-10ms.The response is not conditioned, as it can be observed in any animal or human that is capable of sensory perception (Zheng + Schmid, 2023). The startle holds no voluntary control (Vallis- Sole et al., 1995) and can alert physiological systems in their entirety to become alert to incoming stimuli. This is of great importance, particularly within the research of gait and environmental sounds as unlike other behaviour measures, one cannot stop or control the startle response.

Typically, the startle response is characterised by rapid eye blinking, movement of the limbs (Binder, Hirokawa & Windhorst, 2009) and a spasmodic movement of the head (Britannica, 2023). In terms of physiology, there is a change to heart rate (Holand et al. 1999) electrical brain activity (yang, Logothetis & Eschenko, 2021) and a variation in electrical characterisations of the skin (Sjouwerman & Lonsdorf, 2019), a full extent of this will be covered later in this chapter. The startle response may also facilitate an emotional response (Liu, Amey, Magerman, Scott & Forbes, 2020) that can be externally expressed (i.e., scream) or internalised (I.e., irrational thoughts). Interestingly, the startle response is habitual, that being, as the number of frequency of startles increases, the body becomes habitual, and the degree of startle decreases (Zhang, Wang, Wei, Shi & Yu, 2022). This thesis will however disagree with this statement of habituation. As noted in chapter 5, individuals startled to a group of specific sounds during the first presentation of environmental sounds and at a later time period. Habituation research suggests this startle should be reduce, not the same.

Research, particularly in the field of startle reflex, favours the acoustic startle reflex (ASR), given its measurability, replicatory value and validity of results, thus for the remainder of this chapter, research will only present evidence for the ASR, but a note should be given that additional sensory research (i.e. vision, olfactory & tactile) hold an extensive back catalogue of valuable data linked to the startle reflex (see, Zhang et al., 2022) .

4.9.1 Circuitry and neuroanatomy of the ASR

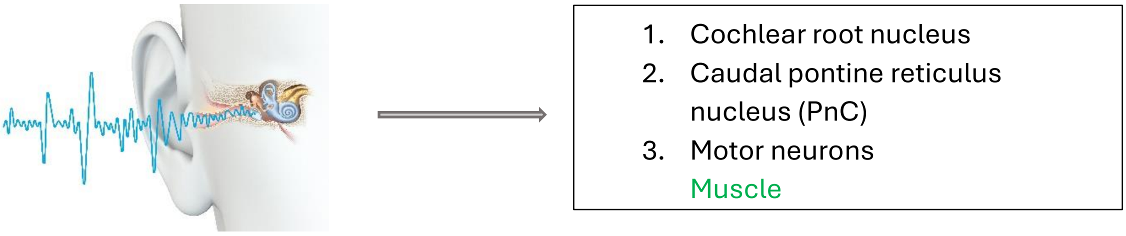
Early research to understand the ASR derived from tracing methods, electrical stimulation, and electrolytic lesions in animals, with such measures particularly favourable for Davis et al. (1982) and their revolutionary model cortical pathways associated with the auditory startle. Davis et al. (1982) wanted to understand the extent of the ASR, in terms of projections throughout the auditory pathways and cortex. Male rats were exposed to anodal brain stimulation, spinal cord stimulation and bursts of 110dB intervals of noise, with an ambient 55dB background playing for the duration of the study. EMG recordings in response to the startling 110dB sound bursts were recorded via an electrode stitched to the quadricep femoris muscle. Data collection and modelling predicted a short stage connectivity model that started at the auditory nerve and terminated at the stage of muscle movement (See figure 17)



1. Auditory nerve
2. Ventral cochlear nucleus
3. Nucleus of lateral Lemniscus
4. Caudal pontine reticulus nucleus (PnC)
5. Spinal interneurons
6. Lower motor neurons

Figure 17 Diagram created by author of this paper, based of research by Davis et al. (1982).

The neuroanatomical and connectivity research that Davis et al. (1982) presented, held favour for the next decade of research, however, research during the 1990s, which still used this model to an extent, paid considerable attention to the PnC, as it was believed that this was the pivotal innovator to the ASR (Koch, 1999,Carlson & Willott, 1998, Lingenhohl, & Friauf, 1992, Huang, Cano & Fenlon, 2021, Zhang, et al., 2022). For example, Koch (1999) noted that subpopulations of giant reticulospinal neurons of the PnC, receive direct acoustic input from multiple nuclei of the central auditory circuit, as well as innovated via other parts of the pontine reticular formation, which in turn project and excite facial cranial and motor neurons (Koch, 1999). In the 1999 paper by Koch, he suggested a far shorter ASR circuitry that previously noted, presenting evidence for a basic 3 stage model (See figure 18).



1. Cochlear root nucleus
2. Caudal pontine reticulus nucleus (PnC)
3. Motor neurons
   Muscle

Figure 18 Diagram crated by author of this paper, based of research by Koch (1999).

The removal of processing stages as noted in Davis et al. (1982) allows for a more direct route, than previously thought, with processing speeds raching a more rapid rate and has become highly favourable in recent research papers with researchers such as that of Zhang et al. (2022) using such model as an exemplar.

PnC activation during the ASR has also been found to be concommitant with additional areas including the Centromedial Amygdala (CMA) and the Periaqueductal Gray (PAG) (Kuhn et al, 2020). In terms of function, the CMA is connected to visceral sensory and autonomic nuuclui of the brain stem, that are involved in respiritory and cardiovascular function (KenHub, 2023). The PAG, is a key structure for propergation and modulation of pain, stress, defensive and aversive behaviour (Mokhtar & Singh, 2022). The idea of both the CMA and PAG being concommitant with the PnC is of particular interest as the CMA and PAG are linked to physiological and emotional changes that occur to the body during times of stress (i.e. HRV, and behaviour modification). Moreover, the amygdala exerts its modulation to stimuli via the hypothalamus, which in its self exhibits change to the endocrine, autonomic, somatic motor and limbic systems. Finally, to further justifly the link between these systems the CMA, PAG and hypothalamus working together form the “Brain Aversion System”, a defensive reponse system to the concept of fear and anxiety, during which an organism expends energy to minimise or avoid (Brandao, Troncoso, Soua Silva & Huston, 2003), thus building a more indepth system that the ASR is facilitated by not only a few stages, rather a collection of brain circuitry working in tandem (See figure 19)

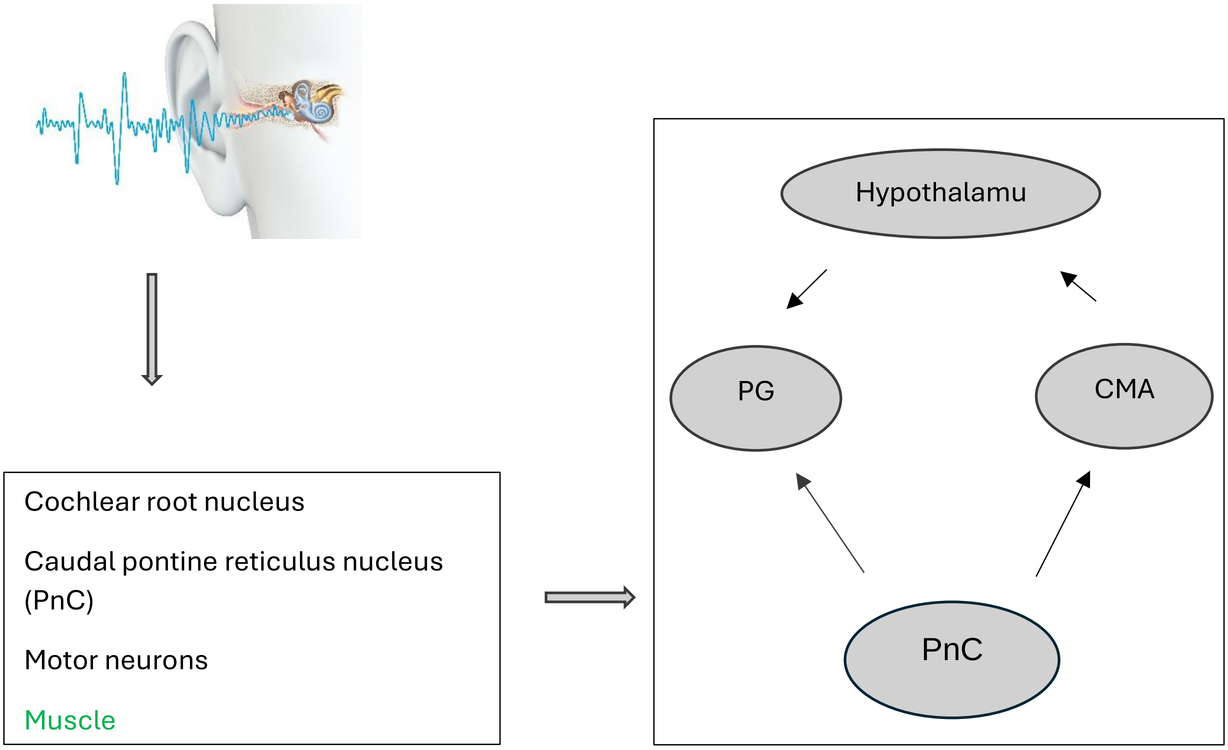


Figure 19 Diagram created by author of this paper.

In addition to the 3 notable areas associated with the Brain aversion system, Hayes & Northoff (2011) suggest, anterior insula, anterior cingulate, ventrolateral orbitofrontal cortex, hippocampus, para hippocampus, fronto temporal gyrus and thalamus all play a contributing role in the analysing, processing, and reaction of an ASR (See figure 20). In relation to anatomic function, the additional areas associated with the brain aversion system regulate anticipation, attention, motivation memory, encoding and retrieval of information, with autonomic modulation possible to via blood pressure and heart rate change. Moreover, areas such as the cingulate cortex are seen as high order motor areas which process incoming stimuli (external and internal emotional state processed in the limbic system) information and translate them into motor commands (Strick, Dum & Picard, 2007). It should also be noted, that the additional areas suggested by Hayes et al. (2011) rely heavily on the limbic system, involved in emotional processing of input from sensory stimuli. For example, when a loud noise is processed, the limbic system activates to create an emotional recollection to what is being heard, thus sending out signals to the relative area (i.e. a scary noise, activates a pathway of increased attention, perception and alertness). In terms of evolutionary adaption, this notion is particularly favourable as the limbic system is thought to be the older part of the brain, developed to manage the fight or flight response to external stimuli (Roxo, Franceschini, Zubaran, Kleber & Sanders, 2011).

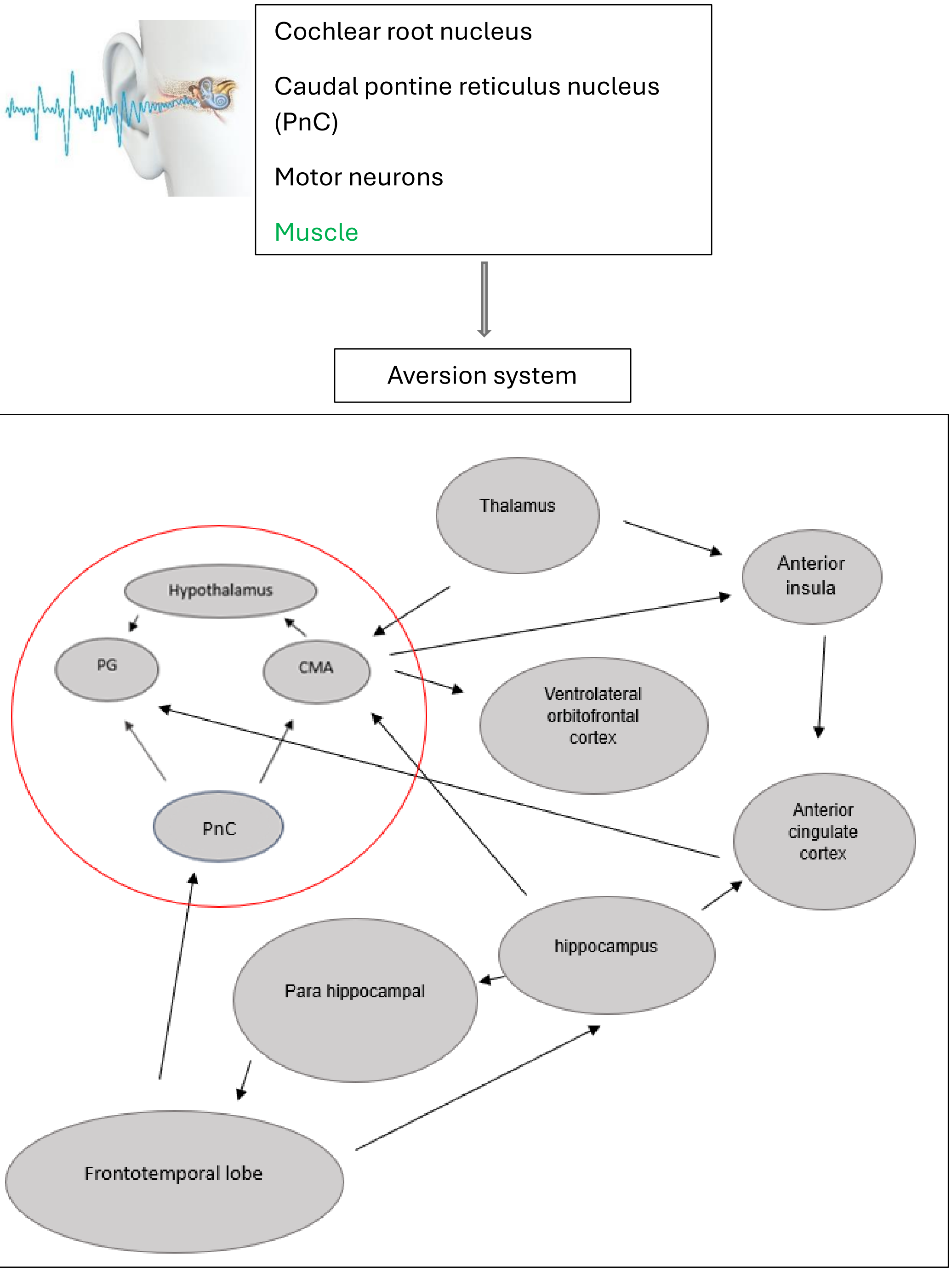


Figure 20 Diagram created by author of this paper.

As presented, a picture is developing of the ASR relying not only on initial auditory processing, but a more complex system of sensory, attentional and memory integration. The complexity of the ASR would explain why the ASR can alter gait, given the ASR rely heavily on attention and sensory aspect of cognition to interact with the environment. Moreover, the memory portions of the brain are need to help evaluate the incoming auditory stimuli coming in, form memories of the stimulus and assign the emotions associated with it. In relation to memory, memory function is multifaceted with integrations deriving form sensory processing, short term memory and long-term memory. Many believe that memory and storage derive specifically from the hippocampus, but multiple cortices of the brain influence memory. Co-ordinated for example, the cerebellum plays a role in procedural memory and motor learning (Mishkin & Appelzeller, 1987), the basal ganglia, facilitates unconscious memory processing (Seger & Spiering, 2011) and the frontotemporal region facilitating autobiographical information (McKinnon, Svoboda & Levine, 2007). It is the role that the additional distinct regions play, that further facilitate how we interact with an incoming sound.

4.10 Auditory startle response and physiological changes

Piecing together the circuitry and anatomical connectivity that may influence the ASR, has provided valuable evidence to support the role that auditory stimuli are capable of activating multiple regions and connections within the brain to efficiently induce measurable change. One such measurable change ubiquitous in ASR research are physiological change. Changes may induce HRV, GSR changes, and alterations to thermoregulation. Understanding physiological changes during the ASR is important for this thesis as physiological measures provide indicators of bodily function and indicators of disease and behaviour. This is something to explore (post-doctoral), to see if physiological measures correlate with individuals who fall more frequent than others.

4.10.1 Alterations to thermoregulation

Thermoregulation is maintaining the physiologic core body temperature, via constantly balancing heat generation with heat loss (Osilla, Marsidi, Shumway & Sharma, 2023). Thermoregulation is maintained by the hypothalamic thermoregulatory centre, that receives constant input from thermoreceptors found peripherally (i.e., skin and senses) and centrally (i.e., spinal cord) (Osilla et al., 2023). Healthy individuals have a core value of 37 +/- 0.5°c. Interestingly, individuals who are presented with an unexpected auditory stimuli have an increase in bodily temperature on the face region. For example, Sonkusare et al. (2019) found a significant change to facial temperature due to the ASR. Twenty participants were seated comfortably and asked to view a 60-second video of ocean waves. During this period, unexpected noises (80dB) were played at random period to induce a startle response. During the exposure to sound, HRV GSR and facial temperature were measured. Analysis found skin response and HRV changes peaked 5-10 seconds post stimuli onset and decreased back to baseline at 10 seconds. Infra-red imaging used to detect facial change found the onset of the auditory stimuli induced a rapid increase in facial temperature which decreased shortly after. Thus, providing evidence of a changes to temperature as a result of the ASR.

The notion of the ASR inducing changes to body temperature is further supported by Nozawa et al. (2006). Facial skin thermograms were used to measure the degree to which the fight or flight reaction was aroused via an acoustic stimulus. Analysis found that 90% of participants had a rapid increase in facial temperature to the facial expression muscles, namely the procerus a small muscle located between the eyebrows and secondly the cheek muscles. Research in the area of ASR and thermoregulation is a growing field with limited research at present. However, the evidence that is available is supporting the role that physiological changes associated with ASR should additionally include the use of thermal measure. As with any research a note of caution should be taken, particularly as the populations used to take such measures are healthy individuals. Individuals who have underlying medical needs may not induce such favourable research outcomes.

4.10.2 Galvanic skin response changes

As noted previously, GSR is a method to measure the electrical conductivity (increase in sweat gland activity) of the skin in response to a stimulus. When used in the correct manner and removing confounding variables such as humidity, medication, and external noise, GSR has been found to be extremely reliable. GSR has been favoured for this reason in ASR research, particularly when individuals are presented with unexpected stimuli of 80dB+. Research have continuously found that the onset of a loud stimuli induces a peak in skin conductance, followed by a rapid reduction (Laine, Spitler, Mosher & Gothard, 2009, Basso, 2001). To assess the degree to which noise may influence physiological parameters such as GSR, Khan et al. (2019) presented a cohort with varied levels of noise sensitivity. Individuals were split into two groups (control and experimental) and presented with noise stimuli for 50 minutes, on different dB, lasting 10 minutes each. The control group had relatively low varying levels and the experimental were bombarded with constant noise stress. GSR parameters found that individuals who were exposed to constant noise exposure stress, had a significant increase in response. GSR peaks as a result of loud noise are additionally found across research noted in both Osilla et al. (2023) and Sonkusare et al. (2019).

4.10.3 Alterations to heart rate

Heart rate variability (HRV) is a measure of the variation in time between each heartbeat (Harvard Health, 2023). Alterations have been associated with a plethora of physiological, biological, and cognitive changes, including affective and attentional regulation (Ruiz-Padial, Sollers, Vila & Thayer, 2003), activation of the sympathetic or parasympathetic nervous system (Tiwari et al., 2021), Cardiovascular fitness (Souza et al., 2021) and cognitive function (Forte et al., 2019). The ASR has also been found to alter

HRV due to the autonomic component of the startle (Holand, Girard, Laude, Meyer-Bisch & Elghozi, 1999).

The presentation of HRV during the ASR have been particularly noted via the use of electrocardiograms (ECG). For example, Holand et al. (1999) evaluated the influence of auditory stimuli on heart rate in humans. Twenty-five participants were played a sound of 55dB through headphones, with the introduction of two acoustic startling stimuli presented at 5-minute intervals, at a level of 110dB. Cardiovascular profiling found a significant change to heartrate at in increase of 10.8 beats per minute (BPM). Interesting, the second auditory stimuli did not raise heart rate to the similar degree as the first auditory onset. Similarly, Lu et al. (2018) found alterations to HRV. Thirty participants, wearing noise cancelling headphones, were subjected to industrial noises, at three pre specified levels (55dB, 75dB & 90dB) for 20 minutes each, whilst heart rate was measured. Analysis of hear rate found sounds that were given at 90dB were able to significantly alter HRV. Furthermore, Jaroslaw et al. (2019) found that the acoustic startle is capable of increasing HRV. Evidence presented favourably acknowledges that the ASR is capable of physiological modulation.

4.11 Auditory startle and gait changes

Instability of human gait, particularly in older adults, is plagued by impaired balance, gait instability, and altered gait patterns. Typically, habitation to the acoustic startle response has been demonstrated to take place quite rapidly (Ornitz & Guthrie, 1989), however, in the moment of the startle, multiple changes are taking place. It is this moment, that we believe is the leading cause of falls. Examining how the startle response is incorporated to the gait to created measurable changes to gait has become increasingly important, particularly in older adults and the possible influence it may have over slips, trips and falls. The auditory startle is proposed to alter gait patterns via a shortening of gait during the step cycle and decrease the range of motion, to quickly regain stability of the gait cycle (Nieuwenhijuzen, Schillings, Galen & Duysens, 2000). Contrasting this, it is also proposed that gait pattern alterations that may increase risk of falls, particularly in older adults, may be a result of abnormal startle effects. It is theorised that motor predictions are reduced during the startle effect, which interferes with balance recovery, inducing balance perturbations, rather than stability (Sanders, Hsiao, Savin, Creath & Rogers, 2019). Opposing theories further suggest that the auditory startle may influence balance and increase falls due to significant acceleration in movement (Nonnekes, Carpenter, inglis, Duysens & Weerdesteyn, 2015). The contrasting evidence into how the auditory startle may influence gait is somewhat complex and broad. As such, the next section will outline current evidence as to how the auditory startle may influence gait, to support the results of gait perturbation that were found in chapter 4 of this thesis.

A common measure to assess the degree to which auditory startle may influence movement is electromyographic activity (EMG). EMG recordings are taken via multiple recording pads placed on specific areas of the lower limbs. Recording pads measure muscle response via detecting electrical potential generated by activation of muscle cells. Analysis of EMG recordings allow understanding of the degree to which muscles activate, how quick activation takes place, the duration of activation and the characteristics of gait (Nieuwenhuijzen et al. 2000). For example, Nonnekes et al. (2013) examined the occurrence of muscle changes during startling auditory stimuli. Participants were administered an auditory startle during five conditions; sitting relaxed, standing relaxed, bearing 60% of weight on right leg, bearing 60% on weight on left leg and finally with 30% of weight supported. EMG recordings were taken from the tibialis anterior and left sternocleidomastoid muscle. Analysis found; the startle response occurs more frequently during normal standing. Moreover, a startle response influences the tibialis anterior more during loading leg responses. Given the loading leg is the point where initial contact takes place, and continuing until the adjacent foot leaves the ground, this might explain why gait perturbation occurs on the onset of auditory stimuli. The muscle activation would signal the foot to stabilise to early, altering gait, thus increasing possibility of slips, trips and falls.

Nieuwenhuijzen et al. (2000) further described the influence of auditory startles on gait via tracking EMG activity in multiple regions. Participants were asked to walk on a treadmill at 4km/h whilst auditory stimuli were presented at different phases of the gait cycle. EMG recordings were taken from the biceps, rectus femoris, tibialis anterior and soleus. Furthermore, the gait cycle was measured via knee angles of both legs and ankles during the stance and swing phase. Analysis found some key features. Firstly, the auditory startle influence was dependant on the step cycle timings. Secondly the tibialis anterior transition from a facilitator response to a suppressive. Finally, gait cycle was shortened and a reduction in ankle and knee motion (Nieuwenhuijzen et al,. 2000). Similar results were found in the step cycle by Schapens and Delwaide (1995). EMG measures taken from the soleus and tibialis anterior, found that whilst the soleus is not influenced by the auditory startle, unexpectedly the tibialis anterior becomes active, during periods where the muscle should be at rest. Given the tibialis anterior plays a defining role in walking via stabilisation of the ankle joint during loading responses of gait (KenHub, 2023), it is possible that a leading cause of falls in older adults, as mentioned previously is due to the ankle not supporting body weight during times of startle. When the foot hits the floor ready for ground clearance into the next stage of gait, the foot seems induce perturbations at such phase.

Foot perturbations and gait changes during the gait cycle are particularly notable when navigating the environment, particularly due to the need to constantly monitor and re-adjust our waking as a response to obstacles within our direction. It is suggested that given sound is able to capture attention at a lower and faster threshold than other sensory modalities (Hidaka & Ide, 2015) obstacle avoidance under loud and unexpected sounds may influence walking, particularly in the environment. A study by Queralt et al. (2008) evaluated the degree to which an auditory startle may influence walking in such a manner. Twelve participants were asked to walk on a treadmill whilst obstacles were released onto the walking area at designated time periods of the gait cycle. Participants were required to complete the walk twice, once during a silent phase and once during and auditory startle condition. Analysis found, during the condition where an auditory startle was played during obstacle avoidance, participants had longer steps. Interestingly, in conditions where the obstacles were present but not released onto the waking area, the auditory startle induces a change to gait, like that of avoiding the obstacles. Activation of muscles were found in the rectus femoris, tibialis anterior and gastrocnemius medialis. No habituation to the auditory startle was found. (Queralt et al., 2008). What is notable, is the activation of the gastrocnemius medialis. The role of this muscle is to plantarflex the ankle, in that it allows the ankle to flex and point down and propel. This is of interest as like tibialis anterior, activation of these muscles can rapidly alter the gait cycle. It can speed up, slow down and destabilise the foot, thus reducing balance and increasing the risk of falls, particularly in elderly.

4.12 Acoustic startle modulation

Evidence presented previously has outlined that the ASR, typically in the form of randomised noise, not specifically environmental noise, can induce a rapid and sequential activation of physiological mechanisms, muscle changes and gait alterations. The implications of the ASR on the human body can induce devastating changes, particularly in the form of gait. Older adults are at increased risk of falls and accidents that can lead to long term changes, both physically and mentally. As such, it is imperative that interventions are created to reduce and stop the rate of which the ASR can induce change. Recent research is beginning to understand that there are modifiable interventions that can reduce the rate to which an individual reacts to the sound and the degree to which individuals can habituate. Gomez-Nieto et al. (2020) outline the four favourable ASR modulations as: fear potentiation of the ASR, sensitisation and habituation to the ASR, medications and Prepulse inhibition (PPI). Each of these modifications has been noted to reduce the strength of ASR. A full evaluation of each measure is beyond the scope of this paper; however, an overview will be provided of PPI given is popularity with research in this field and the benefits is has over inhibiting irrelevant acoustic stimuli. For an overview of additional modification techniques see Gomez-Nieto et al. (2000)

4.12.1 Prepulse inhibition (PPI)

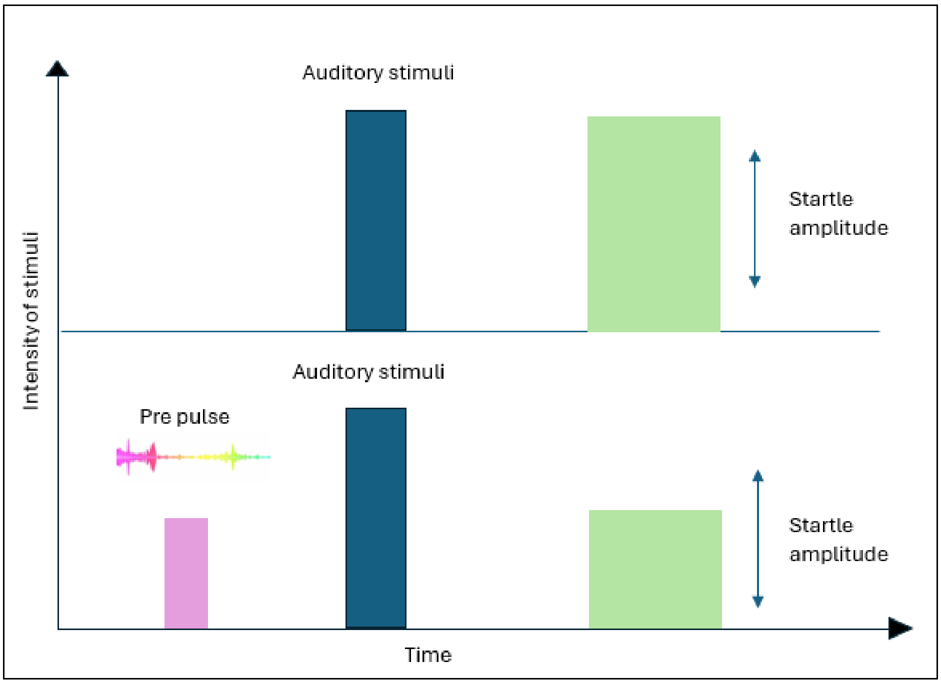


Figure 21 Example of theory behind PPI. Image created by author of paper.

PPI is a neuropsychological process where a weaker sensory stimulus (prepulse) attenuates the motor response (startle reaction) to a subsequent strong startling stimulus (Rohleder et al., 2016) (See figure 10). For example, the presentation of a bell ringing, could theoretically reduce the degree to which a subsequent loud siren alarm may influence a movement that is controlled by the nervous system. It is suggested that the prepulse should be presented between 30-500ms beforehand to provide a favourable reduction of the stronger starting stimuli (de Oliveira et al., 2023). PPI as a modification tool is seen as the best operational measure of sensorimotor gating (SMG), with SMG defined as the ability of the CNS to supress motor response by filtering irrelevant sensory information (de Oliveira et al., 2023). It should be noted at this point that a common misconception of PPI is that it is a form of conditioning, this is not true, PPI does not follow parameters for conditioning as it does not exhibit habituation of extinction over trials (Gomez-Neito et al, 2020). PPI is ubiquitous in research encompassing a range of disorders and diseases from anxiety (Ludewig et al., 2002) through to Alzheimer’s (Ueki et al., 2006). Moreover, animal models have been extremely beneficial in providing detailed models of PPI pathways (Yeomans et al., 2006) in addition to habituation, both short term and long term to the ASR (Valsamis et al., 2011). The amalgamation of both human and animal-based research has paved the way for both modification techniques and theoretical based models to track and monitor disease.

Interestingly, there is believed to be a reduction in PPI in older adults compared to young. This reduction is believed to be related to a sensorimotor dysfunction, which cannot supress excessive behavioural responses to a disruptive stimulus (Jafari, Kolb & Mohanjerani, 2020). Whilst this reduction does not predict cognition (de Oliveira et al, 2023), it does feed into attention control models and the ability of older adults to filter out task irrelevant stimuli. Moreover, it provides evidence that neurofunctional deficits with ageing are always going to exacerbate the incidence of slips, trips and falls in older adults. Whilst PPI inhibition may be reduced in older adults alternative methods to PPI are available, particularly in the form of cognitive training for auditory attention. Although it should be noted that animal research has provided evidence that ACT can improve PPI (Guercio et al., 2020).

4.12.2 Auditory cognitive training (ACT) to improve attention allocation and reduce startle.

ACT is a training process aimed to target neural circuits that influence perceptual information processing to improve attentional control and inhibit irrelevant stimuli (O`Brian et al., 2017), which in the case of this thesis would be to ignore irrelevant sounds and maintain focus on gait to remove perturbation. For example, O`Brian et al. (2017) examined the effects of ACT of event related potentials. Participants were asked to complete an auditory odd ball task before and after a 10-week period. One group had ACT training and one group had nothing. In all participants who were given ACT training, the amplitude of the odd ball stimuli was significantly reduced, thus providing evidence of ACT enhancing attention allocation. Similarly, Kawata et al. (2022) found that ACT was capable of inducing brain plasticity within a 4-week training period. Moreover, Mozolic et al. (2011) found that training could improve selective attention with a reduction in bimodal integration. Furthermore, Lee et al. (2017) found that ACT could improve sustained attention and working memory.

The improvement in attention and cognitive control as a result of ACT would be a beneficial contribution to reducing slips, trips and falls in older adults, via the improved ability to filter out irrelevant stimuli. One question remains from ACT research. How context dependant is the research. Many of the studies related to someone passively sitting in front of a computer with no real-life effects. How would this training benefit individuals in the real world. Moreover, how would this be adapted to the real world, as it is well known that attention is significantly reduced when exposed to persistent noise levels above 95dB (Jafari, Khosrowabadi, Khodakarim & Mohammadian,(1999). It may be beneficial to adapt the premise of ACT to suit walking specifically. It may be useful to have older adults sit outside of their home or sit down when they visit the shops, on a frequent basis, to get used to the noises around them. The more an individual is exposed to noise, the more sensitized they get to it. It is with hopes that when older adults are bombarded with environmental noise when they go shopping etc, they are able to ignore the irrelevant noise and focus on gait, thus reducing the incidents of slips, trips and falls in older adults.

4.13 Final comments

If research is to support the growth and safety of older adults in their personal or external environment, we must address to what extent these sounds are impacting and individual and are there means to reduce the effectiveness of attention capture. By attending to such questions, it is hoped that falls risk could be reduced, social interactions will not be hindered, and older adults will feel comfortable moving around the environment. To aid future research this chapter has outlined:

- Contradictory to previous research, older adults appeared able to resist the capture of processing resources by distracting stimuli to maintain speed/RT performance of the primary visual task.
- Older adults subjectively feel that environmental sounds can elicit a startle at the onset of sound. This “startle” can capture attention and directing it away from task. As this was not found in the data, research suggests that there may be a rapid habituation to the sounds.
- Evidence presented in the auditory startle section, outlines the defining role the onset of sounds may play, in relation to attention re-redirection and gait.

Chapter 5 – Gait efficiency and the influence of environmental sound on gait

Summary of chapter aims and context.

Becoming bipedal may be one of the greatest evolutionary adaptions. It changed how early human interacted and transversed continents, it freed up hands to use tool and increased survival. However, a detriment to becoming bipedal is the loss to agility and stability that we had when walking on all fours, hence the rates of slips, trips and falls, particularly in older adults who have additional age-related changes. Previous chapters have outlined how selective attention plays a defining role in how we attend to our environment. Moreover, it has also been presented in previous research that the unexpected and salient sounds that we hear in our environment are able to capture attention at a lower and faster threshold than other sensory modalities. When pairing distracting environmental sound and reduced selective attention, older adults are at increased risk of changes to their gait cycle. To understand the degree to which environmental sounds may influence gait, this chapter will determine whether the environmental sounds that were used in the STAC test (previous chapter) are capable of creating gait perturbation (I.e., redirecting attention away from gait, to focus on the distracting environmental sounds, causing a change or perturbation to gait). First, an overview will be presented of the gait cycle and the neuroanatomy that facilitates such movement. Moreover, this chapter will provide new research addressing gait cycle changes in older adults via the use of accelerometers. Older adults will be presented with an array of environmental sounds, to understand how gait patterns change in response to the onset of the sound. Moreover, given older adults note a startle effect to environmental sounds, this research will also evaluate if the onset of environmental sounds can create a startle like effect with gait pattern, the moment of sound onset. Cognitive, hearing, balance and polypharmacy correlates were also taken, to understand the degree to which external factors may further exacerbate slips, trips and falls. It was important to gather as much information as possible, as *it will allow this research to take a precision medicine approach to account for individual difference via a large group of confounding variables know to influence gait. The hypothesis is that environmental sounds will have a detrimental impact on gait, via perturbation in the gait cycle. It is also expected that our additional measure such as polypharmacy and cognitive testing will be an influencing factor on gait.*

5.1 Introduction

Bipedalism may be one of the greatest evolutionary adaptions that have made humans what they are today. It has allowed humans to transverse from walking on “all fours” to walking upright on two legs. There are several theories outlining reasons for this drive-in evolution include the Savanna theory, (Dart, 1925), the postural feeding hypothesis (Hunt, 1994), the threat model (Jablonski & Chaplin, 1993), and the thermoregulatory model (Wheeler, 1984). Each model provides argumentative evidence for their theory, with the consensus being that it is related to evolve or become extinct. The earliest possible date of this is thought to be approximately 11.6 million years ago, in the Donuvius Guggenmosi hominin. This species showed characteristics of bipedalism in the spine and legs (Bohme et al., 2019). The consensus amongst academics is that full bipedalism began to take place around 6-7 million years ago in hominin Sahelanthropus. Shortly after this date hominins, Orrortin Tugenensis and Australopithecus Anamensis showed strength adaptations in the legs and knee bone density (Smithsonian, 2023). Moving forward to 2.5 million years ago, Australopithecus Africanus developed a curved spine to fully support the back when walking. By approximately 1.95 million years ago, Homoerectus skeletal remains provided evidence of fully erect bipedalism (see Figure 21) via a hip support of the pelvis and thigh bone, that can facilitate efficient locomotion and allowing further distances to be traversed, at a greater speed (Smithsonian, 2023).

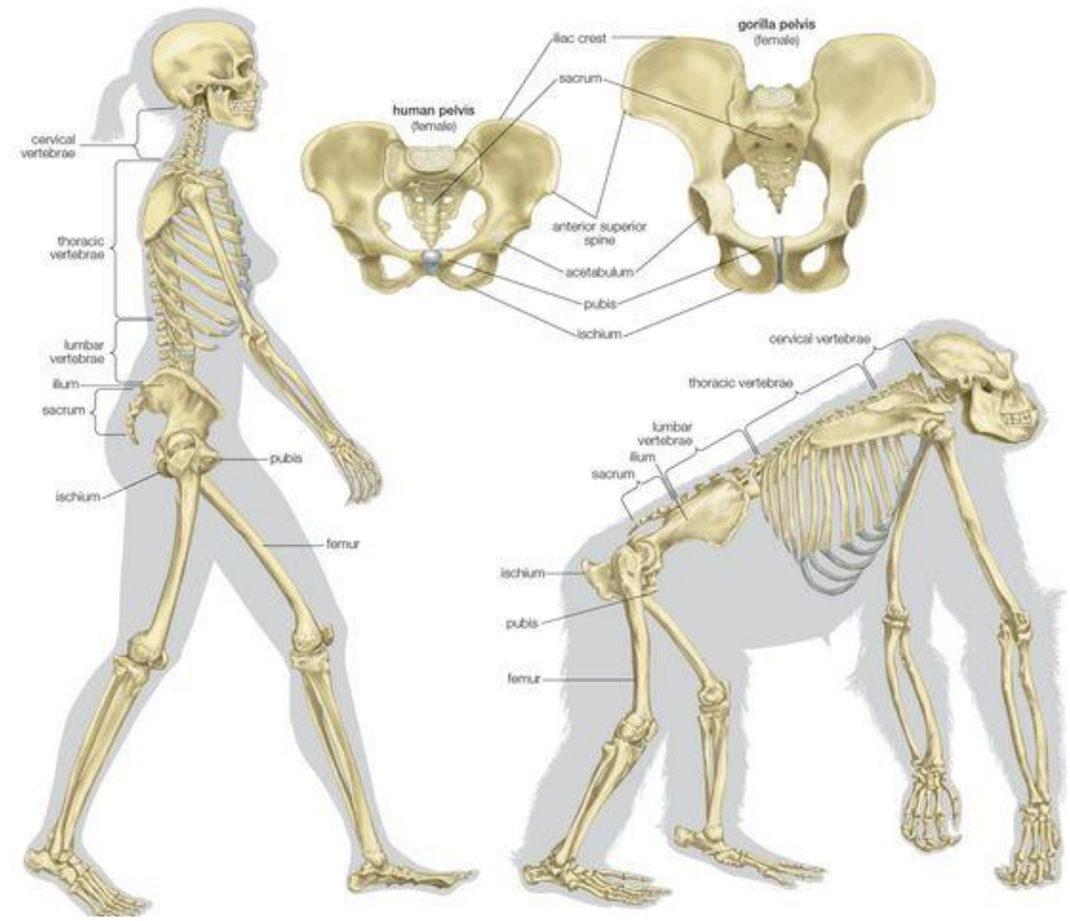


Figure 22 Example of evolutionary changes taken place during bipedalism. Image taken from Britannica, 2023

Becoming bipedal changed how hominin interacted with the environment and surrounds, which consequently provided many benefits as well as costs. For both early hominin and humans today, the benefits of bipedalism are still significant. The early benefits included, freeing up hands to carry food and tools (Ko, 2015), providing greater access to food at higher levels (Hunt, 1994) and the ability to spot possible food sources from a distance (Ko, 2015). Moreover, it allowed early hominin to move up the food chain as we appeared larger and more intimidating to prey, which in turn increase the ability to hunt for food (Jablonski & Chaplin, 1993). Bipedalism also allowed greater and faster movement around the landscape (Ko, 2015), ultimately influencing the great evolutionary migration, around 2 million years ago, out of Africa, through coastal regions (Posth et al., 2016), to Oceana (O`Connell et al., 2018) before crossing into Eurasia around 40,000 years ago (Pavlov, Svendsen & Indrelid, 2001), where evidence shows interactions with Neanderthals and Denisovans.

The negative costs associated with bipedalism, can to an extent out weight the benefits, particularly for females. For example, whilst women have developed a lower lumber region stronger than that of males, to help bear the weight of pregnancy (Whittman & Lewis, 2007), bipedalism made labour and giving birth significantly more difficult and dangerous due to the narrowing of the pelvis, thus creating a smaller birth canal (See figure 1) (Travathan, 1996). For the population on a whole, bipedalism increased the prevalence of lower back pain, slipped disk, arthritis in the hips and knees and collapsed foot arches (Smithsonian, 2023). Lastly, bipedalism has induced a loss to agility and stability that we had when walking on all fours, hence the rates of slips, trips and falls that are prevalent across all ages, particularly older adults.

The importance of researching slips trips and falls, derives from the current figures that suggest 30% older adults over the age of 65 has a fall each year, with around half of those age 80+ having a fall (NHS, 2023). Given that the amount of people in the older generation is growing exponentially, the numbers of older adults who will have a fall will also grow exponentially. Falls in older adults create more increasingly serious injuries than that of younger adults, with the average Fall contributing to hip fractures, broken bones (NHS, 2023). Moreover, Falls are the most common cause of injury related death. In 2017, 5000 people died as a direct result of falls. Falls also impact a person’s confidence and impact how a person interacts with their environment. Following a fall, older adults tend to become withdrawn and lose their independence through fear of a repeated fall. This increases instances of loneliness and reduced ability (NHS, 2023).

Preventing falls in older adults should be a top priority not only because of the devastating implications it has on the individual, but also the average £4.6 million pound it cost the NHS every day to treat (short term and long term) individuals (AgeUK, 2023), accounting for approximately £1.7 billion per year. More research is needed to find preventative measure that can reduce this substantial figure. However, before preventative measure can be put in place, more research is needed to know in greater detail why falls happen, and one such factor of interest of this thesis, is changes or perturbations in gait. Whilst the NHS and AGEUK, (2023) provide an outline of preventative measures such as; removing clutter, removing mats, asking for help, well supported shoes, strength training, eye tests and limited alcohol consumption. Such advice does not include consideration of the unreliable and variable nature of the everyday environment, particularly the “auditory” environment. Everyday sounds can be loud, unexpected, persistent, attention capturing and induce confusion in older adults.

Previous chapters have outlined the importance of sound and the ability of sound to capture and divide/focus attention away from a particular task (Thierry & Roberts, 2007, Huang & Elhilali, 2020). The environment is full of sounds; predictable and unpredictable and because sound is known to distract attention it is possible that certain sounds in the environment are distractible /salient enough to capture attention and processing resources, taking them away from the attentional resources needed for walking and gait maintenance. Thus, possibly contributing to falls. To help understand if this may happen, this study examines whether a range of environmental sounds perturbs gait whilst walking. This therefore is moving away from laboratory to more real-life, more environmentally valid research for context. This chapter will first provide an outline of the gait cycle and the neuroanatomy that facilitates an efficient gait. It will also explore how gait is related to falls and how sound may play an important role in perturbating gait within a noisy environment. Although some work has been done already in this area evaluating unexpected noise and falls (Buyle et al., 2021), noise and stride changes (Mukherjee & Stergiou, 2013) and hold influence over gait dynamics (Hunt, McGrath & Stergiou, 2014), the new / novel research data in this thesis will be derived from accelerometer data, taken whilst older adults were exposed to environmental sounds, played at random times, whilst walking, in order to measure the extent sounds can perturbate gait. First, we will be using accelerometer data will allow an understanding of how environmental sounds alter the progress of gait and gait patterns, which long term may be beneficial for effective development of rehabilitation programmes to reduce falls in older adults.

5.2 Human gait cycle

The human gait cycle can be described as a series of complex movements on two legs, alternately (Kharb et al., 2011), which produce a consistent and energy efficient locomotive movement, allowing a stable forward propulsion of the body (Shah, Solan & Dawe, 2020). As noted by Perry (1985), gait is a repetitious and cyclic pattern of movements that facilitates exquisite and effortless movement. The components of a normal gait cycle require multiple bodily systems including the musculoskeletal, nervous, cardiovascular, and respiratory systems (Kenhub, 2022), to provide balance, mobility, stability and execute control over gait. Co-ordination of the bodily systems and movement allows for a complex, yet fluid, 8 stage cycle (See figure 2), broken down into two distinct phases: the stance and swing. The stance phase of a gait cycle describes the period where the foot is in contact with the ground. This phase accounts for approximately 60% of the cycle and last for approximately 0.59-0.67 seconds, when individual variation is considered. It is thought, the stance phase can be further broken down into 3 subdivisions; contact period (27%), midstance (40%) and propulsive (33%) (Root et al., 1977). The swing phase is the period where the foot is non-weight bearing, accounting for the remaining 40% of the gait cycle, lasting approximately 0.38-0.42 seconds. It should also be noted, during the normal gait cycle, there are two points where both feet are in full contact with the ground. This is termed double limb support (Shah et al., 2020). Visually, this is seen as one foot forward, having landed on the ground and the other foot backwards, about to leave the ground (Kharb et al., 2011).

5.2.1 Initial contact

Initial contact begins when the foot strikes the ground, typically, with the heel first and ankle in the dorsiflexed position. The adjacent foot is at the end of the terminal stance and still in contact with the ground (Shah et al., 2020, Kharb et al., 2011). Initial contact stage requires the use of the gluteus maximus, hamstring, quadriceps, and tibialis anterior. Initial contact is the first part of the initial leg support (Silva & Stergiou, 2020).

5.2.2 Loading response

The loading response concludes the initial double leg response (Silva et al., 2020). Body weight is transferred onto the forward limb with knee braced to act as an absorption to downward pressure (Kharb et al., 2011). As the gait cycle propels forward, the heel causes the foot to make full contact with the floor, with the adjacent leg in a pre-swing phase. Muscles used during loading response include gluteus maximus, quadriceps and tibialis anterior.

5.2.3 Midstance

Midstance is the first part of the single leg support period. The foot remains flat to the floor, with the ankle dorsiflexed without resistance, and the knee and hip are in extension (Shah et al., 2020, Kharb et al., 2011). The adjacent leg is reaching its mid swing phase. The midstance requires little muscular effort, with only the triceps surae activated.

5.2.4 Terminal stance

Terminal stance begins as the heel is lifted off the floor, advancing over the forefront rocker (Kharb et al., 2011). Knee extension increases, as does hip extension, placing the limb in a trailing posture (Kharb et al., 2011). Knee reaches heightened tension, preparing for forward propulsion, via a transfer from potential energy to kinetic. (Silva et al., 2020). The adjacent leg is in terminal swing phase. Muscles used during the terminal stance include triceps surae.

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5.2.5 Pre-swing

Pre swing is when the limb begins to leave the ground, known as toe off, with an increase in ankle and knee flexion and a decrease in extension of the hips (Kharb et al., 2011). Pre-swing is the terminal double leg support and the second loading period (Silva et al., 2020). As the toe leaves the ground, the opposite leg makes contact with the floor (Kharb et al., 2011). The pre swing requires muscular input from the iliopsoas, quadriceps, and tibialis anterior.

5.2.6 Initial swing

Initial swing allows the foot to clear the floor and the hip flexes to allow a forward advancement. The adjacent limb is in early midstance position (Kharb et al., 2011). Initial swing requires the iliopsoas and tibialis anterior.

5.2.7 Mid-swing

With an increase in flexion of the hips, the knee extends, and the ankle continues in a dorsiflex until it reaches a point of neutrality (Kharb et al., 2011). The adjacent limb is in a late mid-stance. According to Kharb et al. (2011), mid-swing has a second phase of movement, as the swinging limb is opposite the stance limb and ends when the limb that is swinging has the tibia vertical. Mid-swing relies on the hamstring and tibialis anterior.

5.2.8 Terminal swing

With a knee reaching a flexed position, ankle in neutral and hips in flexion, limb advancement reaches a complete cycle when the vertical tibia allows the foot to strike the floor (Kharb et al., 2011). The adjacent foot is in a terminal stance. As with the start of a gait cycle, the muscles used are the gluteus maximus, hamstring, quadriceps and tibialis anterior.

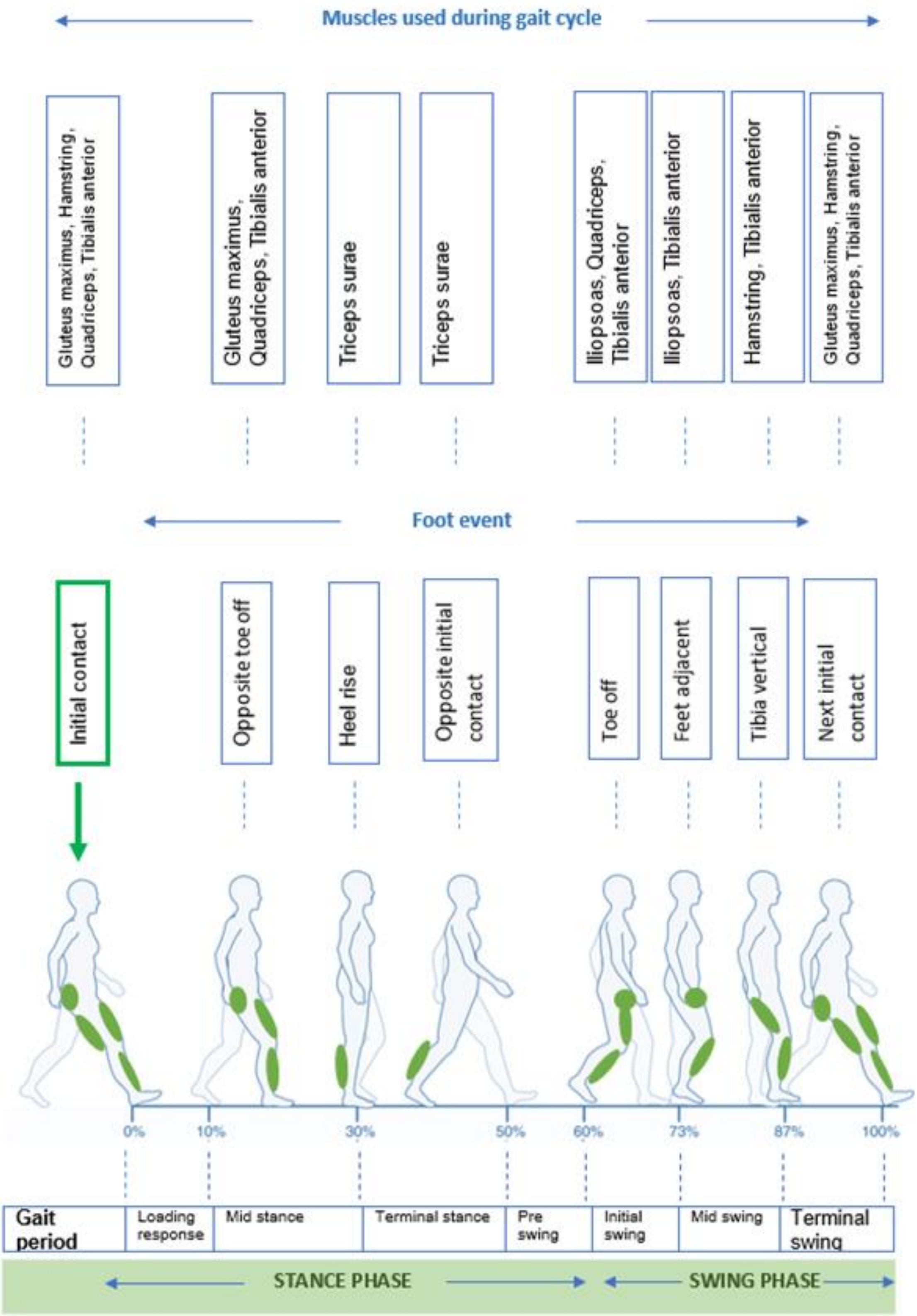


Figure 23 Example of the full gait cycle, including phases and muscles used. Image created by author of this paper

It should be noted that alternative approaches to understanding and quantifying the gait cycle, have approached the phases of gait via ideas such as gait rockers (Perry, 1997) and mechanical power produced (Zelik et al., 2015). For example, Zelik et al., (2015) crated a 5-stage model of gait phases addressing the mechanical power production, based off Centre Of Mass (COM), a point where applied force propels a cycle to move without rotation. The 5-stage model includes; 1) collusion, initial foot contact starts collusion and is defined by a negative individual leg COM. The adjacent heel strike creates a power positive. 2) rebound, with a positive individual leg COM power. 3) pre-load, negative individual leg COM power. 4) push off, defined as a positive individual leg COM power and 5) swing phase with zero individual leg COM power, due to ipsilateral leg achieving zero contact with the floor. Whilst slightly different, the approach holds merit in understanding the concept and mechanics of gait and combining all approaches produces a rigorous and productive model that can not only accommodate gait understanding, but an enhancement in scientific conclusions, evaluation and development of critical interventions (Zelik et al., 2015).

What each model, regardless of specifics, agrees on, is the pre-requisites for gait, i.e., what facilitates and defines a normal gait pattern. Regardless of individual variations, each pre-requisite needs to be met. As noted by Perry (1985), gait needs to have, stability in stance, adequate clearance in the swing phase, adequate step length, appropriate prepositioning during swing and energy conservation. Moreover, an introduction of six determinants of gait by Saunders et al., (1953), provide strategies that the body needs to use to maintain COM, to decrease vertical and lateral displacement, which increase efficiency and energy expenditure. The determinants (movements) that ensure normal gait are 1) pelvic rotation, Pelvic tilt, knee flexion, foot and ankle motion, knee motion and lateral displacement of the pelvis. Saunders et al., (1953) believed that any dynamic that strays from these guidelines resulted in pathological gait. Interestingly, compared to most research in this field, Sander et al., (1953) viewed pathological gait not as a disability per say, but rather an attempt to preserve a low level of energy consumption as possible via exaggerations of unaffected motions. However, it was noted that a loss of two determinants renders efficiency compensation impossible.

Whilst enduring, the six determinants theory is not without flaws, for example, the theory is developed of descriptive observations, not scientifically tested. Recent scientific testing of the theory has found little to no credibility (Kuo & Donelan, 2010) and somewhat discredited (Kirtley, 2006). Moreover, research has shown, the first three determinants make an insignificant impact of vertical displacement of the COM, as well as lack of evidence that is able to link minimising the COM to reduce energy (Physiopaedia, 2022). Finally, Ortega & Farley (2005) present evidence that humans expend more energy when voluntarily reducing vertical displacement of COM compared to when they are walking under their normal gait parameters. It is important to understand this information in order to understand the components or pre-requisites of a healthy gait before comparing that to altered gait.

Inspection of the 6 determinants raises concern, given that the research by Saunders et al. (1953) has been taken as clinically significant and undisputed. Kuo & Donelan (2010) suggest, that rather than taking the 6-determinant research at face value, it should be viewed as a kinematic description of certain features of gait, a subjective model, as opposed to a direct text book theory. Interestingly, the problems associated with the 6 determinants are somewhat rendered in a contrasting model, known as the “inverted pendulum theory” (Cavagna & Margaria, 1996, Cavagna et al., 1963). This theory suggests, energy expenditure reduction, to aid efficient and economical normal gait patterns, is facilitated via an inverted pendulum, which conserves mechanical energy. Direct observations of the energy and leg length change during single limb support, are thought to provide evidence to support this pendulum-based behaviour (Kuo & Donelan, 2010). Moreover, Kuo, Donelan & Ruina (2005), postulate conservation of energy can be obtained via the pendular swing which requires little to no energy. When one leg is on the ground, the rigid pendulum supports the COM with no muscle force and when step-to-step transitions take place, the COM velocity obtained previously, gets redirected to a new pendula arch. Optimal pendular theory step transitions are thought to be most efficient when push off and collusion are of equal magnitude (Kuo et al., 2005)

Movements of humans during the gait cycle have been studies extensively (Kharb et al., 2011, Shah et al., 2020, Kuo et al., 2010,2011), enhancing our understanding of the advantageous nature of bipedal gait. In terms of determinants and metabolic cost of gait, research is still in a somewhat developmental stage. However, Umberger (2010) developed a study that was able to investigate the metabolic cost of walking, via a modelling approach they were able to develop an approximation muscular cost, at different moments of a cycle. With leg swing taking around 29% of muscular cost. During stance phase, double and single limb support period 27% and 44%. Step-by-step transitions represent 37% of total cost or walking. Again, this has been a study of contention, with Kuo et al., 2005 suggesting transitions require around 70% of metabolic cost, and Neptune et al. (2004) suggesting high level metabolic cost is primary focused around single limb support periods. The metabolic cost of gait is an extremely important component of gait as it has been shown that individuals who have increased energy expenditure during gait are more likely to have increased gait variability and poor fitness levels (Kalron et al., 2019). As such, metabolic expenditure can be seen as an additional variable that may further confound gait perturbation in older adults, thus increasing falls risk.

5.3 Neuroanatomy of gait

The gait cycle as outlined above, provides the basic features of external gait. The system that processes, facilitates, and initiates gait is extremely complex. Many would suggest that gait is achieved through the motor cortex, which to an extent is true. Gait however is a complex system, requiring information integration from notable areas such as the cerebellum, sensory cortexes and frontal lobes to name but a few.

Research to explain the neuroanatomy of gait has typically been derived from animal studies (Takakusaki, 2016, Higurashi et al., 2019) and atrophy in humans (Israeli-Korn et al., 2019). For example, Animal research, particularly in rats and mice have provided evidence that gait and gait control are executed via an unconscious gait memory, that illicit a cascade of neurons into the spinal locomotory tracts (Takakusaki, 2016). In Human research, individuals who develop cerebella ataxia, a disorder that influences co-ordination and balance (NHS, 2023) are at increased risk of falls due to slowed gait, staggering, heel to toe displacement and errors to leg and foot placement, with emotional and visuospatial deficits that further exacerbate gait quality. Similarly, individuals with Huntington’s disease, a genetic condition caused by the expansion of CAG triplets in Huntingtin gene, have brain morphological changes in this disease, which disturb motor systems and have a detrimental impact on gait (Wennberg et al., 2017). Furthermore, research has found the core factors of gait (Balance, posture and locomotion), are accomplished via the sensory systems (vision, vestibular and somatosensory) (Mackinnon, 2020). Lastly, research suggest that the limbic hypothalamus plays a defining role in gait via mediating impulsivity over how we interact with the environment (e.g., danger as an emotional response = run away). Evidence suggests gait is not specifically a one system fits all. It is a system of multiple integration, that relies on sensory, emotional and unconscious memory information send to motor regions, to facilitate efficient gait.

The presence of anatomical and cognitive processing working as one to facilitate gait, suggests neuroanatomical control over gait is not specifically achieved via one system (e.g., motor cortex), but it is the amalgamation of multiple systems conceptualising events to facilitate gait, specific for the moment. Collecting hypothesis to explain gait from animal and human research provides a consensus that in addition to the well-known motor cortex, there are 3 distinct pathways that are the major gait facilitators. Firstly, the Mesencephalic Locomotory Region (MLR), Secondly, the Subthalamic Locomotory Region (SLR) and thirdly, the Cerebellum facilitate gait via connections to the motor cortex. Furthermore, previous research by

Richards (2020 unpublished), provides distinct evidence that the basal ganglia and pons are also defining pathways that the motor systems uses to facilitate gait. It is noticeable that sensory integration is not included in the 3 distinct pathways. The reason for such exclusion derives from sensory information acting as an encompassing feature. Sensory integration takes place before gait initiation and post movement, and as such will be discussed separately.

5.3.1 Motor cortex

The motor cortex (See figure 24), is associated with movement and motor control in both humans and animal research, known for the ability to generate signals that direct movement of the body (Yip & Lui, 2022), specifically motor fibres of the pyramidal tract, which synapse with motor neurons in the brain stem and spinal cord (Poon et al., 2008). Located in the frontal lobe anterior to the central sulcus, the motor cortex is subdivided into three distinct categories: The primary motor cortex (PMC), the premotor cortex (PC) and the supplementary motor cortex (SMC). Each subdivision, whilst autonomous in terms of anatomy, work together to produce efficient and streamline movements.

The PMC works alongside multiple other anatomical regions of the cerebrum (Sira & Mateer, 2014), including receiving input from the PC and SMC. Located on the precentral gyrus and anterior paracentral lobule, the PMC is believed to contain a somatopic map of the muscles of the body known as the motor homunculus, with the legs medially, legs laterally and other body regions intermediate (Olson & Colby, 2013). Similar to tonotopic organisation in the auditory system, each area of the map has distinct neurons that are associated with a corresponding muscle. When a specific neuron received proprioceptive input, it sends a signal through the brain stem and spinal cord to the target muscles to facilitate movement (Olsen et al., 2013).

Facilitation of such streamline information transfer, is due to its content of neurons. For example, pyramidal neurons, mainly found in layer v of the primary motor cortex, form a part of the cortico-spinal tract, where the pyramidal neurons send long axon to the contralateral motor nucleus of the cranial nerve and lower motor neurons of the ventral horn. This is partly due to the pyramidal neurons here being giant cells. In addition to pyramidal neurons, the PMC contains intratelencephalic neurons, that project to the cortex and striatum and corticothalamic neurons. Cortical input organisation models suggest that all neurons fire during anticipation and initiation of movement with a range of tract projection that initiate during. For example, Hooks et al. (2013) evaluated organisation of neurons in the motor cortex, via channelrhodopsin-2-assisted circuit mapping was used to monitor connections in into the motor cortex. Results showed that long range excitatory input target the PMC pyramidal neurons, but not in a direct route, rather input enters via a layered manner, with sensory information entering the upper PMC pyramidal neurons and input to the PMC from the orbital cortex and PC have a direct monosynaptic access to neurons that directly project to the brainstem (Hooks et al.,2013)

The functionality of the PMC is thought to be linked to control of voluntary, skilled, and refined movements (Ken Hub, 2023), which in part is due to the plasticity nature of the area. Plowman & Kleim (2009) outlines that the connectivity of this region is highly adaptive, with synaptic plasticity induced in response to stimulation, environmental adaption and skills needed. Similarly, Vandermeeren, et al. (2003) outlines in a review that PMC representations can additionally be altered due to available effectors or sensory deprivation. Moreover, atrophy or lesions within this area are a leading cause of plasticity, due to the reorganisation of the somatopic map in the PMC. Conditions such as Brain injury, multiple sclerosis and motor neuron disease are a classic example to explain that changes that atrophy can cause. For example, those who have a traumatic brain injury are at increased risk of neuronal lesions. If lesion target areas such as that of the anterior horn of the spinal cord, peripheral nerve or muscle, functionality of motor movement is hindered, resulting in hyporeflexia and flaccid paralysis.

The next subsection of the motor cortex is the premotor cortex (PC). The PC lies rostral to the anterolateral area of the PMC. As with the PMC, the PC holds a somatopic representation of musculature, but not as complete as that of the PMC (Mihailoff & Haines, 2018). The PC is highly dependent on input from the sensory areas of the parietal cortex, before projecting onwards to the PMC. Interestingly, although in part believed to play a lesser role than the PMC, the PC has a greater ability to evoke movement due to higher levels of current (Kaas & Stepniewska, 2002), becoming active 100ms before the beginning of a complex sensory guided movement (Pressman & Rosem, 2015). Upper motor neurons in the PC are able to produce a modulatory influence over motor movement via extensive reciprocal connections with the PMC and axons that interlink with the corticobulbar and corticospinal pathways, which in turn target neurons in the brainstem and spinal cord (Purves et al. 2001).

Whilst research has provided evidence of how the PC works, knowledge of the defining role the PC plays in motor control is still relatively unknown. Research has provided some theories such as, movement guidance (Graziano, 2006), gait organisation via auditory influence (Chen et al., 2008) and organisation of most motor movement (Mihailoff & Haines, 2018). In contrast, research has also provided evidence that brain stimulation to the pre motor cortex does not improve gait freezing in condition such as Parkinsons (Tard, Devanne, Defebvre & Delval, 2016). This suggests, that this region does not hold the degree of plasticity other motor areas do. This however has been challenged, by Unger et al. (2023) who found brain stimulation of the premotor cortex enhances interhemispheric connectivity in those with severe stroke, which in turn creates a plasticity effect that improves upper limb recovery.

The final region of the motor cortex is the SMC, consisting of the supplementary motor area, supplementary eye field and the pre supplementary motor area, located in the frontal cortex, occupying the posterior third of the superior frontal gyrus (Nachev, Kennard & Husain, 2008). Whilst there are named divides, namely the supplementary and pre-supplementary, both of which can in part be distinguished by cytoarchitecture and function (Ruan et al., 2018), for the purpose of this section they will be explained as one. The interest in this region derives from a specific readiness potential defined as the Bereitschafts potential. Which is a negative cortical potential initiating approximately 1.5 seconds prior to the onset of movement (Jahanshahi & Hallett, 2003) The Bereitschafts potential provides distinct evidence that the supplementary area is specifically involved in pre-motor organisation, preceding self-initiated movement. Research to support this area derived from brain stimulation (Wilkinson, Duncan, Smith, Fawkes & Marques, 2023), magnetoencephalography (Shibashaki & Hallett, 2006) and electrophysiological evaluation (Brugger et al., 2020).

The bereitschafts potential is particularly noted in Parkinson’s. For example, Brugger et al. (2020) monitored activation and connectivity in the supplementary area in those with Parkinson’s. Twelve patients with freeing of gait and eleven matched controls took part in a multimodal electrophysiological evaluation including the Bereitschaftspotential and movement desynchronised of beta oscillation. Results found prior to volitional movement, those with freezing of gait had a reduced level of Bereitschaftspotential, thus suggesting that the SMA plays a defining role in initiation of movement. A similar study looking at the Bereitschaftspotential in individual with multiple sclerosis, found that contrary to the reduced levels of potential in Parkinsons, those with multiple sclerosis have a earlier onset and longer latency of the Bereitschaftspotential, reflecting prolonged movement preparation (Bardel, Chalah, Creange, Lefaucheur & Ayache, 2022). Similar results have also been found in hyperkinetic movement disorders (Gandhi et al, 2020), further suggesting the SMA is specifically involved in organisation and preceding self-initiated movement.

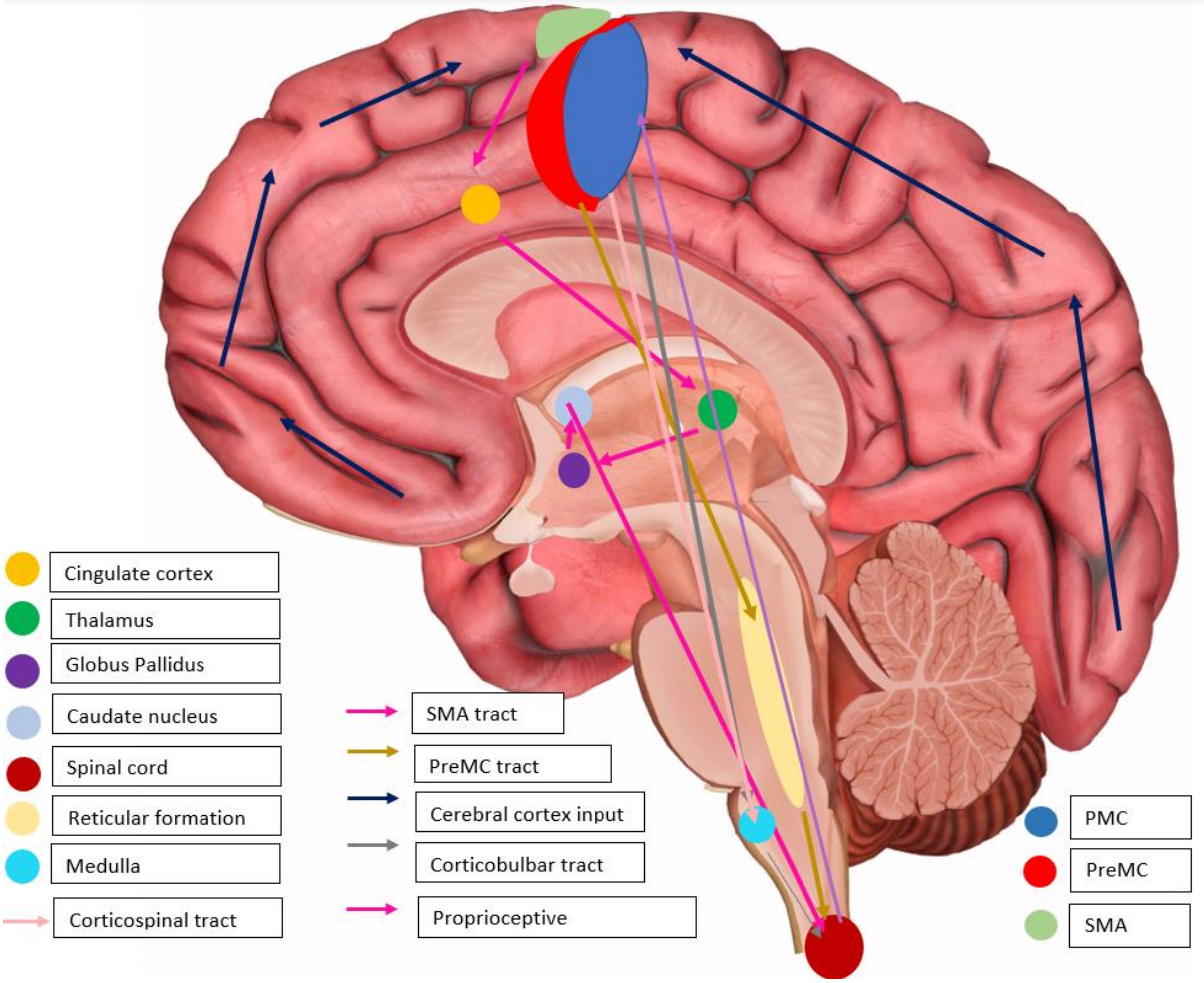


Figure 24 Image taken from Richards (2020 unpublished), incoming connection and projection associated with the motor cortex.

5.3.2 Mesencephalic Locomotory Region

The Mesencephalic Locomotor Region (MLR) (See Figure 25), a defined region of the midbrain, was discovered by Magoun & Rhines (1946), after deep brain stimulation to this previously unnamed region, provoked changes in muscle tone in decerebrated cats. Later studies by Sprague & Chambers (1953) supported the notion of the reticular formation which they described as contained a set of interconnected neurons, spread throughout the brainstem was able to facilitate measurable changes to complex movement. Later research by Shik et al. (1996) and Sherman et al., (2015) found that a specific area of the reticular formation, namely the mesopontine junction was able to immobile decerebrated cats to involuntary walk and gallop (Richards, 2020 unpublished). Present accepted theories outlining the MLR as a specific region specify the MLR is an area of the mesopontine reticular formation, high in cholinergic neurons derived from the Pedunculopontine Tegmental Nucleus (PPN) (Richards, 2020 unpublished), with the addition of the midbrain and extrapyramidal area forming the MLR (Masdeu et al., 1994).

The PPN located in the mesencephalic upper pontin junction, is notable for the dense population of cholinergic neurons (Nowacki et al., 2019). French & Muthusamy (2018) additionally outlines the PPN is not one nucleus, but rather it contains 2 sub nuclei, the pars compacta that houses the abundant cholinergic neurons and the pars dissipita, containing glutamatergic neurons, which as outlined previously are the most abundant excitatory neurotransmitters in the body. The PPN has been linked to many cognitive and physiological function including arousal, attention, learning, reward etc, each of which play a defining role in how we interact with the environment, but it is the voluntary limb movement and locomotion (Tattersall et al., 2014) that is of significant interest. The initiation of locomotion and gait from the PPN is thought to be due to acetylcholine projecting to the ventral horn, sending impulses to the skeletal system (Skinner, Kinjo, Henderson & Garcia-Rill, 1990). Sherman et al. (2015) suggests that spinal cord projections are hard to achieve, particularly via short projections from the ventral horn, rather spiny glutamatergic neurons are the mediators and facilitators of motor movement.

The notion that glutamatergic neurons facilitate gait remains a constant in motor movement research. However, researchers such as Pahapill & Lozano (2000) suggests Sherman et al. (2015) were wrong to exclude cholinergic input and wrong to exclude other neurotransmitters. In a paper outlining the role of the PPN in Parkinsons disease, Pahapill et al. (2000) suggests glutamatergic PPN neurons play a role in the initiation of movement, with cholinergic PPN neurons needed for a steady and maintained locomotion. A further reason not to exclude cholinergic input derives from research presenting evidence that like glutamatergic neurons, the cholinergic neurons in the pars compact subdivision of the PPN, also facilitate afferent and efferent projection to the cerebral cortex, thalamus, basal ganglia, cerebellum and spinal cord (French & Muthusamy, 2018). Thus, contradicting Sherman et al. (2015) and his exclusion of cholinergic projections. Furthermore, deep brain stimulation in Parkinson’s disease to treat freezing of gait has found that both glutamatergic and cholinergic neurons play a defining role due to their contributions to the ascending and descending motor connections (Lin, Ridder & Sah, 2023).

The contribution of the MLR in locomotion are best outlined in animal-based research study by Opris et al. (2019) who achieved a working model of the MLR anatomical activation loop. The proposed mode outlines that simulation awakens the PPN and cuneiform within the MSL, before information is transferred to target neurons in the midbrain, pons and medulla, which are the periaqueductal grey, glutamatergic reticulospinal neurons in the medial reticular formation and noradrenergic nuclei of the locus coeruleus, subceruleus to the serotonergic nuclei. Information travels to the spinal cord where glutamate, serotonin, acetylcholine, GABA, and noradrenaline are each used as transmitters to relay information to process and initiate motor movement. Information then travels back to the MLR to complete a loop cycle. Electroneurogram (ENG) recording of peripheral nerves during stimulation support the MLR loop, as activation of nerves were found in the right and left, biceps, triceps, sartorius and semimembranosus biceps (Opris et al., 2019). This study provides evidence of the MLR, particularly the PPN being a central hub and glutamatergic and cholinergic neurons facilitating information transfer. Moreover, this study provides evidence that in addition to the PPN the Cuneiform nucleus is involved in the generation of locomotion via signal patterns sent to the spinal cord (Xiang et al., 2013). Moreover, this theoretical model introduces serotonin, GABA and noradrenaline as transmitters that facilitate information transfer during locomotion.

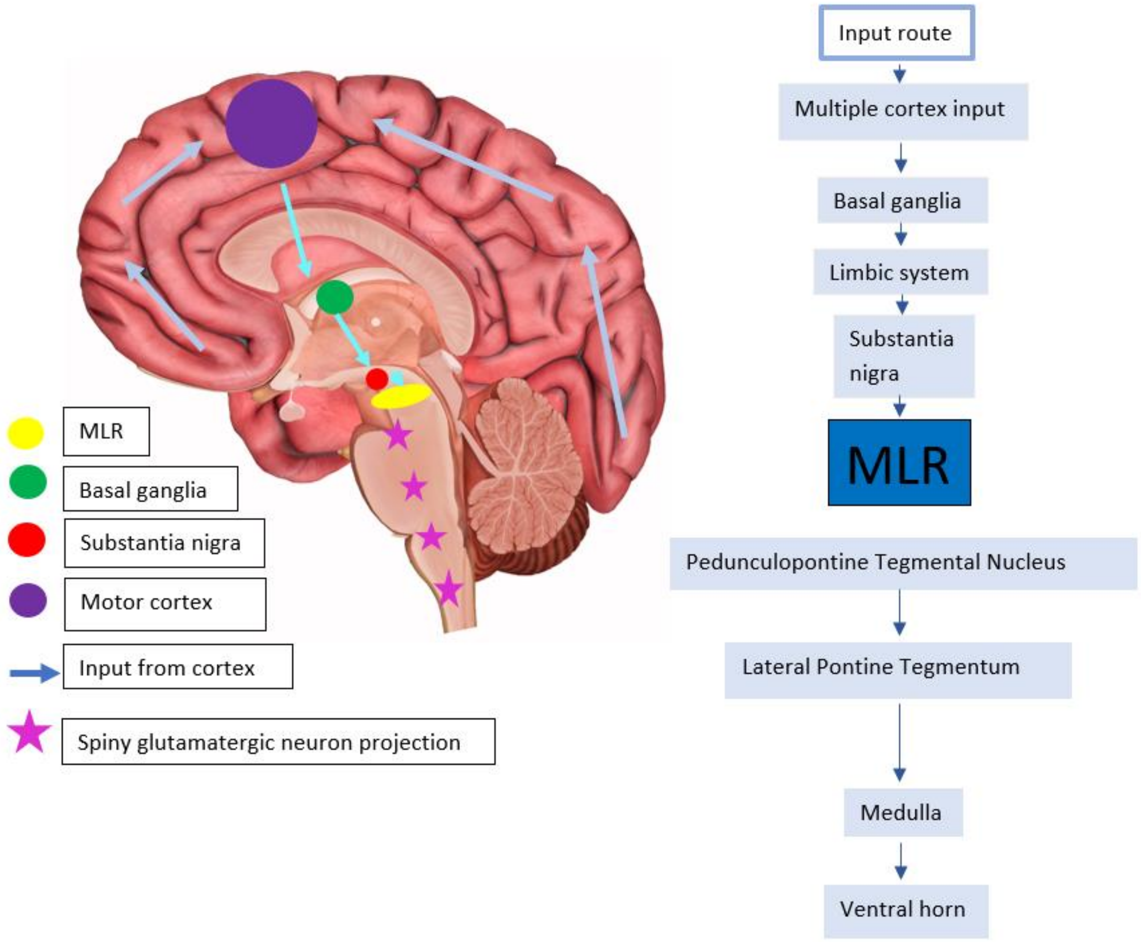


Figure 25 Image taken from Richards (2020 unpublished). connection and projections of the MLR.

5.3.3 The Subthalamic Locomotory Region

The Subthalamic Locomotor Region (SLR) (See Figure 26), forms part of the diencephalon, which along with the thalamus, hypothalamus and epithalamus are situated, either side of the third ventricle, part of fluid filled chambers that are interconnected, and produce cerebrospinal fluid (Prasad & Waller-Mackenzie, 2024). Knowledge of the SLR in movement derives in the most part from animal research models, which suggest that stimulation of the SLR is capable of evoking locomotion (Takakusaki, 2017). Stimulation of this region is not extremely common in humans, however, human research supporting the SLR in movement and gait derives from the link between the SLR and pathophysiology of Huntington’s and Parkinson disease and the associated movement perturbations (Emmi, Antonini, Macchi, Porzionato & DeCaro, 2020).

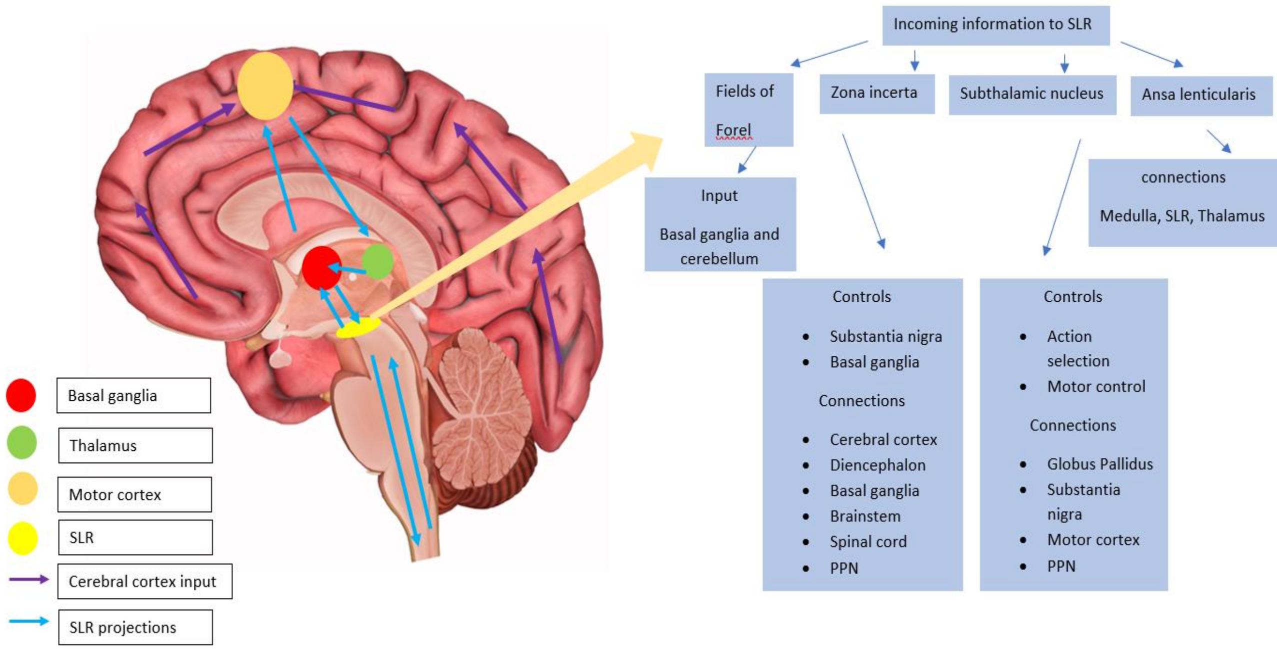


Figure26 Image taken from Richards (2020 unpublished). connection and projections of the SLR.

5.3.4 The Cerebellum

The cerebellum (See figure 27) is the largest part of the hind brain, located in the posterior cranial fossa, behind the fourth ventricle, Pons, and Medulla oblongata (Jimsheleishvili & Dididze, 2023). The cerebellum structure is separated from the main cerebrum by the tentorium cerebella and comprised of two hemispheres joined by the vermis (Jimsheleishvili et al., 2023). Approximately 1mm thick (Van Essen, 2018) and receiving blood supply from the superior, anterior, and posterior arteries, the cerebellum is folded repeatedly on itself, with each fold consisting of a grey matter surround, with white matter making the inner core. Each fold is subdivided into 3 further layers: The molecular level comprising of the external area, The Purkinje layer at the centre and the granular (Van Essen et al., 2018). The most interesting subdivision is the Purkinje layer and its associated cells.

Purkinje cells are a class of cells called large Golgi type 1 (Yang & Lisberger, 2014), with the benefits including: long dendrites & axons, synaptic connections to granular levels and climbing mossy fibres that use glutamate to transmit excitatory information away from the cerebellum, into the cortex via thousands of fibres and branches (Yang & Lisberger, 2014). Motor function in the cerebellum is achieved via the vermis, and influences the shoulder, neck, hips, abdomen, with dorsal muscles controlled by the intermediate cerebella zone (Manto et al., 2012). Manto et al. (2012) further suggest that the lateral area of each cerebellar hemispheres facilitate sequential full body movement and conscious processing over movement. Movement further relies on the nerves that connect the cerebellum to the brain stem and spinal cord, which are made up of 3 fibres called peduncles, that use efferent and afferent fibres to transmit information.

The most recognised connection between the cerebellum and the cerebrum is the direct link to the motor cortex via the cortico-cerebella loop used for motor planning (Gao et al., 2018). The motor cortex sends information to the cerebellum, before the cerebellum incorporates information about body position, balance and orientation before sending information back to the motor cortex in a loop. The connection between the cerebellum and motor cortex have been explored in multiple research fields, particularly via the work of Daskalakis and their research team. For example, in a Transcranial Magnetic Stimulation (TMS) study, Daskalakis et al. (2004) explored the inhibitory and excitatory pathways of the cortico-cerebella loop. Stimulation to the cerebellum showed afferent projections to the motor cortex, where the cerebellum can produce excitatory influence over the motor cortex or inhibit neurons from passing information. It is also, in part, thought to be linked to the role the cerebellum has on plasticity in the motor cortex. In particular, the cerebellum can influence topographic specificity over the motor cortex, due to modulation of peripheral sensory afferents (Popa et al., 2013, Kishore, Meunier & Popa, 2014). The notion of a distinct cortico-cerebella loop has been challenged however, for a lack of anatomical inclusivity. Kelly & Strict (2003) believed additional areas of the brain were used within this loop, as such used trans neuronal transport methods in the form of neurotrophic viruses to understand such circuity. Neurotrophic injections were administered in the primary motor cortex and Broadmann area 46. Tracking of the projections showed the primary motor cortex received input from Purkinje cells, originating in lobules 1v-v1, with Broadman area receiving input form Purkinje cells found in the crus 11 of the anisform lobule in the greater cerebella hemisphere (Kelly & Strict, 2003). Moreover, it was found that there was also direct projection to the pons. Thus, suggesting the cortico-cerebella loop is far more complex that originally believed.

Current knowledge as to the role the cerebellum has over movement and gait is also gain via clinical presentations. For example, hypotonia, ataxia, dysdiadochokinesia and Vermis syndrome, each present with alteration to how the movement of the body is produced or hindered. Ataxia of the cerebellum is the most known, which can produce alterations to the walking and sitting balance, limb co-ordination and eye movement (NHS, 2023). Moreover, individuals with ataxia may develop tremors and lack of sensory capability (KenHub, 2023). Finally, the cerebellum also presents clinically via ocular changes, in the form of nystagmus. Ocular changes are one of many sensory changes associated with cerebellar changes. Additional sensory input from the vestibular system also influences movement. When the brain hears a sound, the persons head turns to attend to the incoming sensory information. The vestibular system detects the head movement and signal the cerebellum to target the eyes to counteract the movement of the head. The cerebellum calibrates the movement allowing the person to maintain balance and stability (Therrien & Bastian, 2019). Presenting research provides evidence that the cerebellum, is highly influential in movement and gait. The cerebellum regulates muscles, co-ordinates movement and implements millisecond changes that allow and individual to constantly adapt to the ever-changing environment.

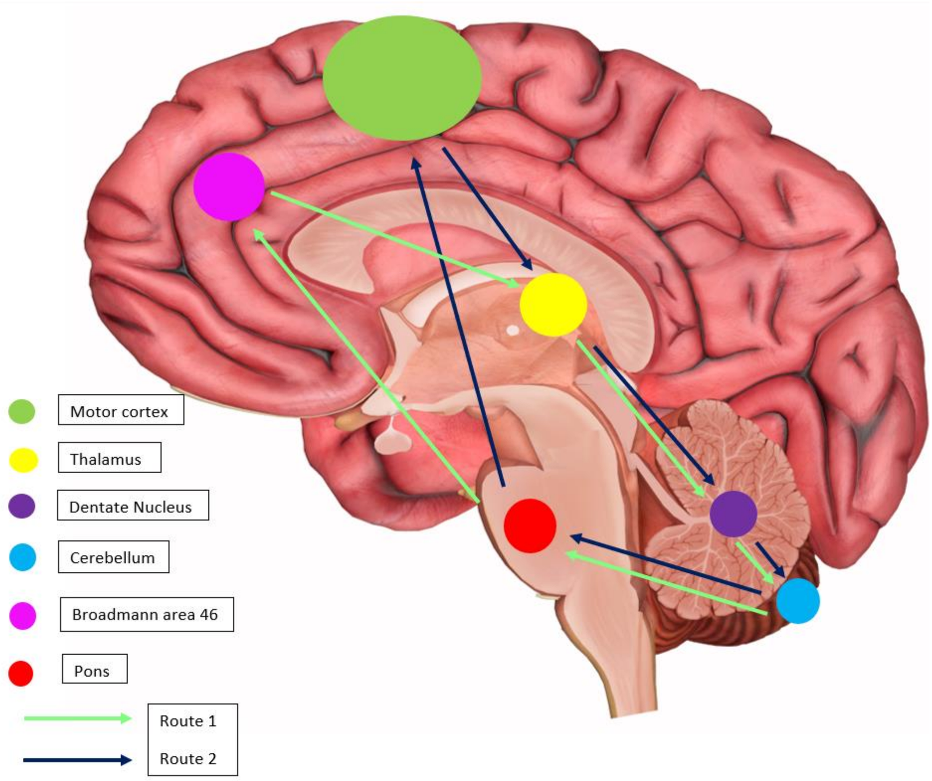


Figure 87 Image taken from Richards (2020 unpublished). connection and projections of the Cerebellum.

5.3.5 Basal Ganglia

The basal ganglia (See figure 28) are a group of subcortical structures, comprising of five pairs of nuclei: The caudate nucleus, Putamen, Globus pallidus, subthalamic nucleus and substantia nigra. Together they form part of the extra pyramidal motor system, working in tandem with the pyramidal and limbic system (Ken Hub, 2023). Connections of the basal ganglia consist of two major pathways: efferent (output) and afferent (input). The afferent projections derive from several regions. Firstly, the cortical striatal pathway forms the entire cortex and merge at the basal ganglia, with this pathway being glutamatergic. Next, the substantia nigra brings supplies of dopamine to promote regulation and efficiency. Furthermore, the Thalamo-striatal connection regulates learning processes, particularly in the form of motor learning, via glutamatergic excitability (Kato, Nishizawa & Kobayashi, 2021). A final proposed afferent connection is from the reticular formation, via nonadrenal transmission. This maintains vital function and modulation and regulation of voluntary movement (Dietrichs, 2008). The afferent and efferent connections explain the input and output functionality and connectivity, however, in terms of functionality, there are 4 categories. The basal ganglia are split into input (afferent) and output (efferent), connecting nucleus and modulatory nucleus (KenHub, 2023). The pathways that the cerebellum uses to initiate movement required 3 specific routes, direct, indirect, and hyper direct to send information to multiple anatomical regions, using multiple neurotransmitters both excitatory and inhibitory. This remains beyond the scope of this thesis, however, for a full overview see Purves et al. (2001).

The functionality of the basal ganglia has direct influence over reward (Larry, Zur & Joshua, 2023) executive function and cognition (Lanciego et al., 2021) with modulatory and information influence over emotion and memory (yang et al., 2023). However, primarily the basal ganglia are responsible for movement control and other motor function such as motor flexibility, gait control, posture, execution of motor plans and somatosensory integration (Visser & Bloem, 2005). Furthermore, evidence suggests the basal nuclei use proprioceptive feedback to compare movement patterns generated in the cerebella cortex, with actual movement (KenHub, 2023), which allows for constant and efficient adaption to motor needs.

Clinical presentation of basal ganglia atrophy provide direct evidence of how the basal ganglia influences movement, particularly in clinical presentations of conditions such as Parkinsons, dystonia, brady kinesia, Hemiballismus and tremor. However, basal ganglia changes during the natural ageing process are further providing some exciting research to justify the role of the basal ganglia and motor movement. For example, Karim et al. (2020) examined basal ganglia connectivity and gait speed in older adults. 269 older adults were assessed for gait speed via a stop watch and fMRI used to track brain activation. Linear regression of data found older adults who had low connectivity in the basal ganglia had reduced gait speed.

A cross sectional study evaluating motor performance in older adults with enlarged perivascular spaces in the basal ganglia (BG-EPVS) by Yang et al. (2022) further provides evidence of the basal ganglia and movement in older adults. 292 participants (99 BG-EPVS, 193 control) had motor performance assessed via gait analysis, Tinetti test, up and go test and the short physical performance battery. Correlation and regression analysis was used to investigate the influence BG-EPVS has over gait. Results found, those with BD-EPVS had reduced speed, cadence, shorter stride length and lower Tinetti scores. Given 3% of the older adult's population are predicted to have enlarged perivascular spaces, particularly in the basal ganglia (Rudie, Rauschecker, Nabavizadeh & Molian, 2018), and around 1 billion older adults globally, this suggests that currently, 30 million older adults are at increased risk of motor change due to small changes in the basal ganglia. This provides direct evidence of anatomical changes that could be a leading cause of slips trips and falls in older adults.

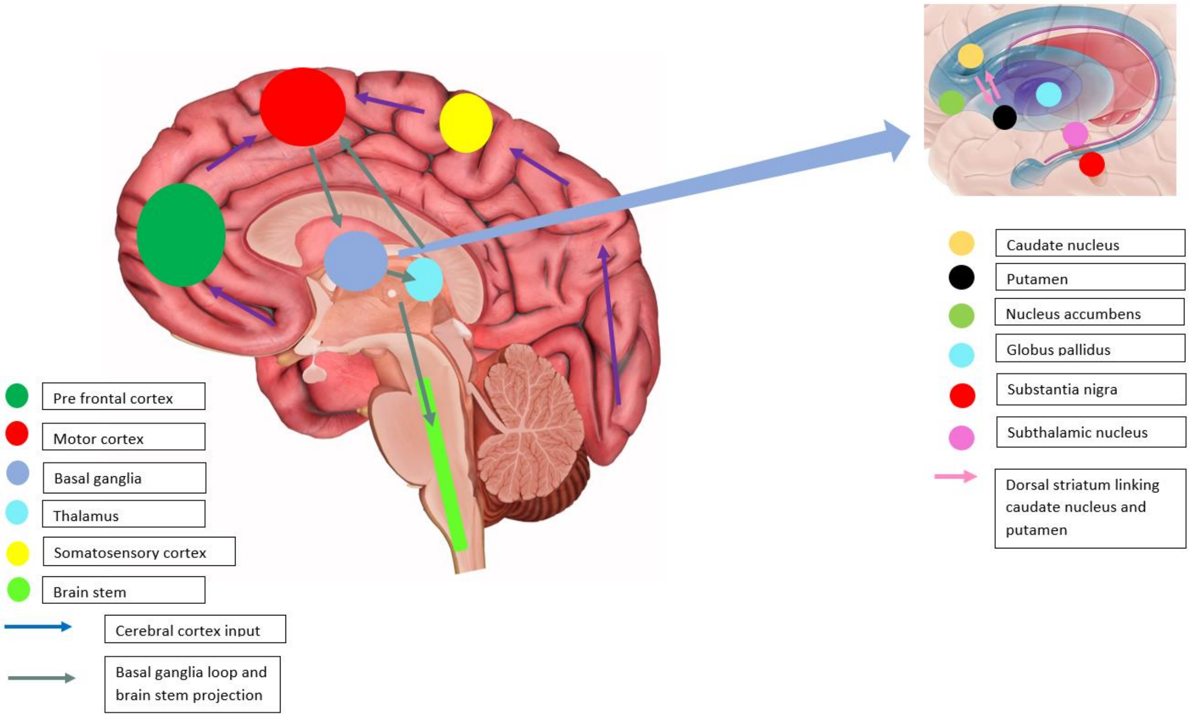


Figure 28 Image taken from Richards (2020 unpublished). connection and projections of the Basal Ganglia.

5.3.6 The Pons

The final anatomical feature of the brain that aids movement and gait is the Pons (See figure 29). The pons is a component of the brainstem, between the midbrain (rostral) and the medulla oblongata (caudal), anterior to the cerebellum. (KenHub, 2023). The Pons houses multiple nuclei that facilitate different roles in the body. The major nuclei being the cranial nerve nuclei, pontine nuclei, solitary nucleus of the lateral lemniscus, nuclei of reticular formation, pedunculopontine nucleus, laterodorsal tegmental nucleus and locus coeruleus. It is beyond the scope of this thesis to go into detail of such nuclei, however, functionally, these nuclei are important for features such as perception, sensation, movement, auditory and visual response, attention, and gait modulation (KenHub, 2023). Interestingly, if we revise the research previously outlined in this thesis, there are notable connection. For example, the lateral lemniscus is a major anatomical feature of the ascending pathways of sound to the auditory cortex, holding tonotopic organisation. Similarly, the pedunculopontine nucleus has been noted by Pahapill et al. (2000) who suggests glutamatergic PPN neurons play a role in the initiation of movement, with cholinergic PPN neurons needed for a steady and maintained locomotion, thus building a picture of how each anatomical feature that facilitates gait, either through direct motor region links of vestibular are connected. The pons hold two major tracts, namely the medial longitudinal fasciculus and central tegmental that house both ascending and descending fibre tracts to the associated nuclei of the pons. Such tracts act as pathways, connections, and act as a central hub for information distribution to other major areas of the cerebellum and cerebral cortex.

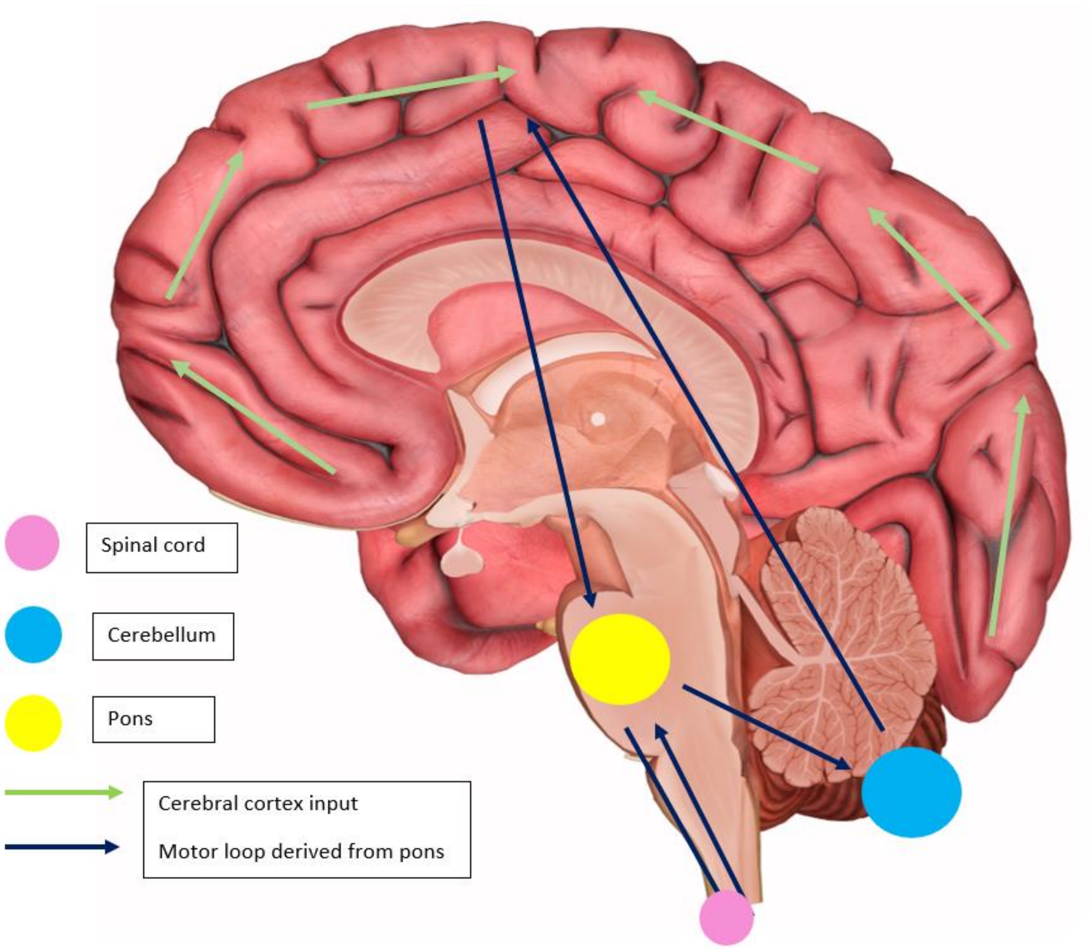


Figure 29 Image taken from Richards (2020 unpublished). connection and projections of the Pons.

5.3.7 Overview of sub-section

This section has provided evidence of the key anatomical features that organise, facilitate and initiate movement and gait. The key anatomical features, whilst autonomous, work as a streamline, interconnected hub, to produce accurate and efficient movement that can alter rapidly, in sync with environmental changes. This information is important to this thesis as the anatomical regions set out do not perform as a singular system, rather interact with multiple cognitive systems we are looking at, including attention, perception, memory and sensory.

5.4 The influence of sensory integration on movement and gait in older adults

The neuroanatomy described so far has specifically focused on regions of the brain that facilitate movement and gait. However, interacting with and moving around the environment requires constant sensory information processing, monitoring and attention and responses, for an individual to be able to interpret and interact with the environment automatically, efficiently and appropriately. Monitoring and attending to the environment are achieved via attention control, as noted in previous chapters and this is integrated also with sensory input (e.g., sound, visual, olfactory, touch), in the form of sensory motor control, where the motor system and sensory systems work synergistically and attentional control. Sensory motor control, is an integrative process, grouping thousands of pieces of sensory information form the periphery, processed by networks and connections hubs, to facilitate muscle activation and co-ordinated movement (Williams & Amendola, 2006), via information about body position, external environment, and perceptual anticipation (Wolpert et al., 1998). For example, when you grasp a cup, the sensory system must transmit information about its location to the retina, before being transformed into motor commands to grasp the cup (Ingram & Wolpert, 2011). Similarly, sensory information must transfer information about size, weight and temperature of the cup, in order to achieve precise grasping.

5.4.1 Visual environment

Research investigating sensory integration and gait has long been researched in the field of vision, particularly via using visual cues such as marks on the floor or visual cues to improve gait patterns in diseases such as Parkinson’s (Azulay, Mesure & Blin, 2006). For example, Vitorio et al. (2014), examined the role of visual cues on gait improvement in Parkinson’s disease.

Nineteen individuals with Parkinsons and fifteen healthy controls took park in four conditions of walking with gaze, gait parameters and accuracy of foot placement recorded. Results found, when visual cues were put in place, individuals with Parkinsons improved their gait. Similarly, a study by Bagley et al. (1991) investigating visual cues of gait parameters in individuals with Parkinson's disease, found similar results. 10 individuals were required to walk three times, over customised distances, with bright coloured triangular rods placed along the walk way. Walking with the visual cues decreased double support time, with increased stride length. This was further supported by Sidaway et al. (2006) who found that visual cuing training improved gait speed and step length. Thus, evidence presented seems to suggest that individuals who have gait perturbation may be capable to improving their performance, via cueing. This may be similar with auditory cues, thus providing a long-term intervention to reduce risk of falls.

The influence of visual cueing on motor movement and gait is also a highly favourable technique to improve gait in older adults, particularly as older adults are at increased risk of falls due to intrinsic (functional decline, fear of falling) and extrinsic factors (Poor lighting, uneven surfaces) (Luo, Lu, Ahrentzen & Hu, 2021). For example, Luo et al. (2021) examined the impact of destination based visual cues on gait characteristics in older adults. Fifteen community dwelling older adults, were instructed to walk from their bed to the bathroom, under two lighting conditions. First with their normal night light and secondly with a led lighting strip. During the walking, motion patterns were recorded. Results found, when older adults walked with the led perceptual cue there was a decrease in walking time, which was additionally accompanied by smother trunk, less trunk jerking and larger acceleration. In a similar study by Sunny & Bhat (2017), looking at the effects of visual cue training on balance and walking in older adults, they found a significant marked improvement in balance and gait, when visual cues were given. Forty participants received balance training for 30 minutes before being split into two groups. One group as an experimental group receiving visual cueing and a second control group, with measure taken before and after balance and gait testing. As noted previously, significant marked improvement in balance and gait, when found in the group who received visual cues. Thus, providing evidence of the role of sensory integration to aid efficient and improved gait and balance.

Sensory integration however, is not always beneficial to gait and balance, particularly as visual information is able capture and divide attention, due to the drain on an already limited resource system, by redirecting attention away from a current task, which in this case is walking. Perturbation in gait due to visual processing requirement are particularly noted in comparative studies between older and younger adults. For example, Bock & Beurskens (2011), studies the effects of visual distractors on gait in older and younger people. Twenty-four participants (twelve old and twelve young), were asked to walk down a designated hallway, whilst foot proprioception was either perturbed by vibration or unperturbed. Moreover, at unpredicted intervals, individuals were asked to turn their head and perform a mental-rotation task. Results found, locomotion in younger adults was unaffected by the introduction of visual changes, however, older adults had a reduction in pace, through smaller movement angles and increased spatiotemporal variability (Bock & Beurskens, 2011). Support for such changes to gait due to visual input, are further confounded by research by Walsh & Snowball (2023) who examined the influence of cognitive and visual task effects on gaze behaviour and gait in younger and older adults. Twenty participants, walked for three minutes on a treadmill, at a preferred walking pace, under three conditions Single, cognitive, and visual dual task conditions. Gait was measured using accelerometery and gaze measured via eye trackers. Compared to younger adults, older adults had increased stride time variability and centre of mass motion complexity’s due to visual effects (Walsh & Snowball, 2023). Evidence outlined, provides evidence of how visual input can not only aid but hinder gait efficiency in older adults, which in turn may have a detrimental impact on the older adults in the form of slip, trips and falls, due to the inability to filter out irrelevant visual input.

5.4.2 Auditory environment

Sensory integration from visual information, can however be influenced by audition. Particularly, as sound is able to capture attention at a lower and faster threshold than other sensory modalities, dominating sensory attention, particularly vision which is suppressed (Hidaka & Ide, 2015). It is postulated that the auditory suppression effect on other sensory modalities, particularly visual perception typically occurs when sensory inputs are presented in a temporally and spatially consistent manner. Evidence to support the influence of auditory input on gait is noted in multiple research fields, including, rhythmic cueing in gait disturbances (Aidin, Engleman & Jankovic, 2015), effects of dual tasks on gait when walking to auditory cues (Hamacher, Hamacher, Herold & Schega, 2016), Gait modification in disease (Howe, Lovegreen, Cody, Ashton & Oldham, 2003) and the influence of auditory-motor coupling on gait dynamics (Hunt, McGrath & Stergiou, 2014). Research in this field does however favours two distinct research paths, firstly, audition is beneficial to gait as auditory cues can facilitate gait improvement, and second, auditory input produces a deficit in gait as it captures and divides attention away from walking, thus increasing probability of falls. The research in this chapter investigates whether environmental sounds will perturb gait, something not previously done.

The first pathway of auditory cueing to facilitate gait, is particularly favoured in clinical settings to improve gait in individuals with Parkinson`s, Multiple Sclerosis, and stroke. It is believed that human locomotion relies on an innate internal timing (Larsson, 2014) that keeps gait consistent. When an individual has limitation and changes to gait due to disease, this internal timing does not cease, rather it cannot be accessed due to the morphological brain changes associated with a disease. Thus, auditory cueing is used to access and reactivate motor connectivity in the brain. It is proposed by Ashoori et al. (2015) that the neurological schema of cued gait training follows a distinct path to modulate motor function. First, external cueing is given via auditory cues. Next the motor programmes in the SMA and cingulate motor area (CMA) pick up on the external auditory cueing and cue motor action, where individuals innately alter their pattern to match the beat (Ashoori et al, 2015). This change in gait patter to match a auditory cue, is capable of modulation of internal packing via sensory feedback, particularly via the spinocerebellar tract. Internal pacing modulation feeds into motor regions of the brain, namely the basal ganglia, SMA, and PMC, before feeding back into the motor programmes where the somatosensory feedback from auditory cueing can modulate the innate internal timing and help plan and predict efficient future cued motor tasks, including gait (Ashoori et al. 2015). The neural pathways of sensory motor changes to perturbed gait provide clear beneficial evidence of auditory input to facilitate gait and demonstrate the powerful effects of auditory cueing.

Auditory cueing, where a movement is synchronised to a sound, is a revolutionary way to improve gait in disease, clinical research and older adults, as it influences temporal parameters of gait. However, what is of interest to the current research study, is the potential for a second pathway of auditory input to produce a deficit in gait, as it captures and divide attention away from walking, thus increasing probability of falls, particularly in older adults. Moreover, pathophysiological changes with hearing and the vestibular system (e.g. hearing loss) can further exacerbate gait perturbations and reduce posture control (Basta, Borsellino, Anton & Ernst, 2023), thus again increasing risk of slips, trips and falls. The control audition has over gait, can produce variability in multiple gait measure, attention redirection. Finally, the introduction of a loud stimulus can increase the prevalence of a startle response, with the startle able to alter gait pattern initiation and sequence (Queralt, Vallis-Sole & Castellote, 2010).

The influence of noise, in any context, can have a devastating effect on balance and functional gait patterns and sequence, particularly with older adults being more vulnerable, with evidence suggesting noise creates and engagement of the attention networks to attend to the sound, not gait (Buyle et al., 2021). To determine the influence of sound on gait, previous research has favoured age comparison studies as they provide evidence of change over a life, where it is suggested, older adults will perform worse. To assess the degree to which gait can be affected by noise, Buyle et al. (2021), examined functional gait in silent compared noisy conditions. Hearing function and cognitive ability were additionally measured. Analysis revealed, significant differences between silent and noisy walking conditions. A positive correlation was found between increasing age and poorer gait performance, poorer hearing, and lower cognitive scores. Moreover, older individuals who performed worse during attention tasks, also had worse functional gait, but only during noisy conditions. Similarly, several studies have outlined that older adults need more resources to maintain stability and posture (Buyle et al., 2021), particularly with auditory dual tasking. For example, Kaipust, McGrath, Mukherjee & Stergiou, (2013) found auditory stimuli influence gait. Twenty-seven older adults and a matched young cohort, walked on a treadmill for 5 minutes, whilst listening to 4 auditory samples (white noise, chaotic rhythm, metronome, and no sound. Stride length, width and interval data were collected. Analysis determined that auditory sounds induced a significant increase in gait variability in older adults, but not young. Similarly, Springer et al. (2006), evaluated gait variability in response to three different auditory dual tasking conditions. Younger and older participants were split into two groups, fallers, and non-fallers, before having gait speed, swing time, and swing variability measured. Analysis found, dual tasking did not specifically affect gait variability in older or younger groups who are not at risk of falling, rather, dual tasking targets those who are already at risk of falling by destabilises the gait particularly in older adults via increased swing time. This is thought to be due to an increased drain on resources, that direct attention away from walking, towards the salient sounds.

Justification for the influence sound has over gait is further confounded and supported via the influence different types of noise have on gait variability. As outlined in chapter 3, distracting, repetitive and noisy sounds are considered more distracting than those of nature for example (Song, Baek, Kim & Song, 2023). Traffic sounds in particular have been shown to influence gait, particularly altering the speed of gait. For example, Franek et al. (2018) assessed the effect of traffic noise and relaxation sounds on pedestrian walking speed in younger adults. Participants walked an urban route for 1.8K, under three conditions; traffic noise, forest bird sound or no sound. Results found participants who walked listening to loud traffic noise had a significant acceleration to gait compared to other conditions. Of interest, walking during the relaxation condition (forest bird sound), saw a decrease in gait speed. These results suggest, different sound can have different influence upon attentional components and gait, this is of importance to the thesis as it is the sounds that are able to capture attention the most, are the sounds that we hypothesise are linked to falls in older adults. This notion is supported by Franek (2019, 2017, 2012), with each supporting paper presenting evidence that loud urban noises increase walking speed, as opposed to nature settings slowing speed.

Gait variability because of loud or unexpected noise, has been shown to influence gait variability and falls in older adults (Buyle et al., 2021), however little has researched environmental sound in older adults specifically like this study. However, what is increasing worrying is hearing loss, affecting approximately twelve million older adults in the UK (RNID, 2023). Those with hearing loss have increased struggles interacting with the environment, as loud noises muffled and quiet noises can be missed. Moreover, navigating the environmental can be challenging as greater resources are allocated to attention control, thus distracting individuals away from other functions such as walking. Some research in this field outlines that poor auditory acuity defined gait variability in older adults (Sakurai et al, 2021, Li et al, 2013). For example, Sakurai et al. (2021) tested the notion that poor auditory acuity increases gait variability. 107 older adults, were invited to take part in a gait study, walking for approximately 5m, on an electronic walkway. Hearing was measured prior to gait research via pure tone average (PTA). Multiple falls over the previous year were also tracked. Analysis found, approximately half of participants had hearing loss. Multiple regression found those who had reduced PTA had slower gait and stride length variability. Those who had hearing loss, are believed to have increased risk of fall due to stride length variability. Similarly, Li et al. (2013) found hearing loss was associate with slower speed. Moreover, Szeto et al. (2021) found that in older adults with hearing loss, there is increased variability of gait, particularly during the double limb support period of the gait sequence. This is particularly worrisome for research undertaking in this thesis as our participants are all older adults, which increases prevalence of auditory loss. Given the link between auditory acuity and gait, all participants in the research outlined in the results section, were given hearing tests. This will allow for a true correlation, if any, for the influence of environmental sounds on gait.

Examining the influence of hearing loss of walking ability has additionally been used as a predictor for walking difficulties and falls in later life. A lab based, longitudinal study by Viljanen et al. (2009) was created to establish if baseline walking measure could predict longitudinal changes to gait. 434 older participants were given a clinical audiometry test, and asked to walk for 2 kilometres, where multiple measures of gait were taken. Analysis of results found, those who had baseline hearing impairment have a slower walking speed, lower walking endurance and self-reported difficulties of endurance, compared to those with normal hearing. Follow up measures found those who have hearing problems are twice the risk of developing new waking difficulties. Thus, providing evidence that hearing acuity is a predictive factor for later problems with gait, thus increasing probability of slips trips and falls. Support for such theory is provided by Gopinath, McMahon, Burlutsky & Mitchell (2016) who found over a five-year period, patients with hearing handicaps had increased risk of falls. 63% increased risk in frailty and odds of falling over time (Kamil et al. 2015) and for every 10dB of hearing loss significant increase in falling (Lin, Ferrucci, 2012).

5.4.3 Sensory integration as a whole

Whilst it is beneficial to address visual and auditory as separate sensory commodities, interacting and walking around the everyday environment is not as simple, particularly as visual, and auditory stimuli relying on integration from both sensory systems, in tandem, to facilitate efficient interactions within the environment. For example, suteerawattananon, Morris, Etnyre, Jankovic & Protas (2004) studies the effects of visual and auditory cues on gait in individuals with Parkinson's. Patients were asked to walk under four conditions (silent, with visual cue, with auditory cue and both cues) on a 7-meter walkway. Study outcomes found that whilst auditory cues improved cadence and visual cues improved stride length, both cues together did not improve gait. Further research evaluating auditory and visual system working together has found that the combination of sound during walking influences gaze patterns. Hildebrandt & Canal-Bruland (2021) examined the effects of sound / no sound on gait, gaze and performance. Results revealed that when there is no auditory input there is a higher gaze stability and had a faciliatory effect on gait pattern. However, when auditory input was scrutinised, delayed auditory feedback, could create unstable gaze patterns, dysfunctional deviations in gait pattern and poor jumping performance (Hildebrandt & Canal-Bruland, 2021)

Interestingly, and in support of Hildebrandt et al. (2021) research paper by Vas, Rand, Fujan-Hansen, Mukherjee & Stergiou (2020) outline that visual cues are a better choice to improve gait and walking is dependent on vision requiring. This is of interest as the visual environment remains relatively stable (e.g., buildings, roads, walkway), whereas the auditory environment is extremely unpredictable. It is postulated that concurrent audiovisual information may impact the co-ordination of complex motor movement (Hildebrandt et al, 2021). As such, the research in this chapter, which will be presented shortly, used an environment that remained stable, free from unexpected visual stimuli, to remove visual confounds, to get a true picture of how environmental sounds may influence gait.

This section has provided key evidence as to the important role sensory information plays on the motor system. The sensory motor system reacts to and attends to the everchanging environment, to facilitate efficient and streamline motor organisation. Unfortunately, as with other variables that change with age, the sensory systems are vulnerable to degradation that influences gait, balance and movement, leading older adults to be at increased risk of falls. Whilst other studies have looked at such change via sounds in the context of falls, this thesis takes previous research further by implementing sounds that have been specifically categorised by older adults as distracting, specifically aimed at dividing attention away from gait. Moreover, external confounding variables (polypharmacy, hearing, cognition & balance) have been measured to provide the most detailed analysis possible. It is with hopes that by accounting for as many external confounds as possible, we will be able to collect a true measure of an individual's gait perturbation, or not, when listening to an array of environmental sounds.

5.5 Quantifying changes that influence balance and gait

To this point, this chapter has provided a detailed background of a normal gait cycle, the neuroanatomy and sensory integration that facilitate such movement. This allows for a full understanding of how gait is initiated and how changes over the course of ageing alter gait. Moreover, it helps explain why sounds, such as those used In the STAC test previously (see chapter 4) may influence gait, leading to increased risk of falls. However, the gait cycle is a delicate movement that is open to change and deviation away from what is defined as normal. Ageing in particularly, opens a new set of variables that can lead to gait perturbations that increase the risk of slips, trips and falls. Older adults are at increased risk of muscle and bone density loss (Colon et al 2018), older adults are more likely to move their body when orientating, thus increasing risk of falls (Di Fabio et al., 2002, Wu, 2001) visual changes (Lord, 2021) in addition to neurodegenerative changes (Zhang et al., 2021). Furthermore, older adults are at increased risk of disease, thus take multiple medication to alleviate illness and disease (Wilson et al., 2011). This section provides an overview of additional variables, like hearing as noted above, which influence gait and increase the risk of slips, trips and falls in older adults. The subsection that follows are important to understand in this thesis, as they provide context for such falls.

5.5.1 Weak muscles

Whilst the gait cycle is only made up of a limited number of phases, the tools needed to facilitate such movement require neuronal processing, perceptual observation, memory, and multiple muscles working together. One component of muscles that has shown to be extremely important during the gait cycle is muscle strength. Strong muscles facilitate the use of a singular or group of muscles to generate a force (Jacob et al., 2009), prevent an increase in the metabolic cost of walking (Esposito & Miller, 2018), allow a flexion and straightening of legs necessary for lifting feet of the ground (Coombs & Garbutt, 2002), facilitate forward motion (Lee, Lee & Kim, 2019), support and progress gait (Liu, Anderson, Schwartz & Delp, 2008), contribute to gait velocity (Mentiplay et al., 2019) and reduce impact force during the gait cycle (Liikavainio et al., 2007). Muscle strength also creates a back bone of stability and fluidity that keeps the gait cycle at a steady and dependable motion. However, as part of the natural ageing process, loss of skeletal muscle mass known as sarcopenia, is extremely common.

Sarcopenia is thought to be due to, in part, molecular mechanisms that alter muscle physiology. An in-depth paper by Wiedmer et al. (2021) put forward several mechanisms that are possible causes for muscle loss including, Hormone function (IGF-1 and insulin), muscle fibre composition, neuromuscular drive, Myo-satellite cell potential to differentiate and proliferate, inflammatory pathways and intracellular mechanisms in the processes of proteostasis (as noted in chapter 1) and mitochondrial function (Wiedmer et al., 2020). Harvard health suggest, Sarcopenia begins around 35 and accounts for approximately1-2% of muscle loss a year, until around the age of 60 where this can accelerate to approximately 3% a year. In terms of Weight, an average older adult who does not do regularly strength training is losing around 4-6 pound a decade (Harvard health, 2023). More worrying is the prediction that sarcopenia increase the risk of disability in older adults by around 1.5-4.6 % (Harvard health, 2023).

Whilst disorders such as Sarcopenia can to an extent be slowed with a programme of muscle conditioning, exercise and nutrition (Nascmento et al., 2019, DiFilippo et al., 2020), Sarcopenia is a common predictor of many adverse outcomes including, increased outcomes including social isolation (Merchant et al., 2020) slips, trips an falls (Landi et al., 2012) function decline (Bjorkman et al., 2019) and fractures (Paintin, Cooper & Dennison, 2018) all of which reduce the quality of a person's life, increase mortality and increase hospital admissions, treatment and care. For example, reviewing the link between muscle mass loss and falls in the older adults, Greco & Migliaccio (2019) found disorders such as sarcopenia are a leading factor of frailty syndrome, which encompasses a loss of daily function, increased risk of cardiovascular disease and balance and falls which raise the risk of mortality exponentially. Similarly, in a review of the association between sarcopenia and falls and fractures in older adults, Yeung et al. (2019) found overwhelming evidence that individuals with sarcopenia increases fall and fracture prevalence in older adults exponentially. This is further supported by Landi et al. (2012) who researched the influence of sarcopenia as a risk factor for falls over a 2-year period. Results of this study found at the end of the 2 years, those with sarcopenia were around three times more likely to fall during a follow up period, relative to those with no sarcopenia, irrelevant of age and gender (Landi et al., 2012). The research noted provides evidence of the growing concern between muscle loss (Sarcopenia) in older adults and the adverse health consequences, namely falls. However, what these papers do not note is a developing concern that disorders such as sarcopenia interact with other common ageing conditions such as osteoporosis, which further exacerbate the prevalence of falls in older adults.

A growing consensus amongst clinical research trials and medical staff is the newly described osteosarcopenia, describing the co-existence of osteoporosis and sarcopenia, with osteoporosis a systematic impairment of bone mass and microarchitecture that result in fragility fractures (Rachner, Khosla & Hofbauer, 2011) and sarcopenia, as mentioned previously, a loss of skeletal muscle mass. The newly described osteosarcopenia is rapidly creating a population of older adults who are increasingly likely to have falls, fractures and are more prevalent due to osteoporosis changes and hospitalisation to recover from the devastating impact of this condition is increased (Paintin et al., 2018). In a review by Teng et al. (2021) analysing osteosarcopenia as a risk factor for fractures, mortality and falls in eight studies, encompassing 19,836 participants, results found, osteosarcopenia significantly increased risk of mortality, increased risk of falls and risk of fractures. Similarly, Kirk, Zanker & Duque (2020) found osteosarcopenia is not only associated with falls and fractures but a decrease in functional capacity and impaired balance, compared to those who do not have such condition. Interestingly, they found that osteosarcopenia is associated with poorer nutritional status, a coincidence noted in multiple research fields monitoring osteosarcopenia (Cvijetic, Keser & Boschiero, 2023, Chew et al., 2020, Atlihan, Kirk & Duque, 2021), suggesting more research is needed in this area, to understand the mechanisms and contributing factors that are leading to the development of sarcopenia and its associated conditions, namely osteosarcopenia, as the expected number of older adults living with this condition will grow exponentially, given the rise in older adult population numbers. Moreover, for individuals who are already at increased risk of falls due to sarcopenia, the introduction of sounds that are capable of dividing attention, increases risk of fall exponentially.

5.5.2 Visual impairment

Another leading theory of falls in older adults is the development of visual impairments. This can include, but not limited to, Losing the ability to see up close, changes to depth perception, distinguishing between colours, age related macular degeneration increased time in adjusting to levels of light, glaucoma, and cataracts (National Institute on Aging, 2023). In a large portion of older adults, vision changes associated with the natural ageing process can be corrected with interventions such as glasses, life style / environment factors. More complex eye conditions such as glaucoma and cataract require more invasive treatment. For example, Glaucoma a condition where the optic nerve, that connects the eye to the brain becomes damaged (NHS, 2023), requires the use of pharmaceuticals to reduce the build-up of pressure and/or laser treatment to reduce intraocular pressure. Similarly, Cataracts, a condition where the lens of the eye becomes cloudy, creating blurred or misty vision, requires surgical intervention. A cut is made into the eye to remove the lens, which then gets replaced with a clear plastic one (NHS, 2023). Irrespective of the form or level of visual impairment, changes to vision amongst older adults are a major health concern and can lead to physical handicap (Loh & Ogle, 2004) mental health changes (McLean, Guthrie, Mercer & Smith, 2014) social isolation (Coyle, Steinman & Chen, 2017) and an exponential rise in the incidents of slips trips and falls (Joseph, Kumar & Bagavandas, 2019, Osaba et al., 2019, Lin & Lee, 2019). Slips, trips and falls due to visual impairment are thought to be linked to an inability to plan, co-ordinate and adapt gait movement in response to the ever-changing environment (Hallemans et al, 2010), Depth perception changes due to conditions (Lord, 2021), balance impairment (Lord, Smith & Menant, 2010) and alterations to the vestibulo-ocular reflex where control over visual fixation is damaged.

5.5.3 neurodegenerative disease

Cognitive decline and neurodegenerative diseases have long been linked to falls in older adults. Pairing this with the role environmental sounds are believed to have on attention control, Individuals living with dementia are at increased risk of falls. Moreover, cognitive functions such as memory loss (Alzheimer's society, 2023) changes to orientation (Alzheimer's society, 2023), attentional control (Zhang et al., 2020) and disturbances in top-down control (Cohen & Verghese, 2019). Also thought to exacerbate gait dysfunction in dementia patients are changes to cognitive flexibility, judgement, inhibitory control, and an increase in risk-taking behaviour (Zhang et al., 2019). The characteristic changes associated with dementia are thought to lead to individuals being twice as likely to fall than individuals who are cognitively healthy, with increased rates of morbidity, mortality and serious injury and hospitalisation (Aizen, 2015). This is of relevance to this study as the population of participants are older adults. As such, cognition levels were measured via the MOCA test. This test will give an indication of participants who may have cognitive impairment and if there is a correlation between cognitive function and gait.

The leading biological cause of falls in dementia patients is the build-up of amyloid and tau proteins. Amyloid protein is a fibrous, insoluble aggregate that deposit plaques in the spaces between nerve cells in the brain and tau protein which creates neurofibrillary tangles that develop in nerve cells, and resulting in blocking of neuronal communication, which alters neuronal turn over, which cascades into neuronal dysfunction and cell death (Reifert, Hartung-Cranston & Feinstein, 2011). The leading hypothesis of amyloid and tau progressing through the brain follows a pattern. Some suggest a pattern starting in the entorhinal cortex, then spreading to the adjacent temporal and frontal parts of the brain, which others determine amyloid and tau spreading in.

5.5.4 Tullio phenomenon

Sound research also postulates that a rare condition called Tulio may induce falls in older adults. First noted in early 20th century by animal biologist Pietro Tullio following extensive experiments on the effects of drilling holes in the semi-circular canals of pigeons, the Tullio phenomenon is a rare response following exposure to auditory stimuli. The auditory stimuli is able to induce disequilibrium (unsteadiness), vertigo, nausea, loss of balance, gait instability and nystagmus which causes rapid and repetitive involuntary eye movement. Tullio typically causes eyes to move from side to side, although it should be noted eyes may move up and down, as well as in circular motions (Kaski et al 2012). Early research into Tullio in humans suggested that the loud noise invoked vertigo and balance changes were due to torsional eye movements and visual field tilting (Deecke, Mergner & Plester, 1981).

However, recent evidence suggest Tullio may be caused by trauma, such as post fenestration surgery (surgery to restore hearing), vestibulofibrosis (scarring between the stapes and the utricle or saccule), perilymph fistulas (tear in membrane between middle and inner ear) and superior canal dehiscence (opening in the bones covering the semi-circular canals) and via disease such as Meniere syndrome. Moreover, there is a small amount of research showing a congenital link, due to abnormalities of inner ear development (Kwee, 1976). The current consensus on the leading cause of Tullio, show favour for superior canal dehiscence.

Superior canal dehiscence is the result of abnormal thinning or incomplete closure between the upper most semi-circular canal which allows sound to emanate through and reverberate the brain inducing a movement of fluid (John Hopkins Medicine, 2023). If we were to imagine sound waves entering the inner ear through tiny holes, this abnormal influx or pumping of sound waves causes excitory endolymph fluid to stimulate hair cells, which facilitates transduction of sound waves into electrochemical impulses. The induced electrochemical impulses converted from the sound wave being pushed through, travel up to the brain and wrongly signals for the head to move, which gets misinterpreted by the brain as a head rotation. The brain then sends signals to the eyes, which compensate by rotating the opposite direction, inducing vertigo and nystagmus (Iversen et al., 2018, Balance & Dizziness Canada, 2023, John Hopkins Medical, 2023). Given vertigo and nystagmus are associated with increased balance instability, chronic dizziness, and gait instability, it may be beneficial in gait, balance, and hearing research to develop an array of questions that may be able to pick up characteristics of Tullio and associated syndromes, given the major implications such conditions can create.

Given the rarity of such condition and the links that it may have with gait perturbation, it is with direction of an audiologist that it may be beneficial to ask participants if they have been diagnosed or have symptoms associated with Tulio. This will be outlined in the results section. Participants were asked if they had a clinical diagnosis, or given rarity in diagnosis, participants were asked if they had experienced any symptoms similar to those of Tulio.

5.5.5 Polypharmacy

A further factor that may contribute to falls in older adults is medication. Specific medications, such as psychotropics (Bloch et al., 2010) blood pressure lowering medication (Fuller, 2000), sleeping medication (Nguyen &Watanabe, 2019) and anticonvulsants (Fuller, 2020), deliver side effects that can cause blurred vision, dizziness, low blood pressure, and impaired alertness, in addition to causing temporary or permanent damage to the ears that can influence balance and co-ordination (Harvard Health, 2023). It should be noted however, that it is not typically the individual drug that gait and balance abnormalities derive from, rather it is the volume of multiple drugs (polypharmacy) older adults take daily. Polypharmacy, defined as the use of multi (typically 4 or more) medications used at the same time by an individual, is common in older adults as with increase in age, there is a greater increase in multiple chronic conditions that typically emerge in complex states. The World Health Organisation note that increasing age is linked to hearing loss, osteoarthritis, COPD, diabetes, dementia, blood pressure changes and mental health change, all of which can on times be experience at the same time (WHO, 2023). Moreover, it is suggested that frailty, urine incontinence, falls, delirium and pressure ulcers are regularly a consequence of multiple conditions emerging during the natural ageing process (WHO, 2023). Given older adults are already at an increased risk of multiple chronic conditions, the use of poly pharmacy should be monitored.

There are growing concerns that the use of poly pharmacy with advancing age is leading to negative clinical consequences, that not only on times exacerbate conditions, but create risk factors that can be avoided via deprescribing (Hoel, Connolly & Takahashi, 2021). An alarming paper published by Maher, Hanlon & Hajjar (2014), laid bare the consequences of polypharmacy in relation to economic impact, health, cognition, and health wellbeing. The results of their research showed that polypharmacy had a significant effect on health care costs, adverse drug events, multi-drug interactions and toxicity, medical non-adherence due to complex medication regiments, urinary incontinence, increased risk of malnourishment, cognitive impairment, functional status diminishing and falls. The repercussions of such polypharmacy are not only increasing the risk for adverse reactions medically but impact morbidity and mortality in older adults, it is creating health problems that could be avoided completely.

The emerging link to gait abnormalities that increase the risk of falls in older adults is extremely worrisome given falls are already a common cause of injury, with around 30% older adults over 65 having a fall each year (Montero-Odasso et al., 2022). Introduction of deprescribing and monitoring polypharmacy may reduce the rate of falls, which will reduce the incidence of serious injury and alleviate the strain on hospital systems. Polypharmacy as an independent variable affecting falls has strong links to influencing falls risk (Hammond & Wilson et al., 2013), increased fall related fractures (Pan, Li, Chen, Su & Wang, 2014), Poor gait performance and gait decline (Montero-Odasso et al., 2019) and decreases in gait speed (Watanabe et al., 2021). Most worry, is a paper by Munson et al. (2016) who evaluated the pattern of prescription drug use before and after fragility fracture. Results found that in the months prior to hip, shoulder, and wrist fractures three quarters of the 168,133 patients were taking at least 1 known drug to influence falls. Post fall, a large group of patients were given further high-risk drug after fracture. The consensus among researchers citing this paper, as with the authors of this paper suggest fractures may be preventable through a concerted effort to manage high risk drugs (Munson et al., 2016) namely reduce the use of polypharmacy in older adults to alleviate falls risk. This is of importance to this thesis as if we are able to find a correlation between those who take polypharmacy and gait perturbation, it provides further evidence for the need of de-prescribing, where appropriate, to reduce the risk of falls.

Whilst the technicalities of why drugs increase the prevalence of falls goes beyond the scope of this thesis, I shall nevertheless explain in a somewhat limited manner why the mechanism of actions with hypertension medication as an example. Hyper tension (High blood pressure) with pressure exceeding 140/90mmHg, require the intervention of drugs to reduce the risk of developing associated conditions such as heart attacks and stroke (NHS, 2023). Most people need a combination of different medicine to control hypertension with Angiotensin-converting enzyme (ACE), Angiotensin-2 receptor blockers (ARBs) and calcium channel blockers the most common choice. Calcium channel blockers, which are typically used in older adults as opposed to angiotensin medication, work via preventing calcium from entering the ells of the heart and arteries. By blocking calcium, blood vessels relax and vasodilate, which in turn improved oxygen to the heart and reduces blood pressure (Drugs, 2023). Amlodipine, the most used calcium blocker in the UK, has reported side effects including, but not limited to: dizziness, palpitations, nausea, muscle weakness (Drugs, 2023).

The strong link between polypharmacy and falls in elderly was a variable that was measured in the study outlined below. It was important to understand if the participants in the study took any medication as not knowing would introduce confounds to our data and not provide a true representation of our results. Moreover, the questionnaire used in this study specifically asks what medication the participants take. By understanding the mediation used, it will allow this research to be linked to previous research in this field or even contradict it.

5.5.6 Common changes during ageing and link to falls

Study	**Common causes of falls in older adults**
Appeadu & Bordoni (2023)	Sarcopenia, cognitive impairment, declining cardiovascular, obesity, osteoporosis, motor instability
Pasquetti, P, Apicella, L, & Mangone, G. (2014)	Sight & hearing loss, Musculoskeletal, CNS
Xing et al., (2023)	Falls caused by balance disorders, including musculoskeletal system, the central nervous system and sensory system
Osaba et al., (2019)	Elderly adults are particularly dependent on vision to maintain postural stability. Distinct changes in spatiotemporal gait parameters are associated with aging, such as slower gait and increased gait variability, which are amplified with exposure to visual perturbations. Increased gait variability, specifically with mediolateral perturbations, poses a particular challenge for elderly adults and is linked to increased falls risk
Kenny, Romero-Ortuno & Kumar (2017)	Muscle weakness, balance & gait disorders, environmental hazards
Dionyssiotis (2012)	History of falls, impaired mobility (e.g., gait) gender, lifestyle, medication, vascular disease, fear of falling.
British government (2021)	Muscle weakness, poor balance, visual impairment, polypharmacy, environmental hazards
Rubenstein, (2006)	Weakness, unsteady gait, confusion, medication
Vaishtya & Vaish (2020)	Impaired vision and hearing, reduction of proprioceptive and vibratory sensation, increased sway, altered gait & poor postural control.
Cebolla, Rodacki & Bento (2015)	Reduced lower limb strength, gait alterations, lower performance in balance tests

Table 6. Table providing leading causes of falls in older adults. No definitive list states where gait, as measured in this study falls. However, gait is a common theme amongst academic literature and government policies, as a leading cause of falls. This table represents key paper in this field. Note-musculoskeletal system is defined as an organ system allowing humans the ability to support and move the body. Secondary note, Sarcopenia is a condition linked to muscle mass loss.

5.5.7 Contributory environmental factors linked to falls

To this point the thesis have covered neuroanatomy, sensory integration, and medical based causes for balance and gait changes in older adults. However, the everyday landscape should be presented as a factor, regardless of the significance this paper finds

Research evaluating the role of the neighbourhood and village environments are quick to acknowledge the role that street level factors may contribute to walking perturbation and falls in older adults (Brookfield, Thompson & Scott, 2017, Curl et al., 2016, Fothergill, O`Driscoll, Hashemi, 2007). Factors such as uneven surfaces, broken pavement, inadequate lighting, wet surfaces, and obstructions are each though to increase the risk of environmental falls. For example, Curl et al. (2016) provides an in-depth overview of this topic via an audit checklist of outdoor fall risks. Twenty older adults (mean age 77), took part in a focus group interviews and a mean walking distance of 0.82 miles, with photos taken of the environment.. Furthermore, a final board or health practitioner took part in a workshop to aid the development of the fall’s checklist. The final checklist of environmental barriers for falls in older adults were found to include; change in floor level, path condition and smoothness, path material, obstructions, road crossing, street crossing, and weather. Thus, providing evidence of leading environmental causes of falls. The problem with environmental barriers such as those noted arise when individual perceptions of fall risk influence confidence and ability. Those who do not feel safe walking due to the outdoor environment are at increased risk of avoidance behaviour and social isolation (Brookfield et al., 2017).

5.5.8 Overview of section

In summarise this section, there are many contributing factors to falls in older adults. A factor that is still relatively unknown is the influence environmental sounds play on gait. Environmental sounds are complex, unexpected and interact with many physiological, biological, and mechanical properties we have as humans. By using the newly collected distraction rated environmental sounds from study 1, the study presented shortly will present new research that will, hopefully answer the question as to the influence of environmental sounds on gait.

5.6 Diagnostic tools for gait measurements.

Measuring gait has rapidly becoming a diagnostic tool for age-related diseases, due to its ability to inform, measure and track progression (Galna, Lord & Rochester, 2012). Wearable technology offers a rare ability to remotely monitor and track older adults in their homes, via innovations that signal alarms if abnormal gait data is received (Godfrey, 2017). Typical gait measurements can monitor symmetry, perturbation, foot pressure, stride length, adaptability, and cadence (Middleton & Fritz, 2013). The most common wearables for gait analysis encompass measurements from; foot step analysis, force and pressure measurements, 3-D motion analysis, muscle function measurements, accelerometers, and slow-motion video. The clinical and research measures of wearables combine validated observational and performance tests, where individuals can perform designated walking tests under observation. Accelerometers, are favoured for research as they are user friendly, less invasive (Jarchi et al., 2018), reliable to at least 83% sensitivity and 89% specificity (Aziz, Park, Mori & Rabinovitch, 2014) and easily transported between research labs. We favoured the use of a METAMOTIONS wearable device (MMS – 10-Axis IMU and Environment monitoring sensory) to collect real-time and continuous monitoring of motion and environmental sensor data.

Accelerometers are particularly good at measuring stride-to-stride fluctuations, regularity and symmetry of gait (Kobsar et al., 2014), with such measures regularly used in research with older adults. For example, Kobsar et al. (2014) evaluated age related differences in stride fluctuations, regularity, and symmetry of gait. Eighty-two participants (41 younger, 41 older) completed a ten-minute walk at a normal pace, whilst wearing a waist mounted accelerometer. Accelerometer telemetry outlined older adults displayed significantly grated step and stride time variability, and lower stride time, with less regularity and symmetry. Similarly, Moe-Nilssen & Helbostad (2005) measured acceleration variability in older adults (fit and frail). Sixty-five older adults (33 fit, 32 frail) were asked to perform a timed walk at different speeds ranging from slow to fast. Step width variability was measured from foot prints and truck acceleration measured via a triaxial accelerometer. Accelerometer telemetry provided evidence that older adults have greater variability in truck. This information is relevant to this research as it provides evidence of accelerometer reliability. Moreover, it provides evidence of possible changes to gait that we may experience with the older adults used in this study.

Of increasing interest is the use of accelerometers to predict falls in older adults which affect one in every three older adults (NHS, 2023). Detection of such falls is imperative as a leading consequence of falling is the “long lie” where individuals, post fall remain laying on the ground whilst waiting for help (Bourke, O`Brian & Lyons, 2007). A study by Bourke et al. (2007) examined the use of accelerometers as measure to detect such falls. Trunk and thigh longitudinal accelerometers readings were recorded during simulated falls (younger adults) and activities of daily living (older adults). Data collection from the accelerometer was analysed for signals, to detect the difference between falls and normal activity. Results found, peak value changes (increase or faster movement) could predict and discriminate the differences, with all fall detection and daily tasks accurately detected. Accelerometer data as collected here, provides evidence of accelerometers being a reliable tool that can be used long term to predict and alert a fall. This could decrease the “long lie”, get faster treatment to older adults should they fall and provide older adults with the opportunity to remain independent for longer periods. Moreover, if this study outlined below favourably argues that environmental sounds can influence the gait cycle, if provides evidence that interventions are needed to those at risk of falls quickly, particularly as environmental sounds are sounds that are in the everyday environment all day every day.

5.7 Gait research – Study 3

The aim of this study is to understand the degree to which environmental sounds may rapidly capture and re-direct attention away from gait, thus creating a perturbation to the gait cycle. Given research highly favours the onset of sound at 80dB (volume of sounds in this study) capable of create an auditory startle, will the same happen in this research. This would be notable via a rapid change in gait pattern, followed by a return to normal baseline walk. Gait measures will look at perturbation, stride-to-stride average, synchronisation, and acceleration post environmental sound onset. If there is a rapid change to gait at onset of the sound, it is highly probable this is related to the auditory startle effect. The objective is also to account for as many external confounds as possible (hearing, polypharmacy, Tulio, Tinetti test of balance and attention control (STAC), to provide clear evidence of individual gait patterns and understand if any of these measure correlate with those who may have gait perturbation. Moreover, it is important to understand if the distracting and unpleasant environmental sounds, taken from study 1 (Chapter3) and study 2 (Chapter 4) are capable of capturing and re-directing attention away from the walking task, thus inducing gait perturbation, in an environment where individuals must constantly monitor the surroundings they are walking in, as opposed to sitting Infront of a computer screen. The hypothesis is that environmental sounds used in this study, will perturb gait (stride-to-stride average, synchronisation, and acceleration) whilst walking. Moreover, given that the population of participants we are testing will have different lifestyle factors, health and cognitive function, there are expected to be individuals who stand out as being influenced by sound more than others. Moreover, what will make this different to other studies in the field is our additional measure (polypharmacy, Tinetti test, MOCA & hearing) which will allow for a greater view of how individual difference may play a defining role in environmental sounds and gait research. Finally, this study repeated the STAC test that was outlined in chapter 4. We have repeated this test, to see if attentional performance scores taken from STAC correlate on the day with individuals who may have significant gait perturbations.

5.8 Material and methods

5.8.1 Participants

Thirty-five participants (range 60 to 79; mean age =67.9, SD = 5.26, 13 male), were recruited from the School of Psychology`s older adults data base at Swansea University. All participants had normal or corrected-to-normal vision and hearing (e.g., hearing aids and glasses) and no self-reported history of neurological and/or psychiatric conditions. Participants were not high risk of falls, have poor mobility, balance issues or an aversion to loud noise. No clinical diagnosis of MCI or dementia. Participants all gave written informed consent prior to taking part in this study. This study was carried out with approval of the university ethics committee (School of Medicine, Swansea University). Retrospective assessment of history of falls was not undertaken as it was an exclusion criterion.

5.8.2 Design

This study used a within subject’s design, where participants were all exposed to every treatment and condition, in the same order (see Figure 30). The STAC test made use of a repeated measures design to evaluate the effectiveness of silence or environmental sounds on attentional performance.

5.8.3 Procedure

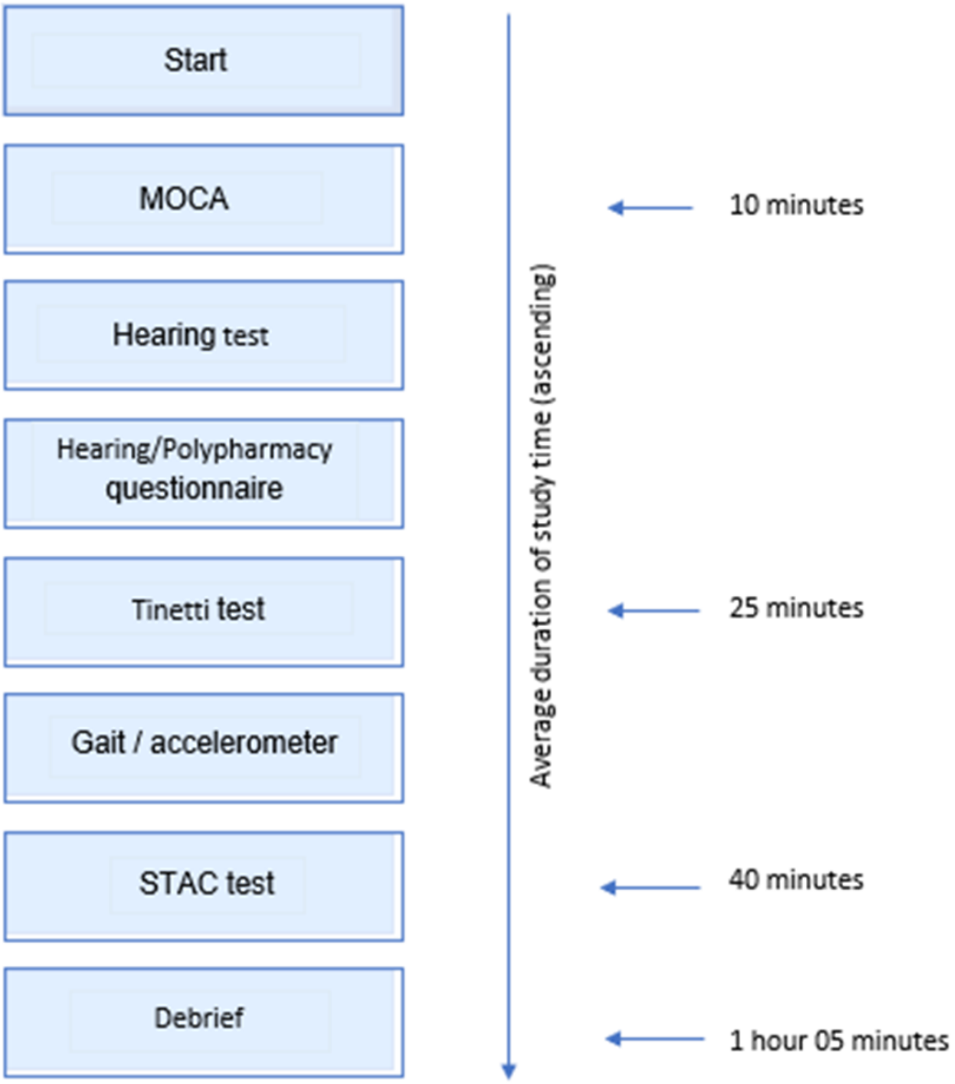


Figure 30 Task order with average duration of each test.

Participants who attended Swansea University campus to take part in this research, were met on campus by the lead researcher (Leanne Richards) and directed to the lab where the research would take place. Once participants were seated, they were re-presented with an information sheet that was sent to them via email, during initial conversational emails about taking part in this research. Participants were asked to re-read the information sheet and if they agreed to still take part, they were to sign and date a consent form. Participants were given an opportunity to ask question before they signed the consent form. Once participants had consented to take part in this research, it was explained that they would be taking part in 5 short assessments and completion of 1 questionnaire (See figure 9).

The MOCA was the first test to be administered, which lasts for a duration of approximately 10 minutes. During this test participants were required to complete a battery of test to assess language, memory, visual and spatial thinking etc (full outline of the MOCA in research design). Participants were told, this test was purely for research purposes and was not a diagnosis, if they feel they have changes to memory, this should be discussed with their practicing doctor. Next, participants were given a 3-minute hearing tests. During this test, participants were sat in front of a 17.3" HP envy laptop, which the test run off. Participants were required to wear over the ear head phones and asked to set the sound to a level that would be the same as if they were listening to an audio book. When the level was set, participants clicked on “start test”. During the test participants would hear 3 numbers through the head phones, which they had to type in. Once the three numbers were typed in, a new set of three numbers would be played, which again had to be typed in. During the test, the numbers that are presented get harder to hear as the level of sound gets quieter and blends into the background noise that is played with the sounds. When participants had completed the hearing test, the researcher removed the laptop and collects the headphones. Next, participants were presented with a questionnaire to collected data on possible hearing issues and medication that is taken daily.

The next assessment used was the Tinetti test. Split into 2 separate parts (balance and gait), participants first took part in the balance section. Participants were asked to complete a selection of movements to assess to what degree they have / can maintain balance. The second part of the test (walking), is collected by the researcher when the participants are walking, as data collection requires information about symmetry, foot clearance etc.

When participants have completed the balance section of the Tinetti test, they are informed that they would now be taking part in the walking aspect of the research. Participants are informed that they will be walking for approximately 5min 30sec. Before the participants are set up for the walking aspect of the study, they are shown the direction that they are required to walk (see figure 12). The route of walking is set out via bright yellow arrows, each approximately 12” long, with a gap between arrows set at approximately 3 feet. When participants are happy with the route they are walking, they are given an accelerometer and asked to attach it to their ankle. They are told the accelerometer should be fitted so that it will not come off, with the accelerometer facing upwards. Next the lead researcher connects overhead earphones to a mobile device that participants are required to carry. This mobile device is used to collect accelerometer data and play a selection of audio to the participant when they are walking. Once, the accelerometer is set up to collect data. participants are told to remain still until the audio file they will be played tells them to walk. Participants are handed the mobile device and the lead researcher starts the audio file. The audio file instructs the participants they are able to start walking after approximately 5 seconds. As noted in the design above, participants will walk through 5 stages. (silence, environmental noise, ascending beeps, environmental noise and silence). The full audio file plays for 6 minutes 3 seconds, however, participants are only walking for 5 min 30 sec. As participants are walking the route, the lead researcher (Leanne Richards), discretely collected data for the walking aspect of the Tinetti test, making sure to stay out of the participants way. When the test is complete, participants are to remain stationary, whilst the data is securely stored. Participants are then able to take off the head phones and accelerometer and sit back in their seat.

The final data collection of this research design, required participants to complete the STAC test, to understand if gait performance correlates with STAC test performance. Participants were then sat in front of a 17.3” HP envy laptop with NVIDIA graphics processing unit featuring accelerated output to device display. Once participants were comfortable, they were given instruction of how to perform the test and were given a practice run of the STAC (lasting approximately 3.2 minutes). Once the practice was over, participants had the opportunity to ask questions before taking part in the experimental runs. In a randomised order, participants were given the 2 STAC tests (sound (including nature background noise) / no sound), with approximately 4 minutes in between (sufficient time for any visual disturbances, as a result of the moving symbols to dissipate. After both experimental conditions were complete, participants were told that they had completed all the tests that were required during their participation. Participants were given a full debrief (verbal and written) of the study that they had taken part in, and asked if they had any questions. Once participants were happy, they were free to leave.

5.8.4 Test variable measures.

5.8.4.1 MOCA

The Montreal Cognitive Assessment (MOCA) is a highly validated and reliable test for early detection of mild cognitive impairment (See Appendix 5). The test takes approximately 10 minutes and allows for a quick and accurate assessment of cognitive functioning such as short-term memory (STM), visuospatial abilities, executive functioning, attention, concentration and working memory (WM), language and orientation to time and place. The MOCA is scored via a total of 30 points, with a score of ≥ 26 falling within health parameters. Individuals who have an education background of ≤ 12 years have 1 point added to the score. The MOCA 8.1 English was used for testing. The lead researcher (Leanne Richards) is trained and certified to administer the test. This test is being administered to understand if any of the participants have clinical symptoms of cognitive decline, as research suggests that older adults who have cognitive decline are at increased risk of falls.

5.8.4.2 Hearing test

This study made use of the Royal National Institute for Deaf People (RNID), free hearing test. This test is designed for the use of individuals who are aged 18 or over and have not been diagnosed with hearing loss. The tests work by monitoring how well the individual can hear speech when there is background noise (RNID, 2023). Individuals are required to wear over the ear head phones and asked to set the sound to a level that would be the same as if they were listening to an audio book, in accordance with RNID instructions. When the audio level is set, the test starts by pressing “Start the check.” During the test participants hear 3 numbers through the head phones, which they had to type in. Once the three numbers were typed in, a new set of three numbers would be played, which again had to be typed in. During the test, the numbers that are presented get harder to hear as the level of sound gets quieter and blends into the background noise that is played with the sounds. Completion of the test presents with a result of no hearing loss or evidence of some hearing loss.

5.8.4.3 Questionnaire

For this research, a questionnaire was developed by the lead research (Leanne Richards), to detect any possible confounding variable that may contribute to balance issue and falls in older adults (see appendix 6). The questionnaire encompasses two key variable domains; auditory functioning/abnormalities and polypharmacy, Hearing and ear factors were addressed via 7 questions (see below). Question 1-3, focus on collecting data on the Tullio phenomenon, an under acknowledged condition where sound induces vertigo, dizziness, nystagmus or oscillopsia. It was important to ask questions linked to Tullio for this study as it will provide possible correlations to those who may have gait abnormalities but also, provide links between the individuals hearing too, given the link between Tullio and ear conditions, namely, Superior canal dehiscence, perilymph fistula, Meiners syndrome, post fenestration surgery and vestibulofibrosis. The next section of the questionnaire (Q4-7) specifically focuses around diagnosis of hearing loss and medical conditions of the ears that may influence how the auditory system processes the sound that participants here during the study. Finally, we were interested in polypharmacy (Q8-12). Polypharmacy as noted previously in this paper, has a considerable influence over falls via medication influencing balance, altering blood pressure, and inducing dizziness. Gait may be altered via, stride length, step length and speed to name a few. The most common medication to influence gait are, anticonvulsants, cardiovascular, anti-anxiety, and opioid based pain medications. Participant scoring for this question was devised via a simple 1 point for yes and 0 points for no. Question 9 remains the only question scoring differently, with participants given 1 point for every medication taken. The higher the score, the increased risk of factors that can contribute to slips, trips and falls.

5.8.4.4 Tinetti test

The Tinetti test is a validated and reliable tool to assess the quality of an individual’s balance and gait, whilst providing a prediction rate for falls (see appendix 7). The Tinetti test is divided into 2 separate sections, with the scores combined at the end. Balance is scored out of a possible 16 points. The researcher observes the participant over a series of position and movements, with an additional observation taken to observe stationary balance. The balance section of the Tinetti test can provide an indication of where problems may lie for the individual. Gait is scored out of a possible 12. During the gait assessment, the research observes the participant for the quality of their gait and to what degree they can meet the assessment domains. The gait section of the Tinetti test provides possible reasons for why gait and balance may be altered in individuals. Given the population of participants used in this study, It is important to understand any balance abnormalities, that could increase risk of falls. Possible reasons for gait abnormalities found in the test may include, but not limited to, weakness in one or both legs, stability issues, weight shifting. Scoring of the Tinetti test is combining the scores of both balance and gait. The highest total score possible for the Tinetti test is 28. The total score represents the individual's risk of falls.

5.8.4.5 STAC test

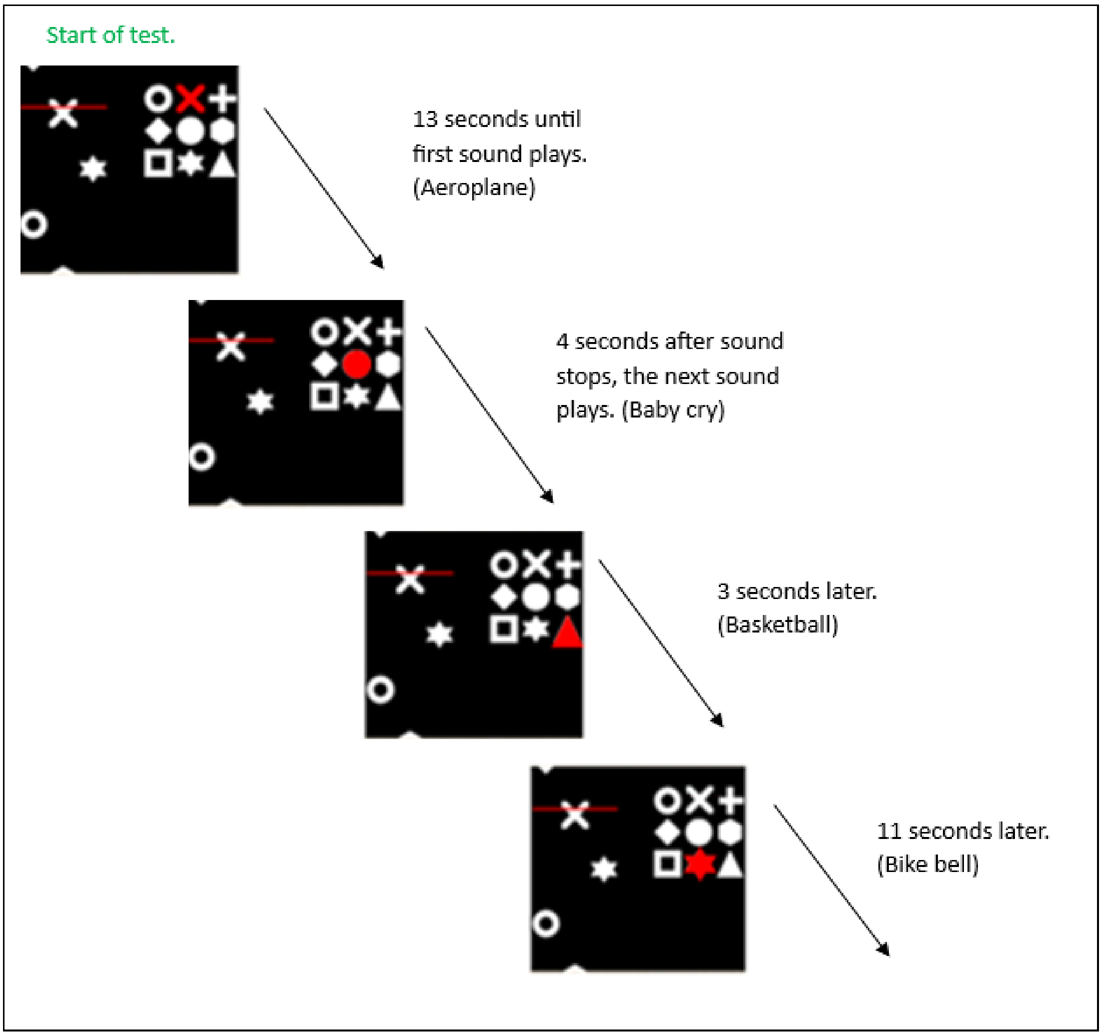


Figure 10 Example of the STAC test and the changing of symbols. Image created by author of this paper.

The Swansea Test of Attentional Control (STAC; Carter, N & Wood, R., unpublished) assesses task switching abilities, including selective attention, task monitoring and response inhibition (Hanley & Tales. 2019). In this attentional control task, the screen is divided into two distinct areas (see Figure 1). Participants are presented with a matrix of 9 distinctive symbols on the right-hand side of the screen. One of the symbols is highlighted red – this is the target. On the left, there is a column of moving symbols that scroll up the screen towards a red line. A modified Parameter Estimation by Sequential Testing (PEST) algorithm was used to adjust the speed of symbols.

During the task, the target symbol in the matrix changed every 10 seconds. This change to symbols is recognised by a new symbol being highlighted red. On the left side, the speed at which the symbols scroll up the screen will vary throughout. The participant was to press the space bar whenever they saw a symbol that matches the target reach the red line (Ideally, when the symbol is part-way through the red line). Participants were instructed not to repeatedly press the space bar for the same symbol.

A practice version to familiarise participants with the mechanics of the task was given to provide perspective on the potential speed increases. Total duration for practice was approximately 3.2 minutes. The main STAC test was broken up into two runs, of approximately 6 minute 48 seconds each (One featuring a selection of environmental sounds audio clips playing over the test, while the other was performed in silence). Sound clips used in this STAC test reach an approximate sound level of 80dB.

The sound index for STAC varies slightly to that of the accelerometer and gait data collection portion of this research. The audio index for the STAC-sound condition includes 30 sound files, known to be distracting and unpleasant based off of previous research by the lead researcher (See Chapter 3 & 4). In addition to the sounds being played at randomised times during the STAC programme, and additional background sound was played, from the start of the STAC through to the end, with no breaks, at a gentle, yet noticeable level. Based upon previous research, it was found that pure silence between sound clips was not representative of an everyday environment. As such, an introduction of nature/birds tweeting were played. The nature/bird sounds were chosen for several reasons; Firstly, they are heard in everyday environments. Secondly, it is not an over bearing sound, to the point of distraction and finally, it is a sound different to that of those played automatically during the STAC test.

The STAC test was administered in this study to understand how participant attention control performance on the day of testing. Moreover, the STAC was used as a correlation measure, to see if those who scored lower on STAC (less attention control) were at greater risk of perturbation.

5.9 STAC test analysis

When the STAC test is complete, data automatically gets saved into an excel folder. When all participants had taken part in this research, data was placed together in a new excel folder, where the mean and SD scores were calculated. SPSS was also used to run paired samples t-tests and a repeated measure ANOVA. As a note. The data failed to save for 1 participant, as such the STAC participant number is 34.

5.10 STAC test results

	Average speed (SPM)	**Final speed (SPM)**	**Hit rate (accuracy &)**
Sound	Mean = 60.7394 SD = 9.98	Mean = 55.1765 SD = 16.48	Mean = 71.1526 SD = 10.67
No sound	Mean = 60.3906 SD = 10.04	Mean = 54.6765 SD = 13.83	Mean = 71.8932 SD = 10.64

Table 9 representation of STAC test results in this study, per condition

Paired samples t-test were run to assess the degree of difference between sound and no sound conditions. No significance was found across each measure. A paired samples t-test assessing the difference between average speed over both conditions found no significance, t(33) = 0.223, p = .825. A paired samples t-test assessing the difference between final speed over both conditions found no significance, t(33) = 0.181, p = .858. A paired samples t-test assessing the difference between hit rate (accuracy) over both conditions found no significance t(33) = 1.031, p = .310.

To understand the degree to which gender may influence STAC, the table below provides an overview of difference.

	Male	**Female**
Average speed (SPM) - sound	60.52	60.85
Final speed (SPM) - sound	59.79	52.66
Hit rate (accuracy) - sound	74.23	69.49
Average speed (SPM) - silent	62.22	59.39
final speed (SPM) - silent	56.42	53.73
Hit rate (accuracy) - silent	74.65	70.39

Table 10 Gender difference across STAC test

To understand if there was any significance in this difference, a repeated measures (sound/no sound) ANOVA, with the between subject's factor gender was performed. No statistical significance was found between the main effect of gender on STAC conditions, F(1,32) = .582, p = .451

Although the STAC test was randomised (sound or no sound first) there is always a possibility of task order effect influencing results. To test if this happened with this data, participant data was split into sound and no sound conditions, as set out previously, with the additional variable measure of task order (did participants run test with sound first or silent first). A repeated measures ANOVA was administered to the data with the within-subjects factor sound or no sound and a between subject factor of task order. There was no significance in the data F(1,32) = .587, p = .449.

As less samples of data were collected than we originally proposed due to COVID-19 restrictions etc, post hoc power computations were performed. R and SPSS outcomes provide evidence that a sample size of 34 would hold statistical power. Furthermore, additional power formulas get a similar result of 32. The reason for the deviation (-2) derives from the power calculator requiring an estimate for sigma d.

5.11 Walking section outline and results

5.11.1 Accelerometer

This study made use of the METAMOTIONS wearable device that allows for real-time and continuous monitoring of motion and environmental sensor data, via a 10-axis IMU. METAMOTIONS is light weight (0.2oz) and approximately 27mm x 27mm x 4mm in the protective case, with a 70-100mAH micro-ISB rechargeable battery. Capable of memory up to 100M data entries, with all data time stamped for synchronisation purposes. Data is transferred via Bluetooth low energy smart v.5.0. and programmable in multiple platforms including C++, Java, and Python. The accelerometer has a range of ±2 - ±16, 16-bit resolution and sample rate of 0.001Hz – 100Hz stream – 800Hz log. This device provides detailed and continuous data of participants gait during the whole walking period.

To remove the risk of type one errors, the accelerometer was calibrated to collect mainly acceleration data. The acceleration data will however additionally allow for data analysis to view synchronicity and degree of perturbation

5.11.2 Sound file

To allow cohesive and accurate gait data, the sound file used during the walking study (see figure 31) was synchronised with the accelerometer and played to participants via a Samsung galaxy mobile phone, with noise cancelling, over the ear headphones plugged in to the aux port. volume was set at a designated volume to remove any confounds and bias. The sound file was broken up into five distinct sections, to provide a detailed overview of participant gait patterns (i.e. stride-to-stride average, synchronicity & acceleration) during silence, environmental sound exposure and during a beep cycle. This will additionally provide an in-depth view of sound onset (i.e., environmental sounds), which we believe may have a startle like effect on gait. When the lead research (Leanne Richards) started the sound file, there was a five second delay before participants were told via the sound file to start walking. Participants first walked during a silent phase to collect a base line measure of participant gait profile. Next participants walked during a period where environmental sounds were played. Completion of the first environmental sound walking phase, was completed via auditory direction from the sound file telling participants to stop walking. Approximately eight seconds later participants were told to start walking again. During this third phase, participants walking to a beep, where we are able to collect information on how participants can rapidly re-adjust to change in gait speed. The beep increased in speed for the first minute, to a rapid walk, before decreasing back to the slow beep that started this section. Once the beep test had finished, participants were instructed to stop walking. Approximately eight seconds later, participants were instructed to start walking. The fourth phase of the study required participants to walk in silence again, before the final phase of the study started. The final phase required participant to walk whilst listening to environmental sounds. After the environmental sounds stopped, participants were instructed to stop walking. At this point the lead research (Leanne Richards), walked over to the participants and stopped data recording.

Figure 31 Visual representation of the sound file used in this research. Image created by author of paper.

5.11.3 Sounds used

The sounds used in this study were a collection of the most distracting environmental sounds, as outlined in study 1. Additionally, we introduced five extra sounds that were not in the STAC test or deemed extremely distracting in study 1. The table below provides an overview of the sounds that were used in the sound file.

Sounds used in gait test
Airplane
Birds
Car crash
Car horn
Cuckoo clock
Dog barking
Jackhammer
Lawnmower
Mosquito
Motorcycle
Police siren
Scream
Sneeze
Telephone
Thunder
Wind
Wind chime

Table 11 Representation of sounds used in the sound file. Sounds not in bold are sounds that participants deemed extremely distracting in study 1 (confrontation naming of sounds). Sounds highlighted in bold represent sounds that were not deemed distracting, but used to see if subjective rating of sounds, provided a true representation of sounds that may capture and divide attention.

5.11.4 Walking route

Each participant walked the same route, spread out over two research labs (See figure 32). Yellow arrows were placed on the floor to provide consistence. Participants were asked to follow the arrows and not to stray away from the designated route. Each participant was given a walk-through of the route by the lead researcher (Leanne Richards) prior to the start of the task.

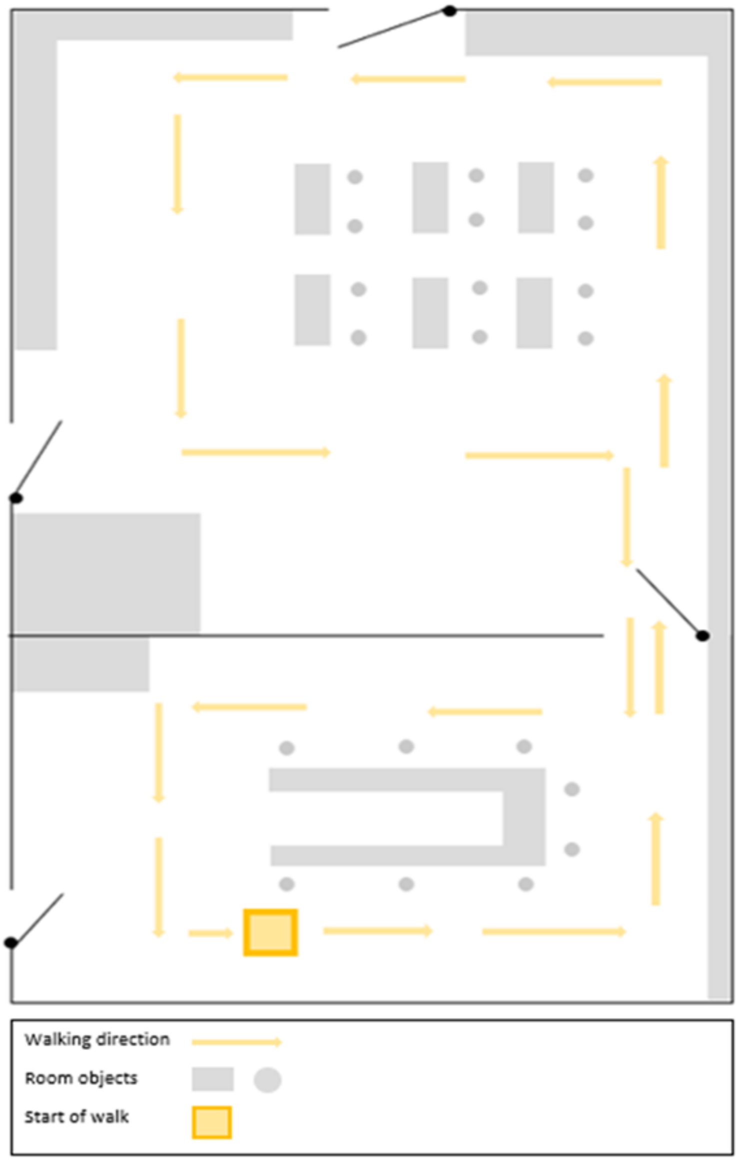


Figure 32 Visual representation of walking route used by participants. Image created by author of this paper.

5.12 Data analysis

5.12.1 Data collection

Data collection was achieved via multiple routes. (1) The MOCA test gets scored at the end of the test via adding up the score for each question. (2) The hearing test, give a hearing output at the end of the test. The result of the test is either no loss or indication of loss. (3) Questionnaire was score via a point system, where associating scores were added at the end of the test (4) Accelerometer data was collected via a METAMOTION device. At the end of each participant session, data was sent from the METAMOTION accelerometer, via Bluetooth, to a computer device ready to be prepared.

5.12.2 Data preparation

One aall data was collected, each measure was prepared for analysis. The MOCA, Hearing test and Questionnaire scores were placed into an excel spread sheet ready to be analysed in SPSS. Accelerometer data, was transferred into a large excel spread sheet that held multiple measures taken by the accelerometer during the walking task.

5.12.3 Data analysis

All data, with the exclusion of the accelerometer data, was processed in excel. Data was assigned mean and SD scores, and gender was pulled out of data also. All data measures were placed into SPSS where Pearsons correlations were run to quantify the strength of the association between each measure and gait (synchronicity and max perturbation).

Acceleration data was collected using MBientLabs M-motion sensors. Data was acquired at a rate of 50Hz in 3 orthogonal axes, with the sensors attached to the top of the participant’s shoe. All analysis was based on the radial acceleration axis – running from knee through to ankle.

Gait perturbation: A linear regression smoothing was used using a window corresponding to 3% of the trace lengths (equates to 11.66 seconds timespan). This provided a smoothed trace in which stride to stride variability is averaged out, leaving perturbation only due to long term changes in response to environmental cues. Perturbation is quoted as the fractional change from the baseline, i.e. 0 equates to zero change, 1 to a 100% modulation.

Gait frequency and variability: gait frequency was calculated from the fundamental peak with the spectrum obtained by FFT of the acceleration time signal. Gait variability was measured as the full-width half-maximum of the fundamental frequency peak

5.13 Results

5.13.1 Profiling baseline gait of participants

The frequency and stride-to-stride variability were measured for the first 25 seconds of the gait analysis during a silent walking phase. Stride-to-stride-average is the distance covered when you take two steps, one with each foot. Thus, the synchronisation measures the co-ordination of the stride, and max perturbation is measuring how perturbed (disrupted) the stride is, in response to the sound.

The plot graph below highlights the walkers gait characteristics (slow/fast) as well as those that have pronounced variability in stride. As expected, there is a high degree of variation between participants, with only participant 1 and 9 having a similar waking pattern (See figure 33)

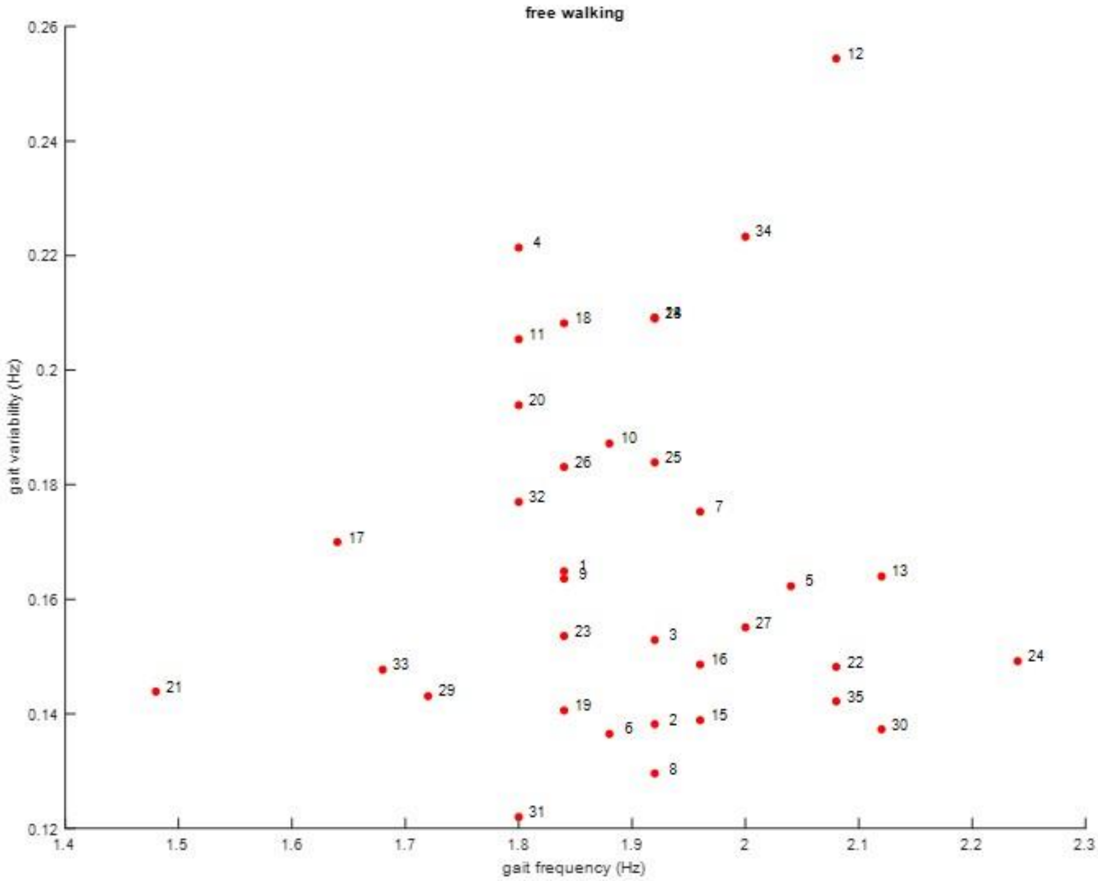


Figure 33 Graph outlining base line variability of participants.

5.13.2 Assessing the startle response due to onset of sound sequence

The short sequence below displays the audio signals for 2 sounds (red) and the acceleration trace (black). The analysis looks at the frequency of these acceleration changes. Evidence found in this graph suggests the onset of sound is able to produce a measureable perturbation in gait (See figure 34).

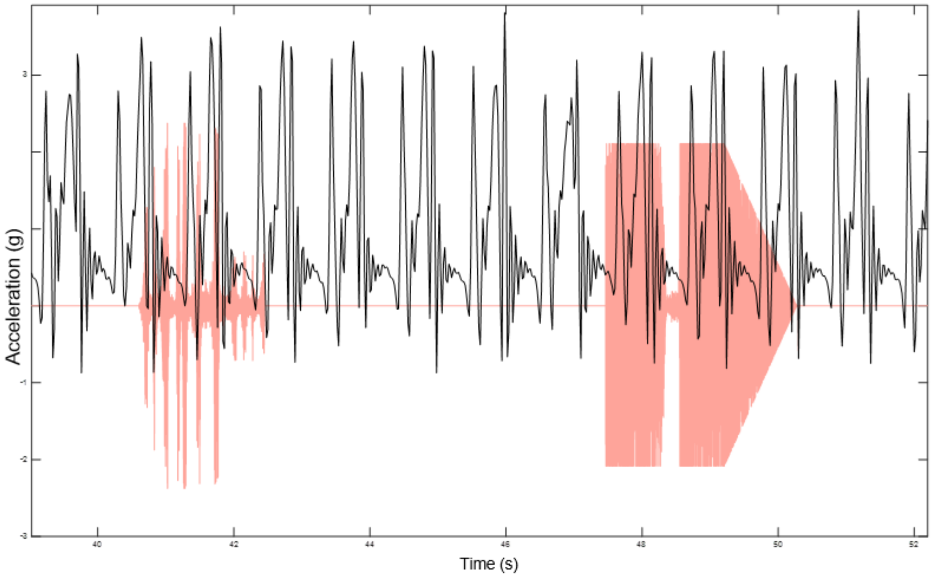


Figure 34 Example of gait changes (black), in response to sound onset (red).

5.13.3 Average acceleration and frequency response

Taking the long-term average of the acceleration trace (smoothed so that individual steps are not visible), a metric was created showing changes taking place in response to each sound heard. The peak in the black trace shows stride-to-stride average is significantly changed in response to sounds (See figure 35). Participants were accelerating rapidly to specific environmental sounds. Moreover, some sounds could produce a reduction in gait speed.

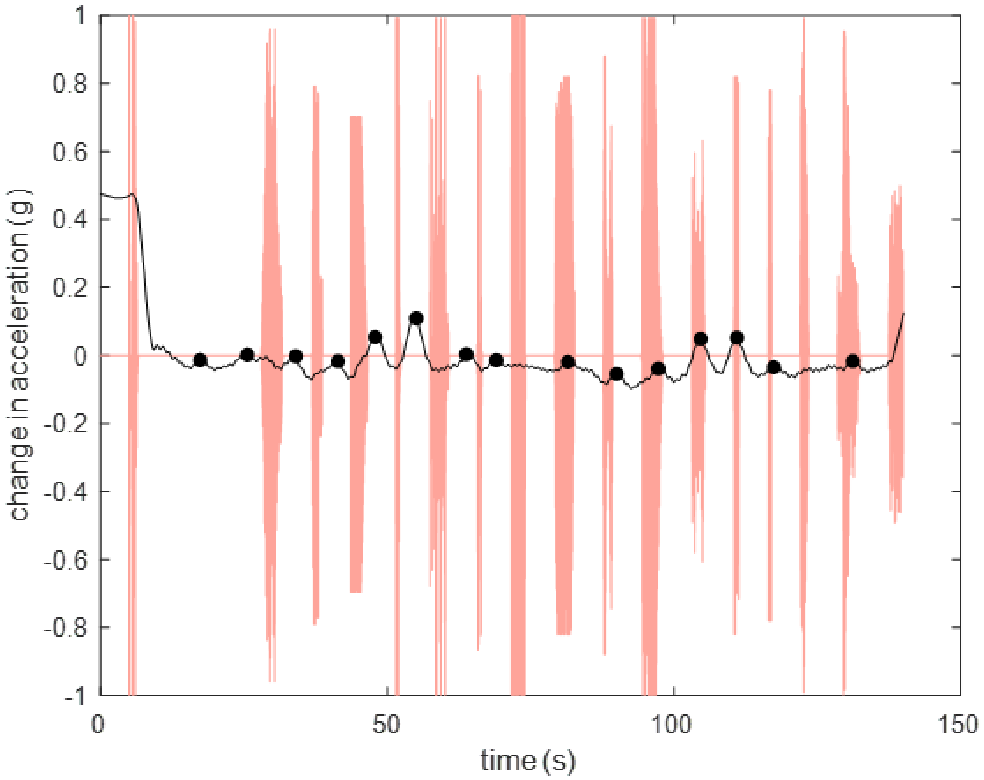


Figure 35 Example of changes in acceleration in response to sound. (black stride, red sound).

5.13.4 Frequency peaks and gait

To understand the degree to which acceleration of gait takes place, in response to the auditory cue, gait changes were measured via frequency response. An audio clip during this study is played every 8 seconds, e.g., noise perturbation within the sound sequence occurred at a frequency of 1/8 = 0.125Hz, thus if gait is altered as a result of the onset of a sound there will be a peak in the acceleration frequency data at 0.125Hz. The example below taken from a data set provides evidence of a strong response to the sound via gait acceleration (Black trace) at the expected frequency of 0.125Hz (audio spectrum - red trace). (See figure 36).

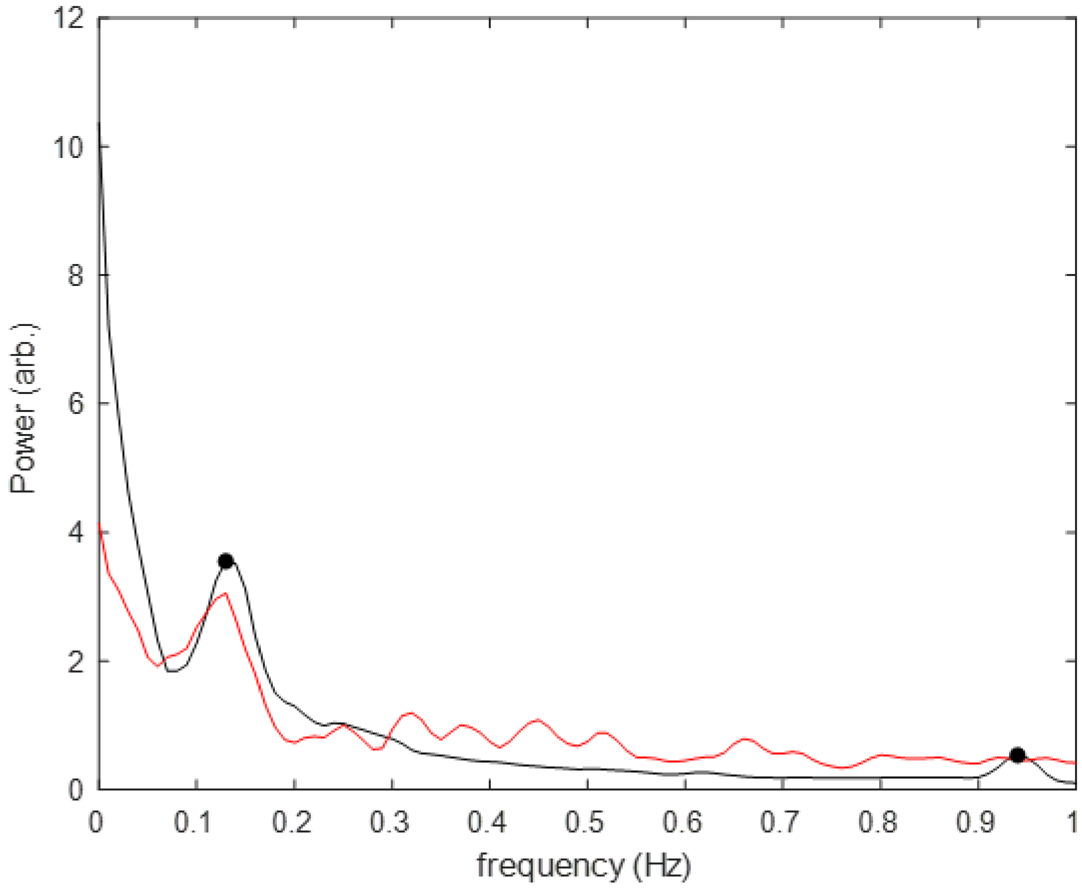


Figure 36 Example of gait acceleration in response to a sound at a frequency of 0.125Hz.

5.13.5 Profiling the population of participants walking to environmental sound.

Using the two metrics previously described we were able to profile participants according to their gait perturbation (startle response). The x-axis is the size of the biggest perturbation in average acceleration (e.g., the change produced by a single sound), with the y-axis, the size of repeated perturbation in response to the series of sounds (obtained from frequency spectrum peak) e.g., repeated change produced by multiple sounds. Both axis are scaled to give relative effect with maximum response scaled to 1 (See figure 37).

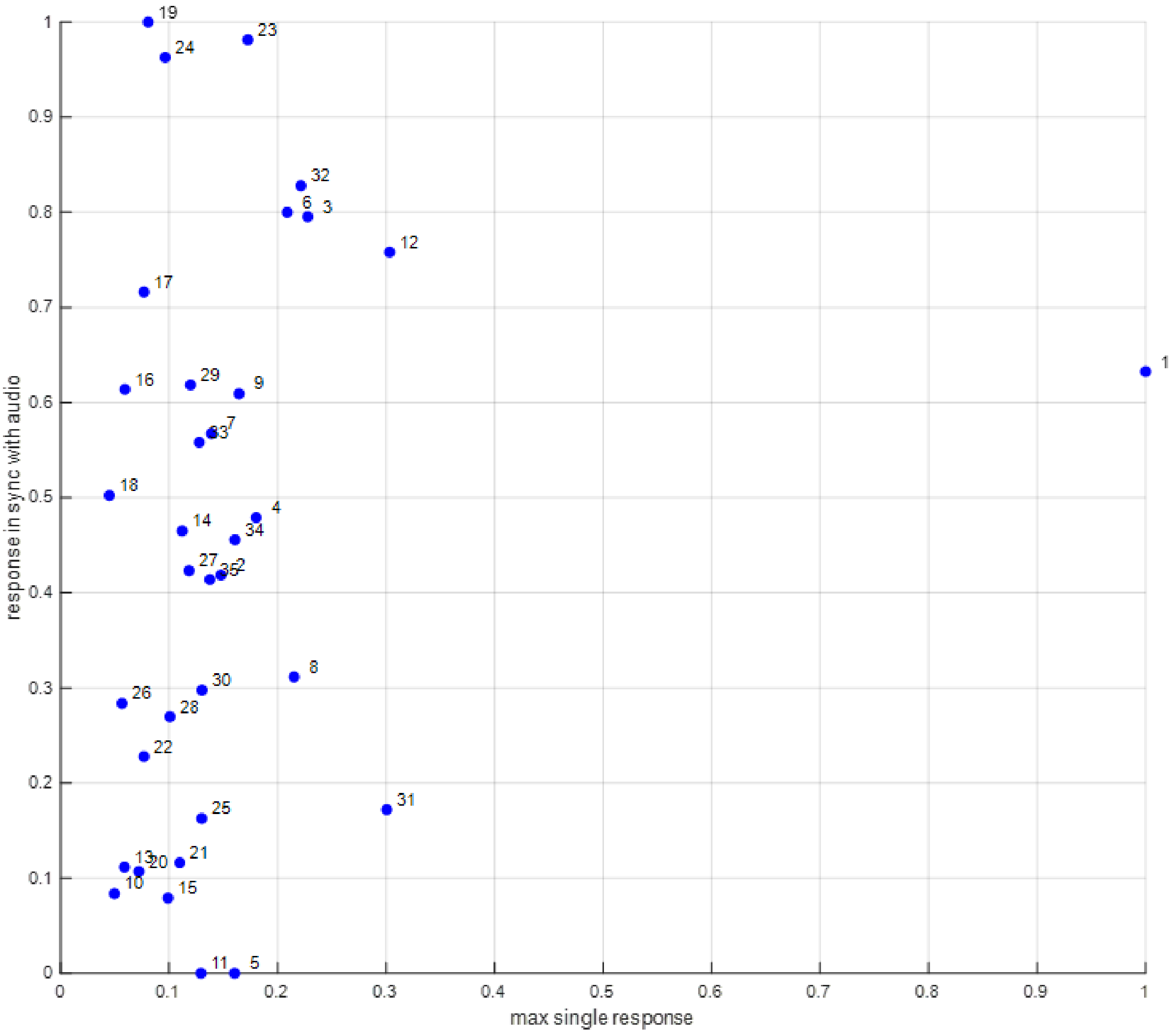


Figure 37 Graph outlining the maximum response to sound.

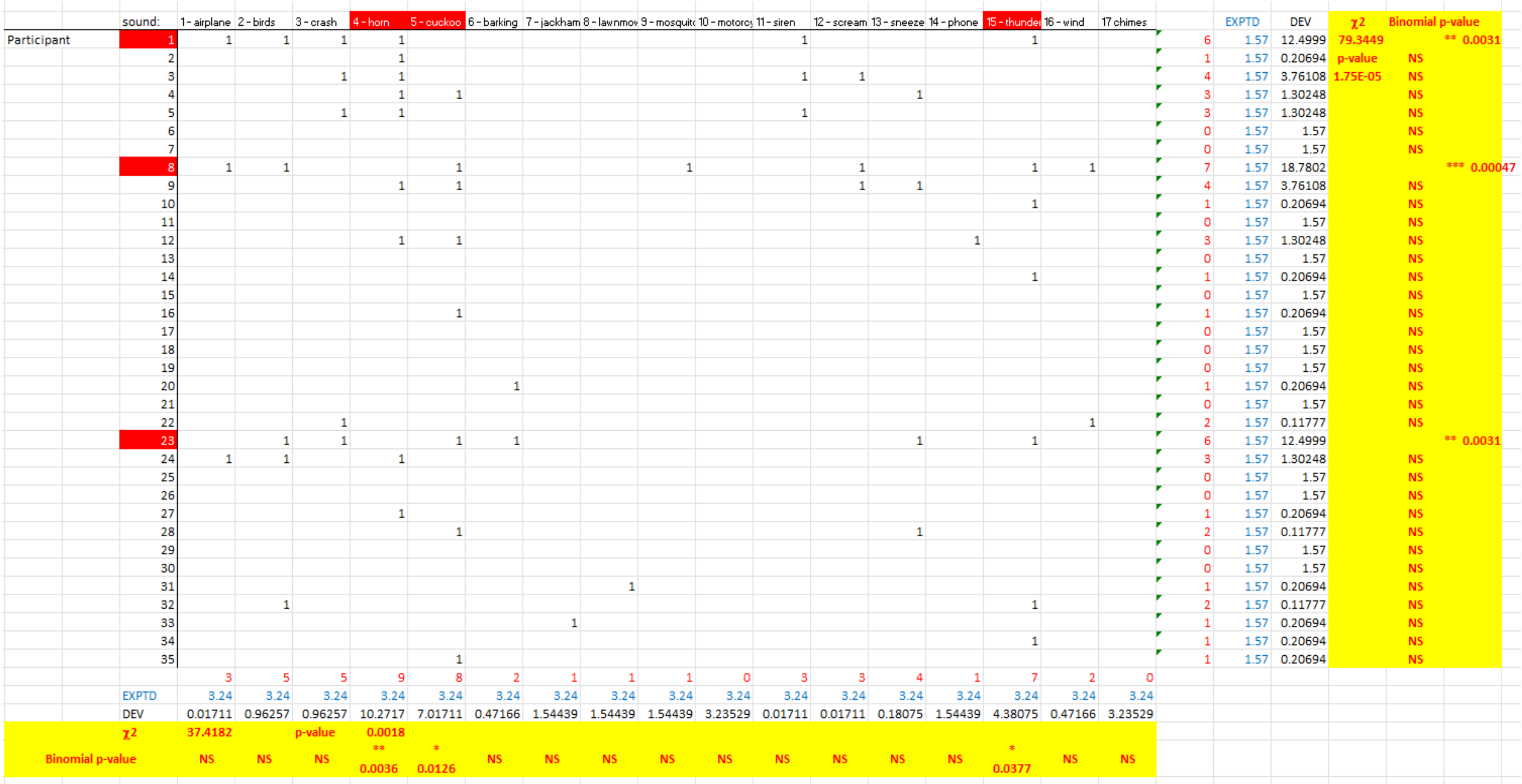
Participant raw data scores for max perturbation and synchronisation (See table 12), provide an alternative view of looking at the data.

Participant	synchronisation	max perturbation
1	0.63	1.00
2	0.42	0.15
3	0.80	0.23
4	0.48	0.18
5	0.00	0.16
6	0.80	0.21
7	0.57	0.14
8	0.31	0.22
9	0.61	0.16
10	0.08	0.05
11	0.00	0.13
12	0.76	0.30
13	0.11	0.06
14	0.47	0.11
15	0.08	0.10
16	0.61	0.06
17	0.72	0.08
18	0.50	0.04
19	1.00	0.08
20	0.11	0.07
21	0.12	0.11
22	0.23	0.08
23	0.98	0.17
24	0.96	0.10
25	0.16	0.13
26	0.28	0.06
27	0.42	0.12
28	0.27	0.10
29	0.62	0.12
30	0.30	0.13
31	0.17	0.30
32	0.83	0.22
33	0.56	0.13
34	0.46	0.16
35	0.41	0.14

Table 12 Participant scores for max perturbation and synchronisation during environmental sound exposure

5.13.6 Startle peaks per participant / per sound

To understand the degree to which a sound startles a participant (i.e., perturbs gait), a Pearson χ^2 test was used for the whole sequence of sounds (statistically relevant variation across participants) and for the whole cohort of participants (statistically relevant variation across sound). In both cases we have a p-value < .05 For individual participants and individual sounds. A binomial probability was used to assess the significance of the number of observed responses in comparison to that expected from the mean number of responses. P-values and * significance levels are indicated on the spreadsheet and the significant entries highlighted in red (participants 1,8 & 23, sounds 4,5 & 15) (See figure 38).



	sound:	1 - airplane	2 - birds	3 - crash	4 - horn	5 - cuckoo	6 - barking	7 - jackham	8 - lawnmov	9 - mosquit	10 - motorcy	11 - siren	12 - scream	13 - sneeze	14 - phone	15 - thunder	16 - wind	17 chimes		EXPTD	DEV	χ2	Binomial p-value
Participant	1	1	1	1	1							1				1			6	1.57	12.4999	79.3449	** 0.0031
	2				1														1	1.57	0.20694	p-value	NS
	3			1	1							1	1						4	1.57	3.76108	1.75E-05	NS
	4				1	1								1					3	1.57	1.30248		NS
	5			1	1							1							3	1.57	1.30248		NS
	6																		0	1.57	1.57		NS
	7																		0	1.57	1.57		NS
	8	1	1			1				1			1			1	1		7	1.57	18.7802		*** 0.00047
	9				1	1							1	1					4	1.57	3.76108		NS
	10															1			1	1.57	0.20694		NS
	11																		0	1.57	1.57		NS
	12				1	1									1				3	1.57	1.30248		NS
	13																		0	1.57	1.57		NS
	14															1			1	1.57	0.20694		NS
	15																		0	1.57	1.57		NS
	16					1													1	1.57	0.20694		NS
	17																		0	1.57	1.57		NS
	18																		0	1.57	1.57		NS
	19																		0	1.57	1.57		NS
	20						1												1	1.57	0.20694		NS
	21																		0	1.57	1.57		NS
	22			1													1		2	1.57	0.11777		NS
	23		1	1		1	1							1		1			6	1.57	12.4999		** 0.0031
	24	1	1		1														3	1.57	1.30248		NS
	25																		0	1.57	1.57		NS
	26																		0	1.57	1.57		NS
	27				1														1	1.57	0.20694		NS
	28					1								1					2	1.57	0.11777		NS
	29																		0	1.57	1.57		NS
	30																		0	1.57	1.57		NS
	31								1										1	1.57	0.20694		NS
	32		1													1			2	1.57	0.11777		NS
	33							1											1	1.57	0.20694		NS
	34															1			1	1.57	0.20694		NS
	35					1													1	1.57	0.20694		NS
		3	5	5	9	8	2	1	1	1	0	3	3	4	1	7	2	0					
	EXPTD	3.24	3.24	3.24	3.24	3.24	3.24	3.24	3.24	3.24	3.24	3.24	3.24	3.24	3.24	3.24	3.24	3.24					
	DEV	0.01711	0.96257	0.96257	10.2717	7.01711	0.47166	1.54439	1.54439	1.54439	3.23529	0.01711	0.01711	0.18075	1.54439	4.38075	0.47166	3.23529					
	χ2	37.4182		p-value	0.0018																		
Binomial p-value		NS	NS	NS	** 0.0036	* 0.0126	NS	NS	NS	NS	NS	NS	NS	NS	NS	* 0.0377	NS	NS					

Figure 38 startle peaks per participant / per sound. A categorical approach was used, scoring each sound/person pair as a 1 if they responded and a 0 if they did not.

5.13.7 comparison of sound / no sound in gait perturbation

To further understand the degree to which sound may influence gait perturbation, a comparison between sound and no-sound output was created to check whether sound effects are due to chance. The two histograms below show the mean detection of perturbation during an acceleration sequence (i.e., The histogram is of peak prominence, i.e. the height of the perturbations in acceleration that we detect). The additional check that we implemented is that if a perturbation is above the threshold we only count it if it is time-correlated to one of the sounds that we play, so the probability of having a random perturbation above threshold and it occurring exactly when a sound is playing is minimal.

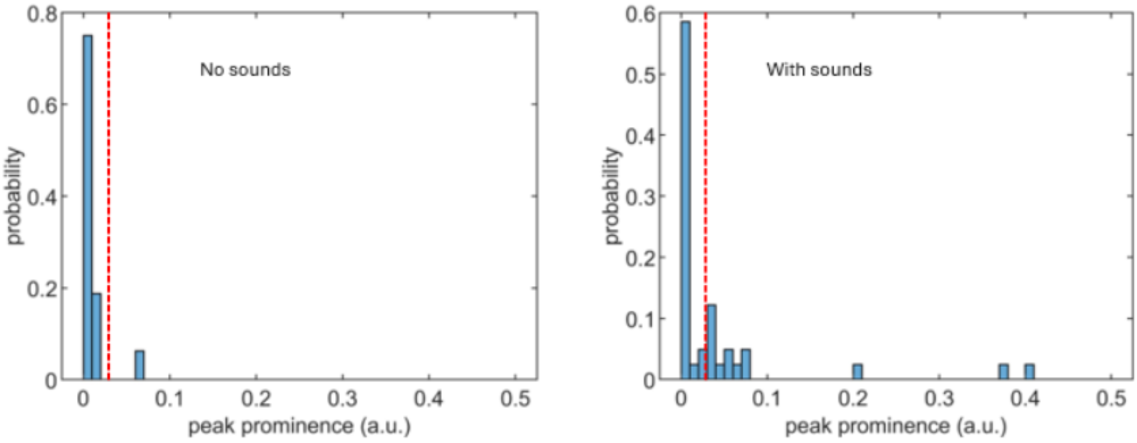


Figure 39, Histograms of detected perturbation in acceleration sequence. Vertical red line indicates threshold level for event detection (peak prominence > 0.02). With no sound, only 1-2 rare events show up, whereas with sound there are multiple events above the threshold, moreover, these are time correlated with the environmental sounds used.

5.13.8 Participant outliers' data

To understand why three participants stood out from the group, it was decided that a “precision medicine “approach would benefit analysis (See table 13). As noted previously, precision medicine is an emerging approach for disease treatment and prevention, with consideration to individual variability, genes, environment and lifestyle factors (NHS, 2020). Thus, instead of looking at the participants as a mean value in a group, individuals can be looked at from a more encompassing perspective. As noted in the diagram below, only participant 23 failed the MOCA test, meaning their cognitive level would be deemed in the category of Mild Cognitive Impairment (MCI), whilst participants 1 & 8 were deemed cognitively normal. Each participant, according to the RNID auditory check were deemed to have some hearing loss, however, nothing clinically diagnosed. No polypharmacy was found across participants. Scores were below average for the STAC test, but no significant according to the mean value score (SPM).

Variable measure	**Non-outlier means**	**Participant 1**	**Participant 8**	**Participant 23**
Gender	22F / 13M	Male	Female	Female
Age	67.97	68	67	79
MOCA	27.29	29 (Passed)	27 (Passed)	23 (Failed)
Hearing	51.43% no loss / 48.57% sign of loss	some loss	some loss	some loss
Polypharmacy	1.82	1	0	0
Tinetti test	27.4	28 (passed)	28 (passed)	27 (passed)
STAC (Sound) Average speed	60.74	53.75 - (Below average)	65.43 - (Above average)	48.96 - (Below average)
STAC (sound) final speed	55.18	41 - (Below average)	60 - (Above average)	37 - (Below average)
STAC (Sound) Hit-rate	71.15	64.36 - (Below average)	74.4 - (Above average)	67.01 - (Below average)
STAC (silent) Average speed	60.39	52.47 - (Below average)	60.37 - (Average)	52.58 - (Below average)
STAC (silent) Final speed	54.68	53 - (Below average)	37 - (Below average)	53 - (Below average)
STAC (silent) Hit-rate	71.89	67.84 - (Below average)	68.7 - (Below average)	71.43 - (Average)
Synchronisation	0.45	0.63	0.31	0.98
Max Perturbation	0.16	1	0.22	0.17

Table 13 Table representing the 3 outliers in the data and their associated measures taken during the test

5.13.9 *Sound analysis for sound that created greatest startle peaks*

Sound analysis was administered to the sounds used in this study, and scored according to the strength of startle, as measured via gait perturbation. Analysis found initial surprise response at the start of the series for all participants, which was expected. Pronounced responses above base line were found for environmental sounds; car horn, cuckoo clock and thunder.

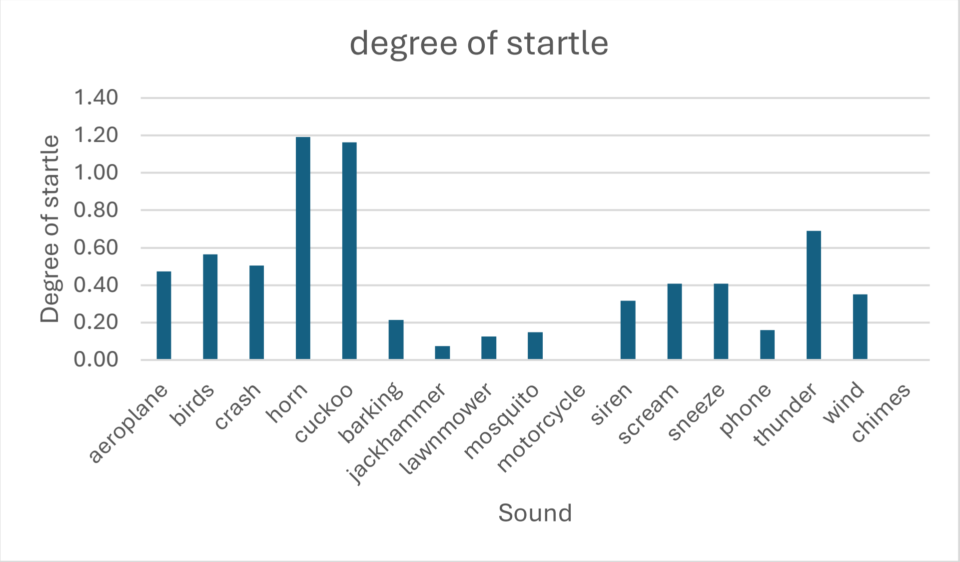


Figure 40 Degree of startle for the sounds used in this study. Horn, cuckoo & thunder showing the most response

The sounds that created the most pronounced responses above base line, showed no specific unique structural patterns, but did each have abrupt volume changes (sudden loud noise) (See Figure 40). A full frequency wave analysis of all sounds use can be found in appendix 8.

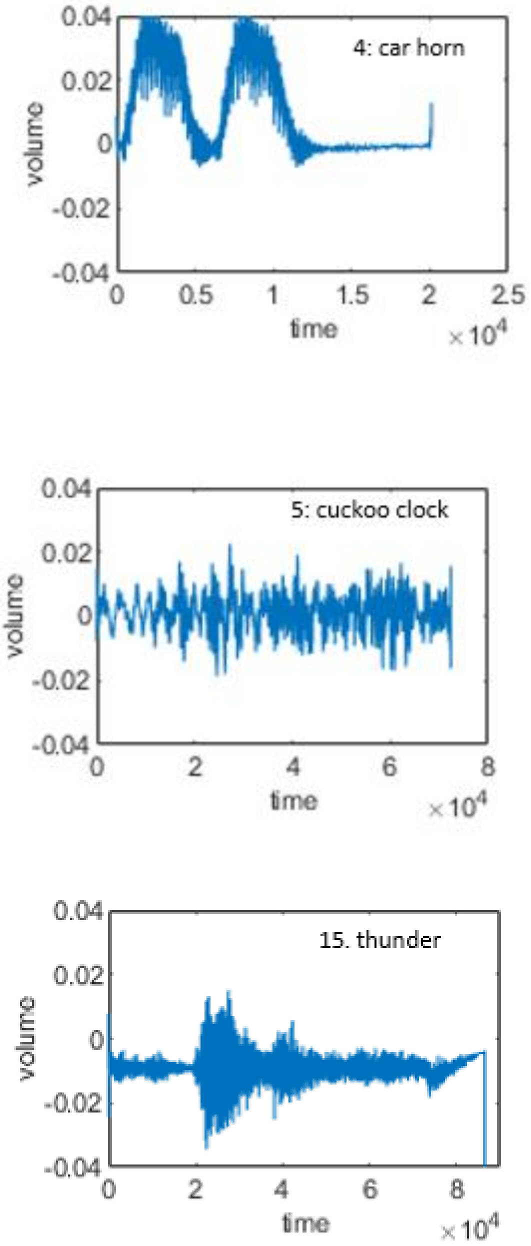


Figure 41 structural patterns of the wave forms for the sounds that created the most startle.

5.13.10 Gait analysis of participants walking during beep sequence.

Analysis of gait during this study additionally looked at variance in gait stride time and foot lift during the beep cycle played at the middle of the auditory file. The beep cycle, lasted for 3 minutes, 3 seconds. The beep gradually increased in speed for approximately 1 minute, 30 seconds before gradually decreasing back to the starting beep speed. Individuals with increased variance in stride time and foot lift, did not show any patterns or correlations with any additional measures used (See figure 41)

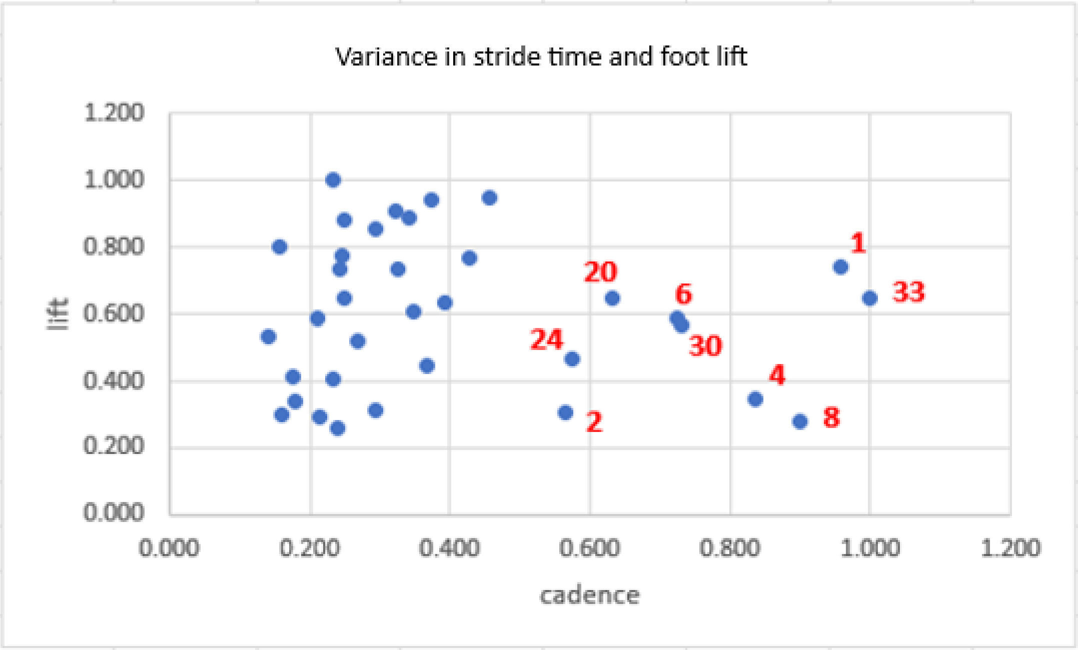


Figure 42 Variance in stride and foot lift during a beep test.

5.13.11 Mean and SD of participant scores for additional test measures:

	Mean	SD
Age	69.97	5.33
MOCA	27.29	2.09
Polypharmacy	1.82	1.95
Tinetti test	27.4	1.02
Hearing test	18 (51.43%) participants no hearing loss during hearing test	
	17 (48.57%) participants showing signs of loss during hearing test	

Table 13 visual representation of mean & SD (study measures)

5.13.12 Correlation between synchronisation and max perturbation of gait on:

As outlined in the method section, It was important to understand the degree to which certain variable may influence gait, to remove any external confounds that may influence our data collection.

5.13.12.1 Age

The average age of participants in this study was 69.97.

A Pearsons correlation coefficient was computed to assess the relationship between age and synchronisation. There was a significant positive correlation between the two variables, r(35) = .380, p = .025.

A Pearsons coefficient was computed to assess the relationship between age and max perturbation of gait. There was no significant correlation between the two variables, r(35) = -.063, p = .718.

5.13.12.2 Polypharmacy

Polypharmacy measures as taken during a participant questionnaire found, the mean polypharmacy score was 1.82. A total of 9 participants in this study take multiple tablets each day (polypharmacy). The most common medication amongst the older adults in this study were heart medication (e.g., blood pressure medication)

A Pearsons correlation coefficient was computed to assess the relationship between polypharmacy in older adults and the degree to which this may influence synchronisation. There was no significant correlation between the two variables, r(35) = -0.43, p = .804.

A Pearsons correlation coefficient was computed to assess the relationship between polypharmacy in older adults and the degree to which this may influence Max perturbation of gait. There was no significant correlation between the two variables, r(35) = -.004, p = .981

5.13.12.3 MOCA

The mean score for the MOCA in this study was 27.29. A total of 6 participants failed the MOCA test, with the lowest score 22.

A Pearsons correlation coefficient was computed to assess the relationship between MOCA scores and gait synchronicity. There was no significant correlation between the two variables r(35) = .010, p = .956.

A Pearsons correlation coefficient was computed to assess the relationship between MOCA scores and max perturbation. There was no significant correlation between the two variables, r(35) = .111, p = .526

5.13.12.4 Hearing

A total of 18 participants in this study were found to have normal hearing, when taking part in the RNID online hearing test. A total of 17 participants were classed as showing signs of hearing loss. During the participant questionnaire, no participants had a clinical diagnosis of Tulio phenomenon, nor did they outline any symptoms that may suggest Tulio.

A Pearsons correlation coefficient was computed to assess the relationship between hearing test results and gait synchronicity. There was no significant correlation between the two variables, r(35) = .084, p = .630.

A Pearsons correlation coefficient was computed to assess the relationship between hearing test results and max perturbation. There was no significant correlation between the variables, r(35) = .191, p = .272

5.13.12.5 Tinetti test

When combining the scores for the balance and gait section of the Tinetti test of balance, all participants except 1, who scored a low score of 23. A score of 23 places the individual at a moderate risk of balance issues. The average Tinetti score was 27.4.

A Pearsons correlation coefficient was computed to assess the relationship between the results of the Tinetti test of balance and gait synchronicity. There was no significant correlation, r(35) = .011, p = .952.

A Pearsons correlation coefficient was computed to assess the relationship between the results of the Tinetti test of balance and max perturbation. There was no significant correlation between the variables, r(35) = .193, p = 268.

5.13.12.6 STAC test

Person's correlation coefficients were computed to assess the relationship between the STAC test (sound and no sound conditions) and gait measures (synchronicity and perturbation).

		AVERAGE SPEED	**FINAL SPEED**	**HIT RATE**
SYNCHRONISATION	Sound condition	r (34) =-.019, p=.913	r (34) =-.012, p=.946	r (34) =-225, p=.210
	No sound condition	r (34) =-.059, p=.739	r (34) =-.050, p=.780	r (34) =-.129, p=.277
MAX PERTURBATION	Sound condition	r (34) =-.109, p=.541	r (34) =-.176, p=.344	r (34) =-.272, p=.199
	No sound condition	r (34) =-.177, p=.317	r (34) =-.155, p=.380	r (34) =-.107, p=.546

Table 14 visual representation of correlations against the STAC test

5.13.12.7 Influence of gender on gait

Finally, to understand the influence gender may play on gait measures, paired samples t-tests were used. A paired sample t-test was computed to assess the influence of gender on gait synchronicity. No significance was found, t(34) = .620, p = .547. A paired sample t-test was computed to assess the influence of gender on max perturbations. No significance was found, t(34) = .981, p = .346

5.14 Discussion

The aim of this study was to create a detailed investigation to understand the influence of environmental sounds on walking integrity in older adults. We looked at stride-to-stride average, max perturbation, synchronisation, acceleration, frequency peaks, food cadence and lift. We additionally measured how external variables, namely polypharmacy, hearing, age, balance and cognition may influence / perturb gait. The aim of introducing multiple test variables was to get a true representation of gait, free from any confounds. Moreover, we believe that taking a precision medicine approach to research, provides an in depth overview of participants, allowing individual variation to show in the data. This also makes it easier to create a “case study” of a participant should they be a data anomaly.

STAC test

The STAC test, as with study 2 (chapter 4) did not show any significant difference between the sound and no sound condition. There was no significant effect of gender, on task order. The outcome of the STAC test contradicts previous research in the field outlining that sound can capture and redirect attention away from a task. The outcome of this study highlights that older adults are more resilient to external sounds that previously expected.

MOCA test

The MOCA test administered in this study provided evidence that the majority proportion of participants were cognitively healthy, with an average MOCA score of 27.29%. The participants who failed the test did not have any link to gender or age. There are many variables that affect the score on the MOCA, which are outlined below.

Hearing

The validated RNID online hearing test given to participants provided evidence that hearing acuity was almost split 50/50, with 18 participants having normal hearing test results on the day, with the remaining 17 showing evidence of loss.

Polypharmacy

The questionnaire used in this study found that approximately 25% of participants were taking medication deemed “polypharmacy” (4 or more). The questionnaire additionally requested information regarding the type of medication taken. Heart medication was the most used medicine.

Tinetti test

The Tinetti test of balance used to assess balance (50% of score) and gait characteristics (50% of score) was passed with nearly full marks for every participant other than one.

Walking study

The results indicate that stride-to-stride average and synchronicity of gait are significantly perturbed in response to the onset environmental sounds. Environmental sounds were capable of accelerating participant walking speed. Support for this derives from the acceleration to gait in response to the sound, where gait acceleration peaks at 0.125Hz, which was the frequency of sounds used. The moment of sound onset is creating a startle like effect, that correlates with the literature on the acoustic startle reflex. Correlation analysis indicated that our additional measures taken during this study provided no significance, except for age positively correlating with gait synchronicity, suggesting that at presented we cannot confirm that measure such as polypharmacy have an influence over gait. Finally, this study measured participant attention control via the STAC test. No significance was found between sound conditions. This mirrors the results from Study 2 (Chapter 4) where no significance was also found.

In line with the hypothesis, the onset of sounds indicated a change to stride-to-stride average, with acceleration peaking at the postulated peak of 0.125Hz. These results met with our expectations and are supported by researcher such as Berlot et al. (2021) who outline the interaction between auditory input and motor function, particularly simple innate protective reflexes, such as fleeing from loud noise, hence the increase in speed found in this study. This provides evidence that the onset of environmental sounds are capable of altering gait. The results are also supported by Franek et al. (2018) who found that exposure to loud noise led to an immediate increase in walking speed. The results of our additional measures (Tinetti test, Polypharmacy, MOCA, hearing test and STAC) do not meet our expectations and are a contradiction to current research. For example, in a study by George & Verghese (2017), examining the relationship between polypharmacy and gait, their results found, older adults who use polypharmacy are at increased risk of slower walking. Moreover, a similar study by Montero-Odasso et al. (2019) found polypharmacy was associated with higher stride, increase gait variability, and increase double limb support. Our research found that individuals taking polypharmacy-maintained gait control, in line with other participants. Further contractions in our results can be found when looking at cognition and gait. In line with previous research, such as Cohen & Verghese, (2019), it was expected that individuals with lower MOCA scores would have significant changes to gait, this however was not found, as data analysis yielded no correlation. Plausible explanations for our lack of correlation between gait and additional measures could be due to limited sample size, as this may reduce the power of the study.

These results build on existing evidence that sound, can produce a measurable change to gait. Moreover, it provides new insight that environmental sounds are detrimental to older adults and can produce measurable changes that could increase risk of slip, trips and falls, something that has not been measured previously. Furthermore, and in support of attention control data collected in chapter 2, this research contributes to a clearer understanding of how the onset of sound can induce a startle effect. As predicted the onset of the sound file crated a startle, with stride-to-stride average additionally significantly changing in response to a sound. This is supported by research such as Nieuwenhuijzen et al. (2000), Queralt et al. (2010) and Nonnekes et al. (2015) that outline the onset of sound can induce measurable changes to posture and gait. Interestingly, Nieuwenhuijzen et al. (2000) outlined that responses to the startle are rapidly adapted to achieve extra stability dependant during the step cycle, this provides further support that the data collected in this study is contributing to existing theories, as the data found multiple reactions to the sounds played, before rapidly habituating.

What is of interest with the sounds used in this study, is sounds that were deemed extremely distracting in study 1 and used in the STAC test study 2, were not the sounds that induced the greatest of stride-to-stride changes. For example, cuckoo and thunder were placed in this sound file to test is participant perception ratings of distracting environmental sounds were correct. Both these sounds have an average rating of approximately 5 on the distractibility scale, making them neither distracting or pleasant. This suggests that what older adults are perceiving to be distracting, may not be the environmental sounds that may influence falls. Whilst the spectral analysis of the most distracting sounds did not find any common features, cuckoo and thunder noises were the sounds that influenced the greatest degree of gait change.

This research has contributed to the understanding that sound, particularly environmental sounds can contribute to detrimental changes to gait in older adults. Moreover, in support of current theories, this research provides evidence that gait changes may be due to a startle reflex that takes place after sound onset, before habituation. Moreover, this paper presented evidence in the form of precision medicine, aimed at looking at a participant not as a mean score, but rather individuals measure that may influence gait. As noted, the participants who were deemed an anomaly in the group, did have hearing loss and scored below average in the STAC. Moreover, one participant had low scores in the MOCA, suggesting cognitive impairment. The three participants, when included in the data as a mean value, do not hold any significance. However, when presented as a individual, there is clear evidence that future research should make use of precision medicine, to evaluate an individual on multiple measures, to get a true representation of data.

The limitation of this study was sample size as it is not as large as we would have wanted. As such, the generalisability is limited. A larger sample size may have produced a larger effect. It was beyond the scope of this current study, but something that will be looked at in the future, is using Mismatch Negativity (MMN) and physiological measure, to assess the degree to which physiological changes are taking place in response to the sounds place. Future research should consider the startle response as a leading cause of falls in older adults. Finally, it is notable that there is a difference in participant numbers, in regard to gender. In a perfect research study, gender numbers would be matched, however this was not possible. Research calls for participants has a higher intake for females compared to that of male.

5.15 Final summary of chapter

- Anatomical changes to the brain during ageing, highly influence gait and attention performance. The basal ganglia specifically should be further addressed given 3% of the older adult’s population are predicted to have enlarged perivascular spaces, particularly in the basal ganglia. Given there are around 1 billion older adults globally, this suggests that currently, 30 million older adults are at increased risk of motor change due to small changes in the basal ganglia. This provides direct evidence of anatomical changes that could be a leading cause of slips trips and falls in older adults.

- This research supports our hypothesis that environmental sounds can produce measurable changes to gait.
- This research also provides evidence of individual difference during the gait cycle at base line and with sound onset.
- This research highlights environmental sounds can create an acoustic startle effect, that influences gait performance.
- This research highlights in the anomaly data outlines the need for a precision medicine approach when understanding data. This research, whilst findings no significance, has shown that if research only focus on the mean of a data set, the individual differences that may influence gait are missed.
- This thesis has taken previous research further by implementing sounds that have been specifically categorised by older adults as distracting, specifically aimed at dividing attention away from gait, and provided evidence that whilst there is individual difference, environmental sounds can alter gait.

Chapter 6 – Summary, major findings and what next?

PhD aims.

Life expectancy is growing. Nearly every corner of the globe is seeing a growing rise in the amount of people living passed the age of 60 (World Health Organisation, 2023). The WHO predicts that the current global population of older adults will rise from 900 million to approximately 2 billion by 2050 (WHO, 2023). Such advancements in ageing knowledge have contributed to a growing population of older adults who are ageing "healthy," with healthy ageing defined as developing and maintain the functional ability that enables well-being in older adults (WHO,2023). However, despite all the policies and interventions developed, to increase the potential for healthy ageing, not everyone achieves this. important example is the risk of falls. Currently 30% older adults has a fall each year, with half this figure continuing to have more frequent and life changing falls. The impact of falls can lead to broken bones, pneumonia, long term disabilities and social isolation. Moreover, falls increase hospitalisation stays and care needs, which have a detrimental impact on mental health, available beds in hospitals and financial economy. The overarching aim of this research is to increase our knowledge of why some older adults may be at higher risk of abnormal gait and risk of falls than others. The main hypothesis running through this set of studies and thesis, is that some older adults experience degradation in their ability to resist attentional capture from highly salient but irrelevant environmental sounds, resulting in the shift of attention and thus processing resources, away from walking and gait maintenance, thus reducing their integrity and raising risk of falls. Walking is a highly complex behaviour involving and requiring the integrity of many aspects of the brain and system functions. It is important to determine in greater details which specific components of this complex behaviour may be affected and why. We examined what sounds are deemed distracting within an older adult population, how different sound conditions influence attention control via the

STAC test, and we examined how environmental sounds influence gait. The focus of this chapter is to draw the thesis together. It will re-present the finds of the studies, provide an overview of why these findings are important and how they improve and support research in this area.

6.1 Findings from the five chapters outlined in this thesis and overview of results.

6.1.1 Ageing (Chapter 1)

The neuronal, physiological, genetic, and cognitive changes, as set out above, are the key hallmarks and elements that facilitate the drive in the ageing process, be it natural or pathological. Whilst disease and genetics play a role, individual difference, maintenance via diet and healthy lifestyle, exercise, cognitive training and socialisation, each impact the brain and body, facilitating a heathy ageing, with enhanced plasticity or increased risk of developing disease. Similarly, the sensory system should not be underestimated in the influence it holds over cognition and motor movement in older adults. This overview has highlighted the links and potential causality between ageing, changes to the musculoskeletal system, attention, sensory processing, cognition, and increased risk of falls in older adults, which later in the thesis will help with the overarching aims of this PhD.

6.1.2 Auditory system (Chapter 2)

The major theme that has emerged from this chapter have outlined a definitive link between environmental sound/noise on attention control and movement. Evidence outlined sound are processed either automatically or require little cognitive processing, whilst some are high level processing (e.g., perception, speed). Evidence has also outlined the auditory cortex is a highly tuned system which is able to detect and process these different patterns and attributes of waves and provide a detailed analysis of each feature of a sound wave and decode the smallest details of spectral and temporal information embedded in sounds (Concina et al., 2019), whilst separating out frequency components of sound, thus allowing the detection, perception and understanding of our sound environment. Furthermore, evidence presented outlined, the effects of noise exposure on hearing are catastrophic, particularly when 50% of hair cells can be damaged for destroyed before noticeable noise induce change (CDC, 2022). The implications this may have on old adults can be devastating. Hearing loss can influence gait, balance, attention, social life, mental health. Moreover, Hearing loss has recently been found to be a defining factor in developing dementia in later life. Moreover, evidence outlined environmental sounds can produce a measurable change to physiology (e.g., heart rate & skin response). Finally, Evidence in this chapter outlined that sounds we hear in our everyday life can create an arousal and fight or flight response that may alter how we interact with or navigate the environment. Muscle become tense, attention control deteriorates and depletes the body of energy and gait may become asymmetric.

6.1.3 Confrontation naming of environmental sounds (Chapter 3, study 1)

The outcome of this study provided a collection of sounds that older adults subjectively rated as distracting and unpleasant. Sounds that were on the extreme ends of distractibility and unpleasantness, were generally agreed on. The results of this study, in terms of distracting environmental sounds, provides new evidence for how older adults perceive the sounds in their environment. Previous research, such as that of Marcell (2000) never explored the perceptions of environmental sounds, rather focused on classification and labelling of them. This research shows clear progression in this field. Moreover, and in line with Marcell (2000) we look at classification of sound. This study was able to reduce the amount of previously outlined sound classifications and reduce it down to 18 distinct categories. This is of particular interest to older adults in the United Kingdom, as the sounds used are the sounds that are generally found in all towns and cities. The categorisation groups that have been collected, along with the distractibility ratings, can support multidisciplinary research. The goal of this data is to develop the mechanics and groundwork to establish peer review sharing of research. The data from this study can improve and co-ordinate effective interventions to help older adults who suffer with attentional and gait issues due to sound exposure. This may include working with different departments win the university, health and social care settings, or to provide evidence of sound that may influence falls local councils to facilitate safe and efficient evaluations of the environment, making them safer for older adults to reduce the risk of falls.

6.1.4 Influence of environmental sounds on attention control (Chapter 4, study 2)

The aim of this study was to understand the influence environmental sounds have on attention control in older adults. Using the sounds from study 1, we integrated the sounds into a within subjects, repeated measures attentional control task, STAC, to measure performance. We hypothesised that performance of the STAC during sound conditions, as opposed to silent, would see a reduction in performance. This was not the case. Data analysis found that there was no significant difference between sound and no sound condition. There are a few reasons why we did not find the results we expected, namely lower participant numbers due to covid restrictions, or older adults may be more resilient to external sounds than previously thought. Research in literature outlines that older adults have a significant reduction in selective attention, this may not be the case. With a growing rise in healthy ageing, and the outcome of this study, is there a need to readdress previous literature, particularly in the field of auditory distractions and attention control. One specific measure that needs to be addressed is the subjective views from participants that some environmental sounds used, could induce a “startle” like response. This notion of a startle, it not new within the research world, particularly within the auditory field, where the auditory startle response is believed to create a measurable physiological response, alter behaviour and performance. The subjective view of a startle to the environmental sounds is particularly important as it is a no suppressible reflex, in that it is automatically created to abrupt changes in our environment (Lindahl, 2015). The startle is of particular interest to this thesis as if the startle is triggered easily or excessively in older adults, there is an increased risk of slips, trips and falls (Lindahl, 2015). There are many ways in which the startle may influence gait. Gait can be accelerated, slowed, hindered, stiffened or frozen.

6.1.5 Influence of environmental sounds on gait (Chapter 5, study 3)

The aim of this study was to understand the degree to which environmental sounds may influence gait. The hypothesis for this study was environmental sounds would produce measurable changes to gait. To allow a full, detailed research design, measures were also taken for balance, attention, cognition level (MOCA), polypharmacy and hearing abilities. Each of these measures are believed to contribute to an increased risk of slips, trips and falls in older adults. Analysis of the results found that environmental sounds can alter gait in some participants. When comparing baseline measures, taken when participants are walking in silent, compared to walking with sounds, participants were presenting with significant changes to stride-to-stride average, with pronounced gait acceleration, in response to the onset of environmental sounds. Strong evidence for gait acceleration was found via gait perturbation taking place at 0.125Hz, the expected frequency of sound, supporting the role of environmental sounds creating an auditory startle response capable of altering gait. Data was additionally collected for startle peaks per participant, per sound. Pearsons tests were used for the whole sequence of sound and for the whole cohort. Significant values of p = .001

were found for 3 participants (1,8,23) who showed the greatest amount of perturbation in response to a sound. The anomaly participants were placed into a case study representation, to understand what may lead to such changes.

Accounting for individual difference and variability, there were found 3 specific sounds (car horn, cuckoo, and thunder) which significantly altered gait pattern away from base line measures taken when participants were walking during silence. This is of interest to this paper as only one of the 3 sounds found to induce variability were deemed distracting by older adults in our confrontation naming of sounds research. It may be that subjective perceptions of sounds are highly variable, dependant on the environment. Sound wave analysis was performed of the 3 outlined environmental sounds, to understand if there were similar soundwave features, but nothing of significance was found. Finally, during the beep sequence that was presented in the auditory file there was a collection of older adults that struggled to maintain an efficient and uniform gait pattern. Analysis found an increased variance in stride-to-stride time and foot lift.

The additional measures (MOCA, questionnaire, polypharmacy, Tinetti test and hearing tests) were administered to each participant to gain as much knowledge as possible of potential variables that may influence gait. 48% of participants have hearing loss, but this did not correlate with gait changes. One individual failed the Tinetti balance test, but no correlation was found with gait. A small handful of participants were classed as taking medication that falls into the category of polypharmacy, but no correlation with gait was found. There was a small selection of individuals who scored low on the MOCA, but no correlation with gait changes were found. The lack of correlation was unexpected, particularly cognition level and polypharmacy which are known to highly influence gait. A possible explanation for the MOCA in particular not correlating with gait, may be due to test anxiety, lower academic attainment, dyslexia and dyscalculia. The MOCA whilst beneficial for testing, does not account for variables such as dyslexia that may impact how a person responds to a question. For example, individuals with dyslexia have problems recalling information, and telling the time. Scores will be significantly reduced if they cannot actively understand or participate in the question. Finally, no effect of gender was found. Nevertheless, this study provided tangible evidence that environmental sounds can create a “startle” like effect which influences gait, via gait acceleration.

The outcome of this study is extremely important to research in this field as it provides evidence that environmental sounds in particularly, a measure that is not commonly used in auditory gait research, can alter gait. This provides favourable evidence that environmental sounds could be a leading cause of slips, trips and falls in older adults. The evidence from this study and study 2, particularly highlight a need to evaluate environmental sounds and a startle as it may be the startle response the begins a cascade effect of gait changes. The evidence from this chapter, may benefit local councils and health care system, who have fall reductions interventions as a key focus of research. By reducing the number of individuals who fall, older adults will be at a reduced risk of injury, and long-term health issues as a result. Moreover, it will free up hospital beds and move monetary resources to other area where it is needed more.

6.2 Positive points from this PhD research

Evidence has been provided of many new and exciting outcomes in relation to the thesis topic “The influence of environmental sound on attention control and gait in older adults”. Firstly, evidence has been presented for a first of its kind perception-based rating and categorisation of environmental sounds. A list has been provided outlining the most distracting sounds that can capture and divide attention, whilst providing a new, reduced categorisation of environmental sounds that can help healthcare systems, universities and councils follow a similar approach to sounds within the environment. Secondly, evidence has been provided on two occasions (STAC study 2 and STAC in study 3) that older adults are more resilient to incoming auditory sounds than originally believed. This is a contraction to the literature, however, given this thesis used environmental sounds as opposed to non-specific sounds, the outcome seems plausible. Moreover, evidence has been presented for an auditory startle. This is an extremely important piece of evidence that may link sounds to falls in older adults. Finally, this thesis has provided evidence that environmental sounds can alter gait via a “startle” that induces gait acceleration. All this evidence combined favourably links environmental sounds to gait perturbation.

It is also positive that this topic of research has been re-addressed. For a period, there seemed to be a dip in research addressing sound and how it impacts cognition and motor movement. We are living in a society with a growing rise in the ageing population, a topic that cannot be ignored. With age comes frailty. It cannot be ignored that 30% older adults are falls in each year, It cannot be ignored that sensory perception overload is something older adults have to cope with on a daily basis, and it cannot be ignored that if something is not done to reduce falls in older adults, our health care systems will not be able to keep up with the burden. This thesis is a positive step forward, providing evidence for the unexpected nature of environmental sounds influencing older adult performance. Moreover, it is a positive link between research presented in this study and the world health organisation findings (chapter 2) on the implications of noisy environments on a health and physiology.

6.3 Limitations from PhD research

Limitations of this research derive from COVID-19. When this PhD started, lock down began and all research proposals outlined in the scholarship proposal had to be re-evaluated. Firstly, we had to remove the use of MMN to measure brain activity. The use of MMN would have provided valuable data of evoked potentials in the brain taking place in response to the environmental sounds used in this study. Second, we had to find a way to collect participant perceptions of the environmental sound. Fortunately, we were able to use Qualtrics to create an online study, however, not all older adults are computer literate and declined taking part. When lock down was lifted, and research was permitted at the university, participant numbers were low due to the restrictions that were rightly put in place. A large proportion of participants had underlying medical conditions that meant they could not take part for safety reasons. Similarly, for our walking study, some older adults declined to take part.

Small sample sizes happen in research, regardless of preparation and expectation. The problems associated with small sample sizes such as, reduced power, increased margin of error, higher variability and difficulty findings statistical effect could not be avoided. As with any good research methodology, to maximise the reliability and replicability of the research in this thesis, every possible measure was deployed to create a strong data outcome. We accounted for as many external confounds possible, stuck to rigid scripts to make sure each person had the same instructions (verbally / nonverbally) and used randomised controls to eliminate bias, probability theory and manipulation of results.

6.4 Future research ideas for post-doctoral fellowship

It is of increasing interest that whilst there is a plethora of information associated with the ASR, PPI and the mechanisms attached, there is very limited research that has addressed any of the afore mentioned measures using environmental sound and gait in older adults. This seems quite peculiar as environmental sounds that we hear every day, define how we interact with the environment. Environmental sounds provide auditory cues that activate memory traces, attention control, fight or flight etc. As such, given the evidence that has been gained during this thesis research and the subsequent ASR evidence that is so beneficial to understanding how environmental sounds influence walking integrity, three favourable research proposals will now be put forward to fill the gap in current literature.

6.4.1 Proposal 1 - Physiological measure taken during gait (i.e. HRV, GSR)

Compiling the evidence derived from the data collected in this PhD and evidence derived from both qualitative and quantitative research already published in literature, it is clear future research evaluating gait, needs to implement physiological change data collection, particularly in everyday life situations not lab based. The benefits of collecting HRV and GSR would allow a full picture to be created of what is taking place when environmental sounds are being heard during walking, to what degree the environmental sounds are peaking physiological change and finally, do some physiological measures peak before others. Moreover, in line with previous research using EMG to track muscle activation during gait (Nieuwenhuijzen et al., 2000), it would be beneficial to monitor what muscles are reacting to the auditory startle (environmental sounds).

In terms of methodology, implementing physiological measures would not require a high degree of effort. HRV and GSR collection can be taken from small portable wearable electrodes placed in designated regions. HRV may be taken from electrodes placed on the chest, whilst GSR may be taken from fingertips or feet, dependant on the measures needed. EMG may be placed on multiple muscles across the lower limbs, with the rectus femoris, tibialis anterior and soleus the most favourable (Nieuwenhuijzen et al., 2000). A common ethical dilemma would be the number of leads that run from the electrodes to the battery packs. This can be alleviated via the implementation of wire gathers. Moreover, wearable technology such as apple© watches, allow wearable technology to be used from a basic watch, whilst still collecting continuous, accurate and reliable data. For a full evolution of wearable devices to monitor physiology, see Guk et al. (2019)

Based off previous literature implementing physiological measure in other fields, it could be hypothesised that when individuals are startle by the environmental sounds used in chapter 4, there would be a peak in HRV, GSR and EMG to the sound, that would rapidly decline within in time period of 10 seconds. If this hypothesis is deemed correct, it would provide evidence that environmental sounds that we hear in our everyday life, create a cascade of events that take place through the nervous system, through the brain and so forth, that increase the risk of slips, trips and falls, particularly in older adults.

6.4.2 Proposal 2 - ACT to reduce gait perturbation.

ACT may be beneficial during future research to assess the ASR during gait in older adults. Evidence of the ACT, as outlined previously can suppress the startle response via auditory training, to normalise everyday sounds. This may be a beneficial tool to reduce the rates of falls. Evidence derived from chapter 4 outlined that three specific sounds could create gait perturbation; thus, it could be hypothesised that the use of ACT may reduce gait perturbation to these sounds. If this hypothesis is correct, older adults who are at increased risk of falls, may benefit from auditory cognitive training to improve how they may react to sound within their environment.

6.4.3 Proposal 3 – Mismatch negativity

Mismatch negativity (MMN) is an event related potential that occurs when a sequence of sounds is interrupted by an odd ball stimulus, differing from the stimuli that have previously been played (i.e. AAAAAAAAAAAYAAAAAA). MMN is of particular interest due to its widely acknowledged role as a reflection of pre-attentive auditory processing (Okeak, Winkler &Sussman, 2008). Originally, this PhD was going to implement MMN as an additional measure to assess the degree to which participants react to an odd ball. This evidence was going to be correlated with gait perturbation and attention control during the STAC test. Unfortunately, this measure was not implemented due to COVID-19 restrictions that were in place for a large portion of this PhD, as such It may be beneficial to use MMN in future research to address our original research plan. Moreover, MMN may provide a good correlate with physiological measure associated with the ASR with MMN.

6.5 Research sharing and multidisciplinary research.

Interdisciplinary teamwork is an important component of research. Working and sharing research with a team allows maximal communication, shared goals, joint problem solving and collective progress evaluation (LaFrance et al, 2019), which in turn improves support for policy and practice, whilst facilitating interventions to people who need them quicker (Nancarrow et al., 2013). To this point, the research undertaken in this thesis has included interdisciplinary research between the medical school, human and health science, and engineering. However, there is opportunity to take collaborations further.

As outliner previously, It is of great importance that the data obtained in this thesis gets shared with those who can make use of it. This may include, but not limited to, hospital and health care centres, working with older adults who are at increased risk of falls or suffer regular falls. Similarly, it will be beneficial to councils, who can further improve town centres via “sensory friendly” times, where older adults can shop and move around their local area without loud music blaring from shops and shopping centres. Moreover, Local home carers may benefit from this information as they can help older adults modify or remove loud and potentially distracting items from their homes.

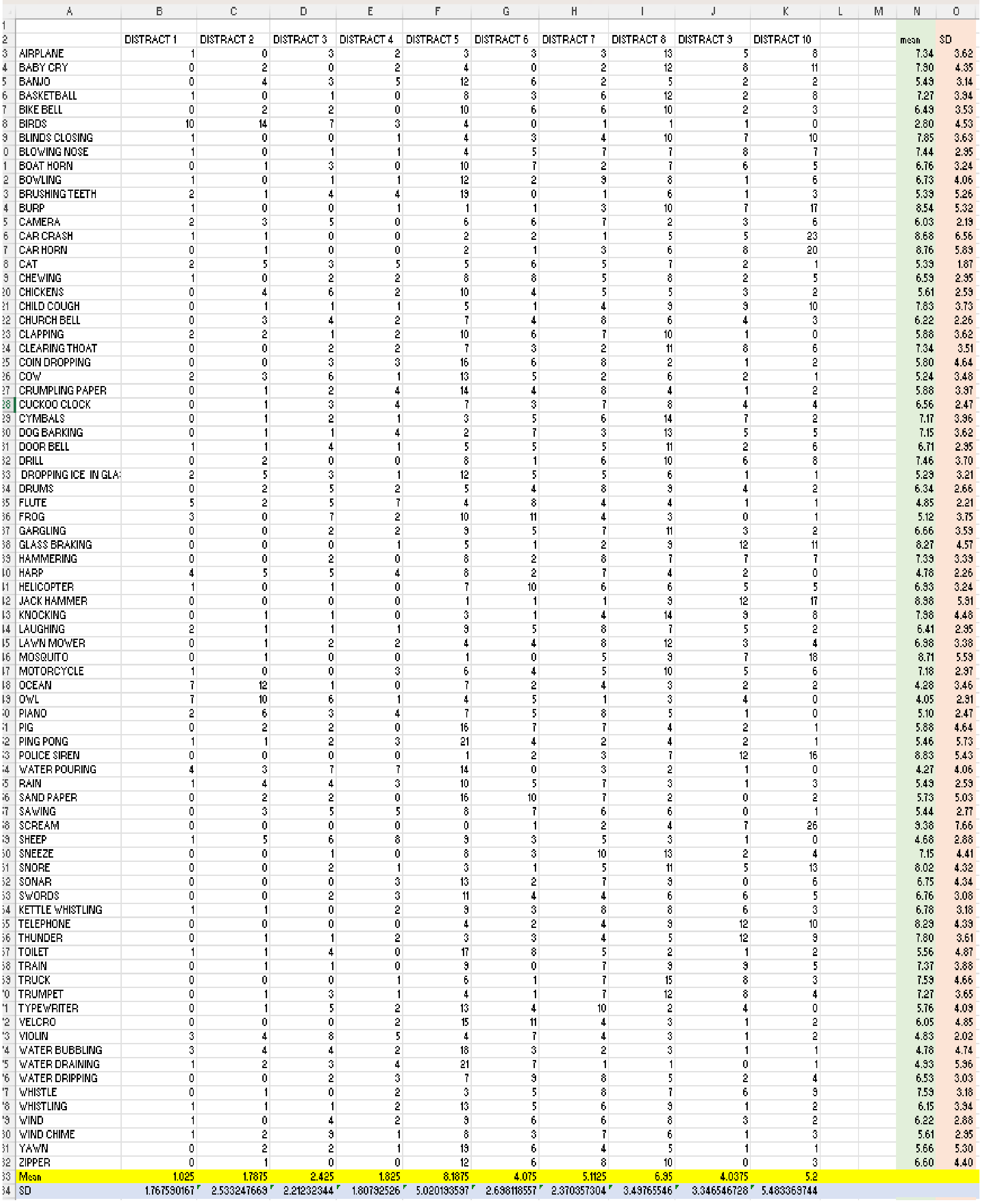
Final thesis remark

The studies carried out in this thesis have favourably presented new evidence that environmental sounds can capture attention and influencing gait. Moreover, this thesis has provided evidence that environmental sounds may influence gait via the auditory startle response.

Appendices

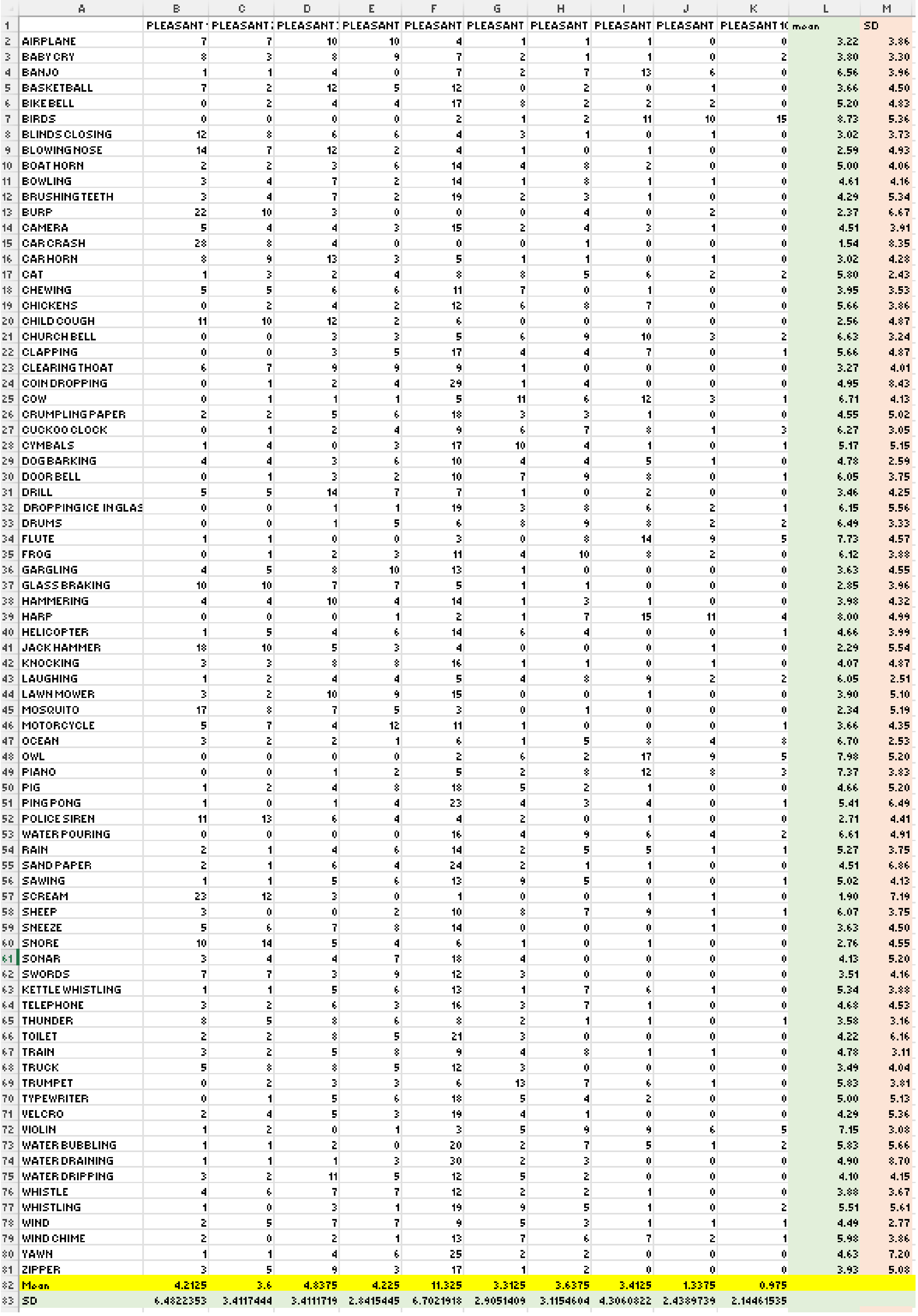
1. Distraction rating of environmental sounds raw data
2. Pleasantness rating of environmental sounds raw data
3. Mean & SD of environmental sounds distractibility/pleasantness.
4. Categorisation list of environmental sounds
5. MOCA
6. Questionnaire (Chapter 5, Study 3)
7. Tinetti test of balance
8. Figures depicting sounds waves of all sounds used in walking study
9. Subjective views of participant experience of STAC test

Appendix 1



	DISTRACT 1	DISTRACT 2	DISTRACT 3	DISTRACT 4	DISTRACT 5	DISTRACT 6	DISTRACT 7	DISTRACT 8	DISTRACT 9	DISTRACT 10	mean	SD
AIRPLANE	1	0	3	2	3	3	3	13	5	8	7.34	3.62
BABY CRY	0	2	0	2	4	0	2	12	8	11	7.90	4.35
BANJO	0	4	3	5	12	6	2	5	2	2	5.49	3.14
BASKETBALL	1	0	1	0	8	3	6	12	2	8	7.27	3.94
BIKE BELL	0	2	2	0	10	6	6	10	2	3	6.49	3.53
BIRDS	10	14	7	3	4	0	1	1	1	0	2.80	4.53
BLINDS CLOSING	1	0	0	1	4	3	4	10	7	10	7.85	3.63
BLOWING NOSE	1	0	1	1	4	5	7	7	8	7	7.44	2.95
BOAT HORN	0	1	3	0	10	7	2	7	6	5	6.76	3.24
BOWLING	1	0	1	1	12	2	9	8	1	6	6.73	4.06
BRUSHING TEETH	2	1	4	4	19	0	1	6	1	3	5.39	5.26
BURP	1	0	0	1	1	1	3	10	7	17	8.54	5.32
CAMERA	2	3	5	0	6	6	7	2	3	6	6.03	2.19
CAR CRASH	1	1	0	0	2	2	1	5	5	23	8.68	6.56
CAR HORN	0	1	0	0	2	1	3	6	8	20	8.76	5.89
CAT	2	5	3	5	5	6	5	7	2	1	5.39	1.87
CHEWING	1	0	2	2	8	8	5	8	2	5	6.59	2.95
CHICKENS	0	4	6	2	10	4	5	5	3	2	5.61	2.59
CHILD COUGH	0	1	1	1	5	1	4	9	9	10	7.83	3.73
CHURCH BELL	0	3	4	2	7	4	8	6	4	3	6.22	2.26
CLAPPING	2	2	1	2	10	6	7	10	1	0	5.88	3.62
CLEARING THOAT	0	0	2	2	7	3	2	11	8	6	7.34	3.51
COIN DROPPING	0	0	3	3	16	6	8	2	1	2	5.80	4.64
COW	2	3	6	1	13	5	2	6	2	1	5.24	3.48
CRUMPLING PAPER	0	1	2	4	14	4	8	4	1	2	5.88	3.97
CUCKOO CLOCK	0	1	3	4	7	3	7	8	4	4	6.56	2.47
CYMBALS	0	1	2	1	3	5	6	14	7	2	7.17	3.96
DOG BARKING	0	1	1	4	2	7	3	13	5	5	7.15	3.62
DOOR BELL	1	1	4	1	5	5	5	11	2	6	6.71	2.95
DRILL	0	2	0	0	8	1	6	10	6	8	7.46	3.70
DROPPING ICE IN GLA	2	5	3	1	12	5	5	6	1	1	5.29	3.21
DRUMS	0	2	5	2	5	4	8	9	4	2	6.34	2.66
FLUTE	5	2	5	7	4	8	4	4	1	1	4.85	2.21
FROG	3	0	7	2	10	11	4	3	0	1	5.12	3.75
GARGLING	0	0	2	2	9	5	7	11	3	2	6.66	3.59
GLASS BRAKING	0	0	0	1	5	1	2	9	12	11	8.27	4.57
HAMMERING	0	0	2	0	8	2	8	7	7	7	7.39	3.39
HARP	4	5	5	4	8	2	7	4	2	0	4.78	2.26
HELICOPTER	1	0	1	0	7	10	6	6	5	5	6.93	3.24
JACK HAMMER	0	0	0	0	1	1	1	9	12	17	8.98	5.91
KNOCKING	0	1	1	0	3	1	4	14	9	8	7.98	4.48
LAUGHING	2	1	1	1	9	5	8	7	5	2	6.41	2.95
LAWN MOWER	0	1	2	2	4	4	8	12	3	4	6.98	3.38
MOSQUITO	0	1	0	0	1	0	5	9	7	18	8.71	5.59
MOTORCYCLE	1	0	0	3	6	4	5	10	5	6	7.18	2.97
OCEAN	7	12	1	0	7	2	4	3	2	2	4.28	3.46
OWL	7	10	6	1	4	5	1	3	4	0	4.05	2.91
PIANO	2	6	3	4	7	5	8	5	1	0	5.10	2.47
PIG	0	2	2	0	16	7	7	4	2	1	5.88	4.64
PING PONG	1	1	2	3	21	4	2	4	2	1	5.46	5.73
POLICE SIREN	0	0	0	0	1	2	3	7	12	16	8.83	5.43
WATER POURING	4	3	7	7	14	0	3	2	1	0	4.27	4.06
RAIN	1	4	4	3	10	5	7	3	1	3	5.49	2.59
SAND PAPER	0	2	2	0	16	10	7	2	0	2	5.73	5.03
SAWING	0	3	5	5	8	7	6	6	0	1	5.44	2.77
SCREAM	0	0	0	0	0	1	2	4	7	26	9.38	7.66
SHEEP	1	5	6	8	9	3	5	3	1	0	4.68	2.88
SNEEZE	0	0	1	0	8	3	10	13	2	4	7.15	4.41
SNORE	0	0	2	1	3	1	5	11	5	13	8.02	4.32
SONAR	0	0	0	3	13	2	7	9	0	6	6.75	4.34
SWORDS	0	0	2	3	11	4	4	6	6	5	6.76	3.08
KETTLE WHISTLING	1	1	0	2	9	3	8	8	6	3	6.78	3.18
TELEPHONE	0	0	0	0	4	2	4	9	12	10	8.29	4.39
THUNDER	0	1	1	2	3	3	4	5	12	9	7.80	3.61
TOILET	1	1	4	0	17	8	5	2	1	2	5.56	4.87
TRAIN	0	1	1	0	9	0	7	9	9	5	7.37	3.88
TRUCK	0	0	0	1	6	1	7	15	8	3	7.59	4.66
TRUMPET	0	1	3	1	4	1	7	12	8	4	7.27	3.65
TYPEWRITER	0	1	5	2	13	4	10	2	4	0	5.76	4.09
VELCRO	0	0	0	2	15	11	4	3	1	2	6.05	4.85
VIOLIN	3	4	8	5	4	7	4	3	1	2	4.83	2.02
WATER BUBBLING	3	4	4	2	18	3	2	3	1	1	4.78	4.74
WATER DRAINING	1	2	3	4	21	7	1	1	0	1	4.93	5.96
WATER DRIPPING	0	0	2	3	7	9	8	5	2	4	6.53	3.03
WHISTLE	0	1	0	2	3	5	8	7	6	9	7.59	3.18
WHISTLING	1	1	1	2	13	5	6	9	1	2	6.15	3.94
WIND	1	0	4	2	9	6	6	8	3	2	6.22	2.88
WIND CHIME	1	2	9	1	8	3	7	6	1	3	5.61	2.95
YAWN	0	2	2	1	19	6	4	5	1	1	5.66	5.30
ZIPPER	0	1	0	0	12	6	8	10	0	3	6.60	4.40
Mean	1.025	1.7875	2.425	1.825	8.1875	4.075	5.1125	6.95	4.0375	5.2		
SD	1.767590167	2.533247669	2.21232344	1.80792526	5.020193597	2.698118557	2.370357304	3.49765546	3.346546728	5.483369744		

Appendix 2



	A	B	C	D	E	F	G	H	I	J	K	L	M
1		PLEASANT	PLEASANT	PLEASANT	PLEASANT	PLEASANT	PLEASANT	PLEASANT	PLEASANT	PLEASANT	PLEASANT 1	mean	SD
2	AIRPLANE	7	7	10	10	4	1	1	1	0	0	3.22	3.86
3	BABY CRY	8	3	8	9	7	2	1	1	0	2	3.80	3.30
4	BANJO	1	1	4	0	7	2	7	13	6	0	6.56	3.96
5	BASKETBALL	7	2	12	5	12	0	2	0	1	0	3.66	4.50
6	BIKE BELL	0	2	4	4	17	8	2	2	2	0	5.20	4.83
7	BIRDS	0	0	0	0	2	1	2	11	10	15	8.73	5.36
8	BLINDS CLOSING	12	8	6	6	4	3	1	0	1	0	3.02	3.73
9	BLOWING NOSE	14	7	12	2	4	1	0	1	0	0	2.59	4.93
10	BOAT HORN	2	2	3	6	14	4	8	2	0	0	5.00	4.06
11	BOWLING	3	4	7	2	14	1	8	1	1	0	4.61	4.16
12	BRUSHING TEETH	3	4	7	2	19	2	3	1	0	0	4.29	5.34
13	BURP	22	10	3	0	0	0	4	0	2	0	2.37	6.67
14	CAMERA	5	4	4	3	15	2	4	3	1	0	4.51	3.91
15	CAR CRASH	28	8	4	0	0	0	1	0	0	0	1.54	8.35
16	CAR HORN	8	9	13	3	5	1	1	0	1	0	3.02	4.28
17	CAT	1	3	2	4	8	8	5	6	2	2	5.80	2.43
18	CHEWING	5	5	6	6	11	7	0	1	0	0	3.95	3.53
19	CHICKENS	0	2	4	2	12	6	8	7	0	0	5.66	3.86
20	CHILD COUGH	11	10	12	2	6	0	0	0	0	0	2.56	4.87
21	CHURCH BELL	0	0	3	3	5	6	9	10	3	2	6.63	3.24
22	CLAPPING	0	0	3	5	17	4	4	7	0	1	5.66	4.87
23	CLEARING THOAT	6	7	9	9	9	1	0	0	0	0	3.27	4.01
24	COIN DROPPING	0	1	2	4	29	1	4	0	0	0	4.95	8.43
25	COW	0	1	1	1	5	11	6	12	3	1	6.71	4.13
26	CRUMPLING PAPER	2	2	5	6	18	3	3	1	0	0	4.55	5.02
27	CUCKOO CLOCK	0	1	2	4	9	6	7	8	1	3	6.27	3.05
28	CYMBALS	1	4	0	3	17	10	4	1	0	1	5.17	5.15
29	DOG BARKING	4	4	3	6	10	4	4	5	1	0	4.78	2.59
30	DOOR BELL	0	1	3	2	10	7	9	8	0	1	6.05	3.75
31	DRILL	5	5	14	7	7	1	0	2	0	0	3.46	4.25
32	DROPPING ICE IN GLAS	0	0	1	1	19	3	8	6	2	1	6.15	5.56
33	DRUMS	0	0	1	5	6	8	9	8	2	2	6.49	3.33
34	FLUTE	1	1	0	0	3	0	8	14	9	5	7.73	4.57
35	FROG	0	1	2	3	11	4	10	8	2	0	6.12	3.88
36	GARGLING	4	5	8	10	13	1	0	0	0	0	3.63	4.55
37	GLASS BRAKING	10	10	7	7	5	1	1	0	0	0	2.85	3.96
38	HAMMERING	4	4	10	4	14	1	3	1	0	0	3.98	4.32
39	HARP	0	0	0	1	2	1	7	15	11	4	8.00	4.99
40	HELICOPTER	1	5	4	6	14	6	4	0	0	1	4.66	3.99
41	JACK HAMMER	18	10	5	3	4	0	0	0	1	0	2.29	5.54
42	KNOCKING	3	3	8	8	16	1	1	0	1	0	4.07	4.87
43	LAUGHING	1	2	4	4	5	4	8	9	2	2	6.05	2.51
44	LAWN MOWER	3	2	10	9	15	0	0	1	0	0	3.90	5.10
45	MOSQUITO	17	8	7	5	3	0	1	0	0	0	2.34	5.19
46	MOTORCYCLE	5	7	4	12	11	1	0	0	0	1	3.66	4.35
47	OCEAN	3	2	2	1	6	1	5	8	4	8	6.70	2.53
48	OWL	0	0	0	0	2	6	2	17	9	5	7.98	5.20
49	PIANO	0	0	1	2	5	2	8	12	8	3	7.37	3.83
50	PIG	1	2	4	8	18	5	2	1	0	0	4.66	5.20
51	PING PONG	1	0	1	4	23	4	3	4	0	1	5.41	6.49
52	POLICE SIREN	11	13	6	4	4	2	0	1	0	0	2.71	4.41
53	WATER POURING	0	0	0	0	16	4	9	6	4	2	6.61	4.91
54	RAIN	2	1	4	6	14	2	5	5	1	1	5.27	3.75
55	SAND PAPER	2	1	6	4	24	2	1	1	0	0	4.51	6.86
56	SAWING	1	1	5	6	13	9	5	0	0	1	5.02	4.13
57	SCREAM	23	12	3	0	1	0	0	1	1	0	1.90	7.19
58	SHEEP	3	0	0	2	10	8	7	9	1	1	6.07	3.75
59	SNEEZE	5	6	7	8	14	0	0	0	1	0	3.63	4.50
60	SNORE	10	14	5	4	6	1	0	1	0	0	2.76	4.55
61	SONAR	3	4	4	7	18	4	0	0	0	0	4.13	5.20
62	SWORDS	7	7	3	9	12	3	0	0	0	0	3.51	4.16
63	KETTLE WHISTLING	1	1	5	6	13	1	7	6	1	0	5.34	3.88
64	TELEPHONE	3	2	6	3	16	3	7	1	0	0	4.68	4.53
65	THUNDER	8	5	8	6	8	2	1	1	0	1	3.58	3.16
66	TOILET	2	2	8	5	21	3	0	0	0	0	4.22	6.16
67	TRAIN	3	2	5	8	9	4	8	1	1	0	4.78	3.11
68	TRUCK	5	8	8	5	12	3	0	0	0	0	3.49	4.04
69	TRUMPET	0	2	3	3	6	13	7	6	1	0	5.83	3.81
70	TYPEWRITER	0	1	5	6	18	5	4	2	0	0	5.00	5.13
71	VELCRO	2	4	5	3	19	4	1	0	0	0	4.29	5.36
72	VIOLIN	1	2	0	1	3	5	9	9	6	5	7.15	3.08
73	WATER BUBBLING	1	1	2	0	20	2	7	5	1	2	5.83	5.66
74	WATER DRAINING	1	1	1	3	30	2	3	0	0	0	4.90	8.70
75	WATER DRIPPING	3	2	11	5	12	5	2	0	0	0	4.10	4.15
76	WHISTLE	4	6	7	7	12	2	2	1	0	0	3.88	3.67
77	WHISTLING	1	0	3	1	19	9	5	1	0	2	5.51	5.61
78	WIND	2	5	7	7	9	5	3	1	1	1	4.49	2.77
79	WIND CHIME	2	0	2	1	13	7	6	7	2	1	5.98	3.86
80	YAWN	1	1	4	6	25	2	2	0	0	0	4.63	7.20
81	ZIPPER	3	5	9	3	17	1	2	0	0	0	3.93	5.08
82	Mean	4.2125	3.6	4.8375	4.225	11.325	3.3125	3.6375	3.4125	1.3375	0.975		
83	SD	6.4822353	3.4117444	3.4111719	2.8415445	6.7021918	2.9051409	3.1154604	4.3060822	2.4389739	2.14461535		

Appendix 3

	Average Distractibility	**Average Pleasantness**
Airplane	Mean = 7.34 Sd =3.62	Mean = 3.22 SD =3.86
Baby cry	Mean = 7.90 Sd =4.35	Mean = 3.80 SD =3.30
Banjo	Mean = 15.49 Sd =3.14	Mean = 6.56 SD =3.96
Basketball	Mean = 7.27 Sd =3.94	Mean = 3.66 SD =4.50
Bike bell	Mean = 6.49 Sd =3.53	Mean = 5.20 SD =4.83
Birds	Mean = 2.80 Sd =4.53	Mean = 8.73 SD =5.36
Blinds Closing	Mean = 7.85 Sd =3.63	Mean = 3.02 SD =3.73
Blowing nose	Mean = 7.44 Sd =2.95	Mean = 2.59 SD =4.93
Boat horn	Mean = 6.76 Sd =3.24	Mean = 5.00 SD =4.06
Bowling	Mean = 6.73 Sd =4.06	Mean = 4.61 SD =4.16
Brushing teeth	Mean = 5.39 Sd =5.26	Mean = 4.29 SD =5.34
Burp	Mean = 8.54 Sd =5.32	Mean = 2.37 SD =6.67
Camera	Mean = 6.03 Sd =2.19	Mean = 4.51 SD =3.91
Car crash	Mean = 8.68 Sd =6.56	Mean = 1.54 SD =8.35

Car horn	Mean = 8.76 Sd =5.89	Mean = 3.02 SD =4.28
Cat	Mean = 5.39 Sd =1.87	Mean = 5.80 SD =2.43
Chewing	Mean = 6.59 Sd =2.95	Mean = 3.95 SD =3.53
Chickens	Mean = 5.61 Sd =2.59	Mean = 5.66 SD =3.86
Child cough	Mean = 7.83 Sd =3.73	Mean = 2.56 SD =4.87
Church bell	Mean = 6.22 Sd =2.26	Mean = 6.63 SD =3.24
Clapping	Mean = 5.88 Sd =3.62	Mean = 5.66 SD =4.87
Clearing throat	Mean = 7.34 Sd =3.51	Mean = 3.27 SD =4.01
Coin dropping	Mean = 5.80 Sd =4.64	Mean = 4.95 SD =8.43
Cow	Mean = 5.24 Sd =3.48	Mean = 6.71 SD =4.13
Crumpling paper	Mean = 5.88 Sd =3.97	Mean = 4.55 SD =5.02
Cuckoo clock	Mean = 6.56 Sd =2.47	Mean = 6.27 SD =3.05
Cymbals	Mean = 7.17 Sd =3.96	Mean = 5.17 SD =5.15
Dog barking	Mean = 7.15 Sd =3.62	Mean = 4.78 SD =2.59
Door bell	Mean = 6.71 Sd =2.95	Mean = 6.05 SD =3.75
Drill	Mean = 7.46	Mean = 3.46

	Sd =3.70	SD =4.25
Dropping ice in glass	Mean = 5.29 Sd =3.21	Mean = 6.15 SD =5.56
Drums	Mean = 6.34 Sd =2.66	Mean = 6.49 SD =3.33
Flute	Mean = 4.85 Sd =2.21	Mean = 7.73 SD =4.57
Frog	Mean = 5.12 Sd =3.75	Mean = 6.12 SD =3.88
Gargling	Mean = 6.66 Sd =3.59	Mean = 3.63 SD =4.55
Glass breaking	Mean = 8.27 Sd =4.57	Mean = 2.85 SD =3.96
Hammering	Mean = 7.39 Sd =3.39	Mean = 3.98 SD =4.32
Harp	Mean = 4.78 Sd =2.26	Mean = 8.00 SD =4.99
Helicopter	Mean = 6.93 Sd =3.24	Mean = 4.66 SD =3.99
Jack hammer	Mean = 8.98 Sd =5.91	Mean = 2.29 SD =5.54
Knocking	Mean = 7.98 Sd =4.48	Mean = 4.07 SD =4.87
Laughing	Mean = 6.41 Sd =2.95	Mean = 6.05 SD =2.51
Lawnmower	Mean = 6.98 Sd =3.38	Mean = 3.90 SD =5.10
Mosquito	Mean = 8.71 Sd =5.59	Mean = 2.34 SD =5.19
Motorcycle	Mean = 7.18 Sd =2.97	Mean = 3.66 SD =4.35

Ocean	Mean = 4.28 Sd =3.46	Mean = 6.70 SD =2.53
Owl	Mean = 4.05 Sd =2.91	Mean = 7.98 SD =5.20
Piano	Mean = 5.10 Sd =2.47	Mean = 7.37 SD =3.83
Pig	Mean = 5.88 Sd =4.64	Mean = 4.66 SD =5.20
Ping pong	Mean = 5.46 Sd =5.73	Mean = 5.41 SD =6.49
Police siren	Mean = 8.83 Sd =5.43	Mean = 2.71 SD =4.41
Water pouring	Mean = 4.27 Sd =4.06	Mean = 6.61 SD =4.91
Rain	Mean = 5.49 Sd =2.59	Mean = 5.27 SD =3.75
Sandpaper	Mean = 5.73 Sd =5.03	Mean = 4.51 SD =6.86
Sawing	Mean = 5.44 Sd =2.77	Mean = 5.02 SD =4.13
Scream	Mean = 9.38 Sd =7.66	Mean = 1.90 SD =7.19
Sheep	Mean = 4.68 Sd =2.88	Mean = 6.07 SD =3.75
Sneeze	Mean = 7.15 Sd =4.41	Mean = 3.63 SD =4.50
Snore	Mean = 8.02 Sd =4.32	Mean = 2.76 SD =4.55
Sonar	Mean = 6.75 Sd =4.34	Mean = 4.13 SD =5.20
Swords	Mean = 6.76	Mean = 3.51

	Sd =3.08	SD =4.16
Kettle whistling	Mean = 6.78 Sd =3.18	Mean = 5.34 SD =3.88
Telephone	Mean = 8.29 Sd =4.39	Mean = 4.68 SD =4.53
Thunder	Mean = 7.80 Sd =3.61	Mean = 3.58 SD =3.16
Toilet	Mean = 5.56 Sd =4.87	Mean = 4.22 SD =6.16
Train	Mean = 7.37 Sd =3.88	Mean = 4.78 SD =3.11
Truck	Mean = 7.59 Sd =4.66	Mean = 3.49 SD =4.04
trumpet	Mean = 7.27 Sd =3.65	Mean = 5.83 SD =3.81
Typewriter	Mean = 5.76 Sd =4.09	Mean = 5.00 SD =5.13
Velcro	Mean = 6.05 Sd =4.85	Mean = 4.29 SD =5.36
Violin	Mean = 4.83 Sd =2.02	Mean = 7.15 SD =3.08
Water bubbling	Mean = 4.78 Sd =4.74	Mean = 5.83 SD =5.66
Water draining	Mean = 4.93 Sd =5.96	Mean = 4.90 SD =8.70
Water dripping	Mean = 6.53 Sd =3.03	Mean = 4.10 SD =4.15
Whistle	Mean = 7.59 Sd =3.18	Mean = 3.88 SD =3.67
Whistling	Mean = 6.15 Sd =3.94	Mean = 5.51 SD =5.61

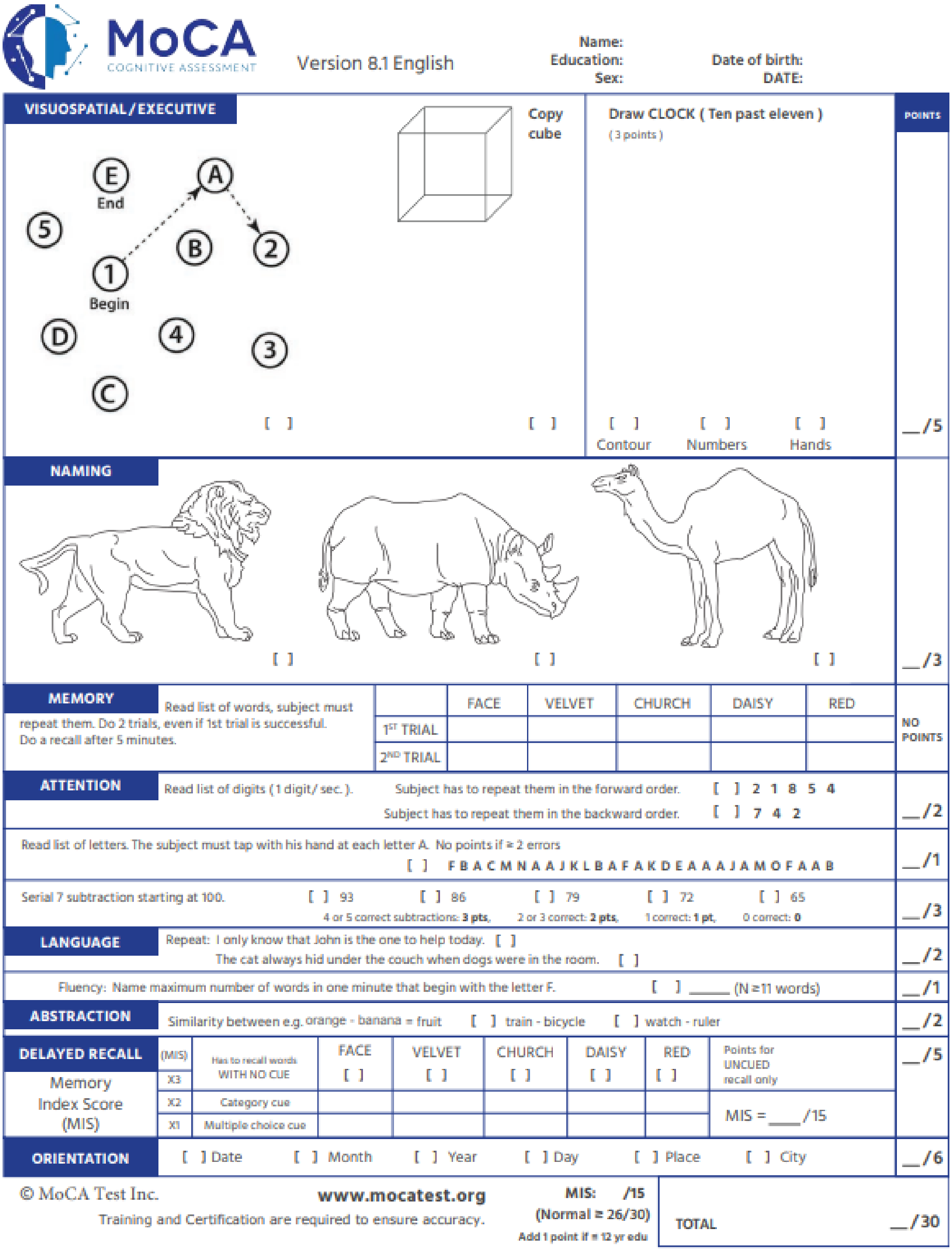
Wind	Mean = 6.22 Sd =2.88	Mean = 4.49 SD =2.77
Wind chime	Mean = 5.61 Sd =2.95	Mean = 5.98 SD =3.86
Yawn	Mean = 5.66 Sd =5.30	Mean = 4.63 SD =7.20
zipper	Mean = 6.60 Sd =4.40	Mean = 3.93 SD =5.08

Appendix 4

ARMY	HUMAN	MUSICAL	NATURAL WORLD	INDUSTRIAL	MECHANICAL	ANIMAL	COMMUNICATION	DANGER
ARMY	HUMAN	MUSIC	NATURE	BUILDING	MACHINE	ANIMAL	COMMUNICATION	ACCIDENT
MILITARY	HUMAN/PERSONAL BEHAVIOR	MUSIC ACTIVITY	NATURAL WORLD	CARPENTARY	MACHINERY	ANIMAL SOUND	DIRECTING	ANTI SOCIAL
WARFARE	HUMAN ACTIVITY	MUSIC HUMAN	OCEAN	MANUFACTURING	MECHANICAL	ANIMAL MANAGEMENT	NON-VERBAL SIGNALLING	DAMAGE
MARITIME	HUMAN BEINGS	MUSICAL	THE SEA	MENDING	ENGINE	ANIMAL NATURE	APPLAUSE	VANDALISM
NAUTICAL	HUMAN DIGESTION	REED	ENVIRONMENT	METAL	ENGINEERING	ANIMAL BIRD	VOCAL	VIOLENCE
FIGHT	HUMAN DISEASE	INSTRUMENT	ENVIRONMENTAL	TRADE PERSON	APPARATUS	BIRD	SOUND	SAFETY
HUNTERS	HUMAN EMOTION	INSTRUMENTAL	WEATHER	TOOL/ USE OF TOOL	CLOCK	BIRDS	ELECTRONIC	
	HUMAN ENDEVOUR	PERCUSSION INSTRUMENT	MARINE	WOOD	TECHINICAL	AMPHIBIAN	DISTRACTING	
	HUMAN NOISE	MECHANICAL MUSIC	LIQUID	WOOD WORK	FUNCTIONAL	AVIAN		
	HUMAN SOUND		NOISE POLLUTION	WORK	TIME PIECE	PET		
	HUMAN RELATED		NOISE	WORKING	TIME	POULTRY		
	HUMAN VOICE		NATURAL	WORKING TOOLS	HOROLOGY	FAMILY PET		
	HUMAN WORKING		WATER	WORK MAN	GADGET	INSECT		
	THE BODY			PLUMING	MECHANICAL ELECTRIC	INSECT FLYING		
	CHILD			ROAD NOISE	MECHANICAL MAN MADE	ORNITHOLOGY		
	CHILDREN			ROAD WORKS	DEVICES	DOMESTIC ANIMAL		
	THRISTINESS			DIY				
	EATING			DIY TOOLS				
	FAMILY			CONSTRUCTION				
	THROAT VOICE			LABOUR				
	PEOPLE			MANUAL / WORK				
	BODILY FUNCTION			MAINTINANCE				
	BODILY NOISE			COMMERCIAL				
	BODILY SOUND			EQUIPMENT				
	PARENTHOOD			INDUSTRY				
	DIGESTION			INDUSTRIAL				
	HUMAN ACTION			INDUSTRIAL NOISE				
	SLEEP			MAN MADE				
				HUMAN WITH TOOLS				

TRANSPORT	HOUSEHOLD/RESIDENTIAL	WARNINGS	LIFESTYLE	HYGIENE + HEALTH	AGRICULTURE	MISCELLANEOUS	EMOTION + EXPRESSION	WORK
TRANSPORT	HOME	ALARM	RECREATION/SPORT	DENTAL HEALTH	FARM	TRADITION	APPRECIATION	OCCUPATION
TRANSPORT MECHANICAL	HOME IMPROVEMENT	ALERT	HOBBY	ORAL HYGIENE	FARM ANIMALS	LUCK	ANNOYING	OFFICE
TRANSPORTATIONAL	HOUSE	NOTIFICATION	LIFE LIFESTYLE	HYGINE	FARM YARD	PAST TIME	BOREDOM	OFFICE EQUIPMENT
LOCOMOTIVE	HOUSEHOLD	AUDIABLE SIGNALLING	LEISURE	MEDICAL	COUNTRY SIDE	CEREMONY	ENJOYMENT	RETAIL
AVIATION	HOUSE ITEM	DANGER	LEISURE ACTIVITY	ILLNESS	COUNTRY SOUND	ART	HAPPINESS	OUTDOOR WORKING
AIRCRAFT	HOUSE WORK	WARNING	LEISURE SPORT	HEALTH	AGRICULTURE	ARTIFACTS	FEAR	ENTERPRISE
TRAVEL	CLEAN	EMERGENCY	EXERCISE	BIOLOGICAL		HABIDASHERY	HABIT	DOMESTIC COMMERCIAL
FREIGHT	CLEANLINESS	EMERGENCY SERVICE	COMMUNITY	PERSONAL		MISCELLANEOUS	EMOTION	COMMERCIAL
FLIGHT	KITCHEN	EMERGENCY VEHICLE	ACTIVITIES	PERSONAL HYGIENE		PHENOMENONO	EMOTIONAL	SECRETARIAL
FLYING	KITCHEN SOUND		AUDIENCE	DIET		EXPENDITURE	IGNORANT	
CYCLING	KITCHEN GADGED		ENTERTAINMENT	HUMAN AIRWAY OBSTRUCTION		FINANCIAL	PLEASANTNESS	
VEHICLE	BATHROOM		PARKS			MONEY	PERSONAL BEHAVIOUR	
VEHICULAR	COOKING		PLAYING			CLOTHING	TIREDNESS	
VEHICLE BOAT	GARDEN		SOCIALISING			FANTASTIC	PLEASURE	
DRIVING	FOOD		SPORT			DROPPED ITEM	RUDENESS	
TRAFFIC	FOOD AND DRINK		SPORT EQUIPMENT			GENERAL NOISE	AMUSEMENT	
HIGHWAY	DRINKING		CAMPING			GENERIC	FRIGHT	
SHIPPING	DRINK		EVERYDAY			GARDEN PARAPHANALIC		
MOTOR	NOISY TOY		PHOTOGRAPHY			UNWRAPPING		
	BEVERAGE		GARDENING			URBAN SETTING		
	DOMESTIC		RELIGION/RELIGIOUS			REFRESHMENT		
	DOMESTIC ACTIVITY		BEER MAKING			OBJECT		
	BUILDINGS		GAMES			MATERIAL		
			LIFE			ECCLEUSUASTICAL		
			ARTS			ELEMENT		
			CHILDREN PLAYING			UNKNIOWN/DON’T KNOW		
						WASTE		
						CONFECTIONARY		
						ACCESS		
						NONE		
						GENERAL		
						UNIDENTIFIABLE		

Appendix 5



MoCA COGNITIVE ASSESSMENT

Version 8.1 English

Name:
Education:
Sex:
Date of birth:
DATE:

POINTS

VISUOSPATIAL / EXECUTIVE

[ ]

Copy cube

[ ]

Draw CLOCK (Ten past eleven) (3 points)

[ ] Contour [ ] Numbers [ ] Hands

__ /5

NAMING

[ ] [ ] [ ]

__ /3

MEMORY Read list of words, subject must repeat them. Do 2 trials, even if 1st trial is successful. Do a recall after 5 minutes.

	FACE	VELVET	CHURCH	DAISY	RED
1ST TRIAL					
2ND TRIAL					

NO POINTS

ATTENTION Read list of digits (1 digit/ sec.).

Subject has to repeat them in the forward order. [ ] **2 1 8 5 4**

Subject has to repeat them in the backward order. [ ] **7 4 2**

__ /2

Read list of letters. The subject must tap with his hand at each letter A. No points if ≥ 2 errors

[ ] **F B A C M N A A J K L B A F A K D E A A A J A M O F A A B**

__ /1

Serial 7 subtraction starting at 100. [ ] 93 [ ] 86 [ ] 79 [ ] 72 [ ] 65

4 or 5 correct subtractions: **3 pts**, 2 or 3 correct: **2 pts**, 1 correct: **1 pt**, 0 correct: **0**

__ /3

LANGUAGE Repeat: I only know that John is the one to help today. [ ]

The cat always hid under the couch when dogs were in the room. [ ]

__ /2

Fluency: Name maximum number of words in one minute that begin with the letter F. [ ] _____ (N ≥11 words)

__ /1

ABSTRACTION Similarity between e.g. orange - banana = fruit [ ] train - bicycle [ ] watch - ruler

__ /2

DELAYED RECALL

Memory Index Score (MIS)

(MIS)	Has to recall words	FACE	VELVET	CHURCH	DAISY	RED	
X3	WITH NO CUE	[ ]	[ ]	[ ]	[ ]	[ ]	Points for UNCUED recall only
X2	Category cue						MIS = ___ /15
X1	Multiple choice cue						

__ /5

ORIENTATION [ ] Date [ ] Month [ ] Year [ ] Day [ ] Place [ ] City

__ /6

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Training and Certification are required to ensure accuracy.

MIS: /15
(Normal ≥ 26/30)
Add 1 point if ≤ 12 yr edu

TOTAL __ /30

ADMINISTERED BY Richards, Leanne MOCA CERTIFIED RATER ID GBRICLE710622423-01

Appendix 6

Balance and gait questionnaire

Thank you for taking the time to complete this questionnaire. We are collecting this data to understand if hearing/hearing problems and pharmaceuticals may influence the gait cycle.

(Please circle your response to each question)

Have you experienced vertigo following the onset of a loud noise?

Yes	**No**

Have you suffered with balance changes following the onset of a loud noise?

Yes	**No**

Have you suffered with auditory or visual change following the onset of loud noise?

Yes	**No**

Have you been ever diagnosed with Hearing loss

Yes	**No**

Have you been ever diagnosed with Labyrinthitis

Yes	**No**

Have you been ever diagnosed with Meniere’s disease

Yes	**No**

Do you experience frequent light-headedness when looking up or down

Yes	No

Do you currently take daily medication? ***(If no, please ignore the remaining questions)***

Yes	No

How many different tablets do you take a day?

Do you take opioid-based pain medication?

Yes	No

Do you take cardiovascular medication?

Yes	No

Do you take anticonvulsant medication?

Yes	No

Do you take anti-anxiety medication?

Yes	No

Participant ID	
Date	

Appendix 7

TINETTI BALANCE ASSESSMENT TOOL

BALANCE SECTION

	Date		
Sitting Balance	Leans or slides in chair = 0		
	Steady, safe = 1		
Rises from chair	Unable to without help = 0		
	Able, uses arms to help = 1		
	Able without use of arms = 2		
Attempts to rise	Unable to without help = 0		
	Able, requires > 1 attempt = 1		
	Able to rise, 1 attempt = 2		
Immediate standing Balance (first 5 seconds)	Unsteady (staggers, moves feet, trunk sway) = 0		
	Steady but uses walker or other support = 1		
	Steady without walker or other support =2		
Standing balance	Unsteady = 0		
	Steady but wide stance and uses support = 1		
	Narrow stance without support = 2		
Nudged	Begins to fall = 0		
	Staggers, grabs, catches self = 1		
	Steady = 2		
Eyes closed	Unsteady = 0		
	Steady = 1		
Turning 360 degrees	Discontinuous steps = 0		
	Continuous = 1		
	Unsteady (grabs, staggers) = 0		
	Steady = 1		
Sitting down	Unsafe (misjudged distance, falls into chair) = 0		
	Uses arms or not a smooth motion = 1		
	Safe, smooth motion = 2		

	Balance score	/16	/16

Completed by: .... **Signature:** ....

Designation: .... **Date:** ....

TINETTI BALANCE ASSESSMENT TOOL

GAIT SECTION

	Date		
Indication of gait (Immediately after told to 'go'.)	Any hesitancy or multiple attempts = 0 No hesitancy = 1		
Step length and height	Step to = 0 Step through R = 1 Step through L = 1		
Foot clearance	Foot drop = 0 L foot clears floor = 1 R foot clears floor = 1		
Step symmetry	Right and left step length not equal = 0 Right and left step length appear equal = 1		
Step continuity	Stopping or discontinuity between steps = 0 Steps appear continuous = 1		
Path	Marked deviation = 0 Mild/moderate deviation or uses w. aid = 1 Straight without w. aid = 2		
Trunk	Marked sway or uses w. aid = 0 No sway but flex. knees or back or uses arms for stability = 1 No sway, flex., use of arms or w. aid = 2		
Walking time	Heels apart = 0 Heels almost touching while walking = 1		
	Gait score	/12	/12
Balance score carried forward		/16	/16
Total Score = Balance + Gait score		/28	/28

Risk Indicators:

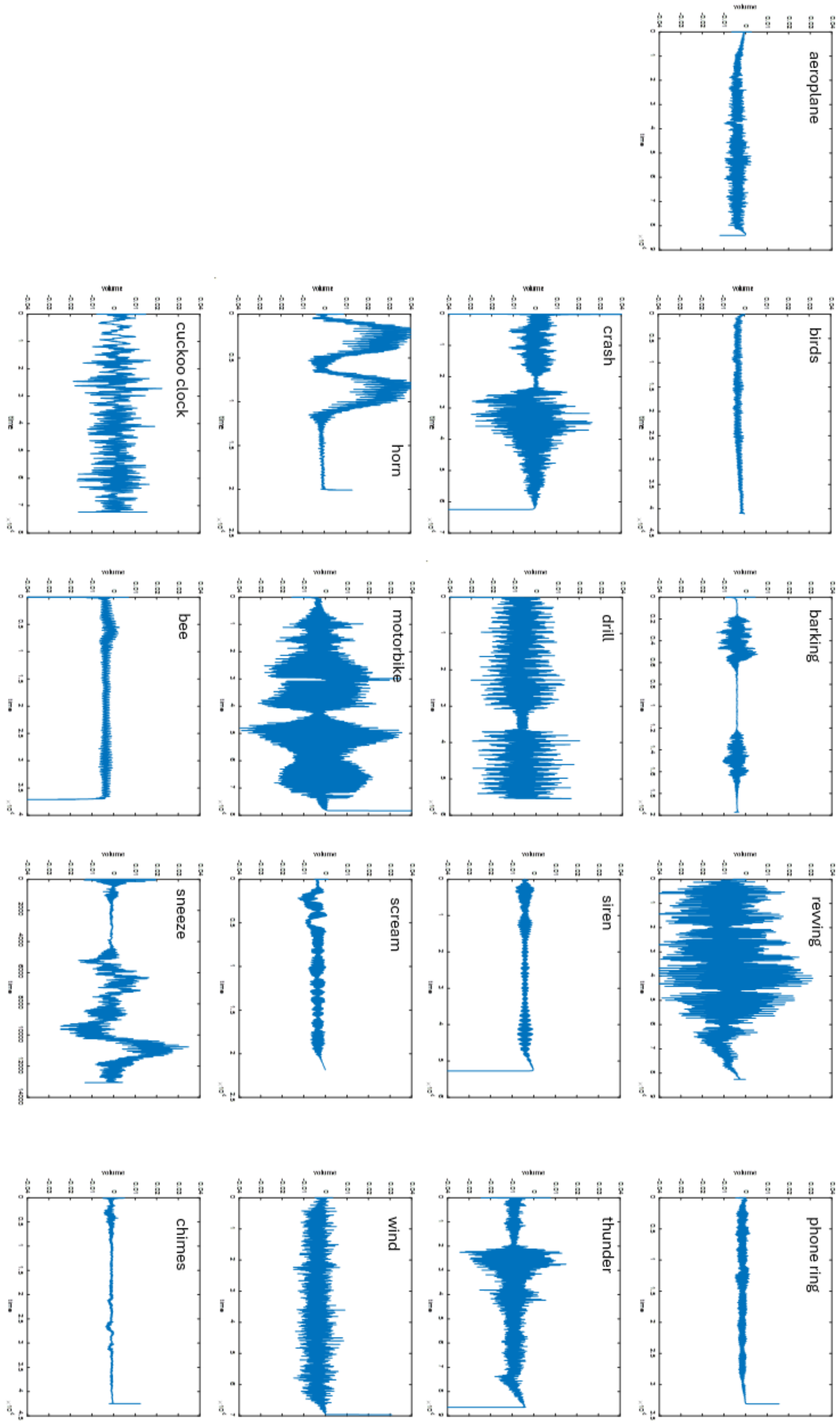
Tinetti Tool Score	**Risk of Falls**
≤18	High
19-23	Moderate
≥24	Low

Tinetti ME, Williams TF, Mayewski R, Fall Risk Index for elderly patients based on number of chronic disabilities. Am J Med 1986:80:429-434

Completed by: .... **Signature:** ....

Designation: .... **Date:** ....

Appendix 8


aeroplane
birds
barking
revving
phone ring
crash
drill
siren
thunder
horn
motorbike
scream
wind
cuckoo clock
bee
sneeze
chimes
volume
time

Appendix 9

Participants were asked at the end of the test how they felt the study went. The views / comments below are a collection of what participants stated. There was a consensus of views, particularly via feeling startle to sounds, hence the limited selection of responses.

- First few sounds presented in the sound test were startling as they were not expected
- First 5 or 6 sounds startle and took away focus
- Attention was not as good when the sounds were playing
- Participant 10 – the onset of sounds startles and it was noted that it made her jump
- The test being run with sounds was distracting and felt like it reduced performance
- Distracting sounds were representative of job role (i.e., midwife outlined that the screaming, baby crying and siren noise placed her on heightened alert, where she felt concentration was increased. A steel worker noticed the heavy industry noises which they felt increased their attention, but did not notice other sounds used)
- A selection of participants outlined that they felt a startle throughout the test not just at the beginning.
- Those who are active in the environment (i.e., walking) felt that whilst the environmental sounds capture their attention quickly, they got used to it as they walking in noisy environments every day.
- Task performance was better with silent condition as there was no distraction
- Sounds helped performance and concentration of the screen (noted in 4 participants)
- Attention could not be sustained longer than approximately 4 minutes during the sound condition, but comfortable with silent condition

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