The complex interrelationship of sleep and circadian rhythmicity with falls risk and postural control in healthy adults in the field and in the laboratory: Effects of sex, sensorial feedback and work environment

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Abstract

Background**:** Postural control is fundamental for maintaining balance and stability during daily activities and work-related tasks. Impairments in postural control increase the risk of falls and accidents, particularly among aging populations and in high-risk occupational settings. Sleep and circadian rhythmicity are critical physiological processes that support neural functions underlying postural control. Disruptions in sleep and circadian rhythms, common with aging, certain health conditions, and shift work are major risk factors for adverse health outcomes, including falls. However, the specific impact of sleep propensity and circadian rhythmicity on postural control as individuals age remains unclear, as does the influence of sensory feedback and sex on this relationship. Additionally, the extent to which lengthy work hours, shift work, and insufficient sleep contribute to fall risk in hazardous occupations is not well understood. The current study aimed to address these gaps through comprehensive observational and experimental research, focusing on how sleep and circadian factors affect postural control in aging populations and high-risk occupational environments.

Methods: The first study investigated the intricate relationship between sleep and circadian rhythmicity in older men and women and consisted of an observational and an experimental phase. In the observational phase older adults (N=166) with no cognitive impairment underwent a comprehensive screening assessing sleep, lifestyle, mental health, and self-perceived risk of falls. In phase two a subgroup of the screened participants (N=38) took part in a randomized experimental laboratory-based study involving 40 hours of sleep deprivation or multiple naps to assess the effect of sleep restriction, time of the day and sensorial feedback on balance control. Subjective and objective vigilance, visuo-motor coordination, and postural control were assessed at four-hourly intervals throughout the session. Postural control was characterized by quantifying the dynamics of the body's center of pressure using a force plate under varying visual and haptic feedback conditions.

The second study investigated the feasibility of remotely assessing sleep and postural control in a group of mariners on duty (N = 105), who completed multiple questionnaires concerning health, lifestyle, work patterns, sleep, and fall-related concerns.

Results: In the community-dwelling cognitively healthy older adult cohort, higher self-perceived risk of falls was associated with poorer reported sleep quality as well as with lower self-reported mental and physical health. There were also some sex differences, with women reporting worse sleep quality and

showing a significantly stronger association between falls concerns and physical health, whereas men showed a significantly stronger association between falls concerns, age, and bedtime. Interestingly physical health was the only independent predictor of self-perceived risk of falls when all potential predictors were included in a multivariate model. In the experimental study sleep restriction did not have an independent effect on postural control but increased the subjective effort to maintain balance. Moreover, sleep deprivation disrupted postural stability substantially more in males, particularly in the eyes-open sensorial condition. The remote assessment of self-reported sleep, lifestyle and wellbeing and falls risk in mariners proved feasible and showed that longer self-reported sleep latency was associated with increased falls concerns in this population.

Conclusions: The findings provide a better mechanistic understanding of the multifaceted nature of postural control, indicating that older men with sleep disturbances are at increased risk of falls, particularly at night and in dim light conditions. Increased sleep latency, commonly associated with sleep-onset insomnia, appears to correlate with falls concerns in mariners. The current study suggests that tailored fall prevention strategies should consider the effects of sex, sensory context, sleep, and circadian disruption in both community and occupational settings.

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Abbreviations

AP - Anterior-posterior

APOE – Apolipoprotein E

BMI - Body Mass Index

CCI – Cognitive Change Index questionnaire

CoP - Center of Pressure

COGT – Cognitive Test Battery

EC – Entorhinal Cortex

EC - Eyes Closed

ECG - Electrocardiography

EEG - Electroencephalography

EMG - Electromyography

EO - Eyes Open

EOG - Electrooculography

ESS - Epworth Sleepiness Scale

FES - Falls Efficacy Scale

FP - Force Plate

FT - Force Torque

GABA – Gamma-Aminobutyric Acid

GAD-7 - Generalized Anxiety Disorder Questionnaire

GMQ - General Medical Questionnaire

ISI - Insomnia Severity Index

KDT - Karolinska Drowsiness Task

KSD – Karolinska Sleep Diary

KSS - Karolinska Sleepiness Scale

MADRE - Mannheim Dream Questionnaire

m-ACE – Mini Addenbrooke's Cognitive Examination

MCI – Mild Cognitive Impairment

MCTQ – Munich Chronotype Questionnaire

MEQ - Morningness-Eveningness Questionnaire

MESOR – Midline Statistic Of Rhythm

ML - Medial-lateral

MN – Multi-nap

N1, N2, N3 – Non-REM Sleep Stages 1,2,3

NREM – Non-rapid Eye Movement Sleep

PC - Postural Control

PCT - Posturography Test

PHQ-9 - Patient Health Questionnaire

PSG - Polysomnography

PSQI - Pittsburgh Sleep Quality Index

PVT - Psychomotor Vigilance Task

RT - Reaction Time

SCN – Suprachiasmatic Nucleus

SD - Standard Deviation

SDMT – Symbol Digit Modalities Test

SEM - Standard Error of the Mean

SE – Sleep Efficiency

SF-36 - Short Form 36

SQ – Sleep Quality

TIB – Total Time In Bed

TMT – Trail Making Tests

TST – Total Sleep Time

ToT - Time on Target

VAS - Visual Analog Scale

Conference Participation

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Z. Shabana, A. Michalak, V. Grove, S. Laycock, L. Johannsen3, A. S. Lazar; "Effects of sleep loss and time of day on postural control: A randomized controlled sleep deprivation versus multi-nap study in healthy older men and women" ESRS 2020, Sevilla, Spain.

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Statement of Contribution

During my doctoral research, I made significant contributions across all phases of the project, including study design and methodological planning, ethics applications and amendments, participant recruitment, comprehensive data collection, data analysis, and dissemination of findings. My involvement was hands-on and extensive, reflecting my commitment to advancing the understanding of sleep and postural control, particularly within the unique context of maritime workers. This research interest originated from my background as a medical navy officer, where I often witnessed and experienced the adverse effects of sleep loss on performance and balance control.

Study Design and Methodological Planning

At the outset, I was instrumental in designing the study and planning the methodology, which was crucial for addressing gaps in the existing literature. I formulated research questions, developed hypotheses, and determined appropriate observational and experimental methods. This included selecting suitable measurement tools for assessing sleep, circadian rhythms, and postural control, while considering factors such as sensory feedback and sex. By ensuring methodological rigor and alignment with research objectives, I contributed to the scientific robustness and credibility of the study.

Ethics Applications and Amendments

I played a pivotal role in the ethical aspects of the research. I prepared and submitted ethics applications, amending the ethical framework to incorporate the postural control aspect and the risk of falls. For the mariners' study, I developed a new ethics proposal from scratch, addressing unique considerations inherent to maritime research. Throughout the study, I managed ethics amendments, ensuring compliance with institutional and national guidelines. This meticulous attention to ethical standards upheld the integrity of the research and reinforced the ethical practices within our research group and the university.

Participant Recruitment and Engagement

A significant portion of my work involved recruiting participants for all phases of the study, utilizing diverse strategies to ensure a representative sample. I engaged with participants through interviews, phone calls, and administering cognitive tests and questionnaires. These interactions were critical for building rapport, ensuring participant compliance, and gathering high-quality data. My efforts directly contributed to the success of the research projects and strengthened the collaborative environment within our team.

Data Collection and Laboratory Work

My involvement in data collection was extensive and hands-on. I managed data collection across all phases, including both field and laboratory settings. In the laboratory, I was responsible for the physical setup and operation of experiments, often working 12-hour shifts to accommodate participants' schedules and experimental protocols. This sometimes involved extending beyond scheduled hours due to colleagues' absences or the need for handovers, demonstrating my flexibility and dedication.

I managed equipment, guided participants through procedures, and ensured the smooth operation of data collection processes. Tasks such as connecting electrodes to participants required precision and care to ensure accurate data recording and participant comfort. My meticulous approach was crucial for obtaining reliable data on postural control and related physiological measures, directly impacting the quality and validity of the research findings.

Data Analysis and Management

After data collection, I undertook comprehensive data analysis, managing all phases of this process. I was involved in data management tasks such as backing up files, checking data quality, and organizing datasets. I processed and analyzed the data using software tools including MATLAB, SAS, and SPSS. This involved running scripts, performing statistical analyses, and interpreting results. I created statistical figures and tables to visualize the data and support the findings, contributing to the clarity and impact of the research outcomes. My analysis focused on identifying patterns and correlations regarding how sleep and circadian rhythms impact postural control among healthy older adults and maritime workers.

Dissemination of Findings and Academic Impact

I actively contributed to disseminating the research findings through publications and conference presentations, both as a main author and co-author. Presenting at international conferences elevated the visibility of our work and fostered academic discourse (see page 8).

Contribution to the Research Group and University

Given my active involvement in running the Wellcome trust-funded research study my work has bolstered the research efforts of the Sleep and Brain Research Unit at the University of East Anglia (UEA), contributing to its mission of enhancing health and well-being through sleep research.

By adhering to high professional standards in conducting scientific research I have supported the group's reputation for excellence. My flexibility and dedication in handling extensive data collection and laboratory procedures have enhanced the operational efficiency and research output of the unit.

Furthermore, I played a crucial role in the procurement of necessary materials and equipment for the project. This involved identifying suppliers, managing budgets, and ensuring timely delivery of resources essential for the study's progression. This work has significantly facilitated the research effort of the SBRU.

Beyond the core aspects of my thesis, I contributed to related projects within our research group, demonstrating collaborative spirit and supporting the broader activities of our team. I assisted in distributing actiwatches to participants for other studies, ensuring accurate recording of sleep patterns and activity levels. I also played a role in managing reimbursements for staff and participants, helping to maintain positive engagement throughout the study period. These collaborative efforts have enriched the research outcomes and expanded the impact of our work across multiple domains.

Summary

In summary, my contributions to the research were multifaceted and extensive. From engaging with participants and collecting data to managing laboratory sessions, procuring materials, tailoring ethical

frameworks, and analyzing data, each aspect of my involvement was driven by a commitment to excellence and a passion for advancing knowledge in the field. The novel insights derived from my research not only contribute to academic literature but also have practical implications for improving safety and performance in various occupational settings. Additionally, my support in ancillary tasks like distributing actiwatches and managing reimbursements further underscores my comprehensive involvement in the research efforts.

Through my doctoral research, I have significantly advanced the understanding of how sleep and circadian rhythms impact postural control, particularly among older adults and maritime workers. By integrating study design, ethical considerations, comprehensive data collection, and rigorous analysis, I have contributed to the scientific robustness and credibility of the research. My findings have practical applications for improving safety and reducing falls risk, informing interventions and policies that enhance health and well-being on a broader scale. My contributions have supported the goals and reputation of the Sleep and Brain Research Unit and the University of East Anglia, advanced scientific understanding within the academic community, and have the potential to benefit public health and safety.

General Introduction

Postural control is a fundamental requirement for human performance, providing individuals with the ability to maintain balance and orientation during various activities. These include basic activities such as standing or walking, as well as more complex movements required in daily life and occupational tasks (Shumway-Cook & Woollacott, 2007). Effective control of posture is essential not only for maintaining balance in routine activities but also for safely performing work-related or athletic tasks. In occupational environments where physical hazards are present, good postural control contributes significantly to personal safety and operational efficiency.

Control of posture depends on the intricate integration of sensory, motor, and cognitive processes. The human body utilizes three primary sensory systems to sustain balance: the visual system provides information about body position relative to the environment; the vestibular system detects changes in head movement and spatial orientation; and the somatosensory system conveys feedback from muscles and joints regarding body position (Horak, 2006). These sensory inputs are integrated by central nervous system pathways, which coordinate appropriate motor responses to maintain balance and stability.

Multiple factors influence the effectiveness of this complex physiological process, underscoring the importance of studying postural control in both older adult populations and occupational contexts. As individuals age, sensory and motor functions typically decline, leading to reduced postural stability and an increased likelihood of falls and related injuries (Rubenstein, 2006). Among older adults, falls represent a leading cause of injury and mortality, often resulting in diminished quality of life and substantial healthcare costs (Ambrose, Paul & Hausdorff, 2013). Additionally, various acute and chronic health conditions—such as stroke, Parkinson's disease, and multiple sclerosis can disrupt neural pathways essential for balance, further compromising postural control (Horak, 2006). Sensory impairments, including deficits in vision or vestibular function, also adversely affect balance, with the risk of such impairments increasing with age (Tideiksaar, 2002; Macedo et al., 2015).

Environmental factors such as uneven surfaces, inadequate lighting, and confined spaces can further challenge postural control. This is particularly relevant in occupations with a high risk of falls or accidents, where such environmental challenges are common (Komisar et al., 2019). Lifestyle factors, notably sleep, also play a critical role in supporting effective postural balance. Sleep is a vital physiological process that influences central nervous system function, which underpins cognition, motor coordination, and the neuromuscular integration required for balance (Alhola & Polo-Kantola, 2007). Insufficient sleep can

disrupt these processes, leading to impaired balance, slower reaction times, and increased fall risk (Stevens et al., 2020).

Both the quantity and quality of sleep tend to decline with age, which can have profound implications for neurological health and postural control. Older adults often experience reductions in deep sleep and more fragmented sleep patterns, which are linked to an elevated risk of falls posing significant challenges for public health systems (Crowley, 2011). Understanding how sleep patterns interact with balance control in older adults is therefore crucial, given the high prevalence of sleep disturbances in this population and their association with increased risk of injury.

Recent research has greatly advanced our understanding of the importance of sleep, emphasizing not only its duration but also its quality. Sleep involves multiple stages, including non-rapid eye movement (non-REM) and rapid eye movement (REM) phases, which cycle throughout the night. The architecture of these stages plays an essential role in cellular restoration, neuroplasticity, and memory, all of which have critical implications for mental and physical functioning (Stickgold, 2005).

Patterns of sleep disruption, such as those experienced by shift workers, have been shown to significantly impair postural control and increase the risk of accidents (Belenky et al., 2003; Ma et al., 2009). Sleep disturbances disrupt circadian rhythms, the internal biological clocks that regulate sleep–wake cycles and other physiological processes, thereby negatively affecting both cognitive and physical performance. Maintaining healthy sleep patterns is thus essential for preserving postural control and reducing the risk of falls, especially in occupations that inherently involve elevated risk.

The maritime industry offers a distinctive example of such challenging work environments. Mariners are frequently exposed to extended working hours, irregular shift patterns, confined living quarters, and limited natural light, all of which can disrupt sleep and circadian alignment (Flynn-Evans et al., 2016). Additionally, mariners must maintain balance on moving vessels while navigating unstable environments that demand rapid reactions and precise motor coordination for safety (Paillard, 2017). Environmental challenges such as limited visibility and unsteady surfaces further complicate the maintenance of balance in these settings (Komisar et al., 2019).

Investigating mariners provides valuable insights into how sleep disturbances impact postural control under extreme conditions, with implications that extend to other high-risk professions. By examining the experiences of maritime workers, this research aims to deepen our understanding of how sleep, circadian

rhythms, and environmental factors interact to influence equilibrium and functional performance in demanding contexts.

This thesis addresses two primary research questions concerning postural control and sleep. These questions are explored across two main chapters with multiple sub-sections. Chapter 1 investigates the complex, both non-causal and causal, relationships between sleep and postural control in healthy older adults. It begins with a narrative review of the pertinent literature (1.1), followed by sections outlining the study aims and objectives (1.2), the methodology of two empirical studies (1.3), and their results (1.4). The first empirical study employs an observational design to explore associations between subjective sleep parameters and self-reported fall risk, while the second uses an experimental design to determine the mechanistic effects of acute sleep restriction and time of day on objectively measured postural control. Both studies also examine the role of sex differences, given their relevance to fall risk and susceptibility to sleep loss. This chapter concludes with a discussion of the findings (1.5).

Chapter 2, motivated by occupational health concerns, focuses on the self-reported challenges mariners face regarding sleep, circadian rhythms, and potential fall risk. Due to the limited research in this area and the logistical challenges of conducting sleep studies among maritime workers, this chapter primarily assesses the feasibility of using a questionnaire-based methodology to generate meaningful quantitative data on sleep and postural control in this population. It includes an introduction to the occupational health context (2.1), research aims and objectives (2.2), methodology (2.3), results (2.4), and a discussion (2.5).

Finally, Chapter 3 provides an integrated discussion of key findings on the interplay of sleep, circadian rhythms, postural control, and fall risk. It highlights common themes, such as the impact of sleep disruption on fall efficacy, and examines population-specific differences in sensory integration and occupational hazards. This chapter also outlines the strengths and limitations of the studies, discusses unexpected findings, and suggests implications for practice and directions for future research to enhance safety and well-being across diverse adult populations.

In summary, exploring sleep, circadian rhythms, and their impact on postural control is essential for understanding broader implications for health and safety, particularly in aging populations and high-risk occupational settings. This thesis aims to clarify these relationships, providing a foundation for future research and interventions aimed at mitigating falls risk and enhancing overall well-being.

Chapter 1

Postural Control, Sensory feedback and Risk of Falls: The Impact of Sleep and Circadian Rhythmicity in Healthy Older Men and Women

Postural control is known to be the ability to maintain stability and orientation during daily tasks ranging from simple movements to more complex activities. In later adulthood, physiological shifts affecting sensory processing, motor function, and cognitive capacity often reduce postural stability, contributing to elevated fall rates and associated injuries. Investigating the factors that influence postural control in older populations is of critical importance.

Sleep represents a key determinant in this process. Adequate sleep restores cognitive function and supports motor coordination, but aging frequently brings about alterations in sleep patterns such as reduced total sleep time and increased prevalence of insomnia, that compromise daytime alertness and mental functioning needed for balance. Alongside these sleep disruptions, circadian rhythms, which regulate the sleep–wake cycle and other biological processes, also affect overall health and sleep quality. Circadian misalignment, commonly observed in advanced age, can compound existing sleep disturbances, further undermining postural stability.

These interconnected influences of sleep, circadian rhythms, and postural control warrant focused attention, particularly given the heightened vulnerability of older adults. This chapter explores these relationships in healthy older men and women, illustrating how shifts in sleep architecture and circadian regulation may increase the risk of falls. A clearer understanding of these mechanisms is essential for enhancing sleep quality, support balance, and ultimately promote safer aging with reduced risk to fall incidents.

1.1 Background

1.1.1 Postural Control and Falls Risk

Postural control (PC), the ability to maintain or restore the body's center of mass within the base of support, is fundamental to our daily functioning. From standing and walking to complex athletic movements, effective postural control is critical. PC, just like most functions in our organism, presents marked changes throughout the lifespan associated with maturation and aging. As individuals age, several physiological changes occur that affect their ability to maintain balance and posture, thereby increasing

the risk of falls (Lord et al., 2003; Rubenstein, 2006). The risk of falls can also increase in various health conditions affecting the visual, vestibular, and/or various segments of the proprioceptive and sensory-motor systems in any age group. Importantly, falls represent a significant hazard to health in numerous occupations where a combination of extended work hours and adverse environmental factors (e.g., reduced visibility, moving platform, lack of support) compromise PC. This thesis seeks to comprehensively explore the complex interrelationship between sleep, circadian rhythmicity, and risk of falls in healthy older men and women, as well as in a pilot manner in mariners, an occupation exposed to multiple risk factors for falls.

1.1.1.1 Definition and Components of Postural Control

Postural control is a fundamental neurophysiological function (Winter et al., 1998; Pollock et al., 2000), essential for maintaining balance and orientation of the body (Peterka & Loughlin, 2004; Thomas et al., 2003). Postural control involves both static and dynamic components. Static posture control means keeping a steady position when standing without motion. Measures like COP displacement and sway speed evaluate stability (Raymakers et al., 2005). Dynamic posture control is about maintaining balance during movements, for instance walking or weight shifting. Parameters such as stride length, the speed of gait and capacity to recover from disturbances give understanding into dynamic stability (Horak et al., 1989). To comprehend postural control we must recognize its complex structure which includes sensory input systems, central processing and motor output. These sensory systems cover the visual, vestibular and somatosensory roles. Each system is very important as they provide signals about where your body is positioned in space (Fitzpatrick, R., & McCloskey, D. I., 1994). This data then gets processed inside the brain - more especially within neural networks found in areas of the brain like the cerebellum and sensorimotor cortex that produce motor outputs. These outputs manifest as coordinated muscle activities that maintain or alter body positioning to achieve a balanced state. Postural control is achieved through the fine-tuned interaction between multiple sensorimotor processes (Horak, 2006) and its impairment can increase the risk of falls (Redfern et al., 2001). Given that life evolved in the presence of gravity, there is a complex neurophysiological system in place that is responsible for maintaining tonic muscle contractions that will act against gravity, stabilizing the positions of body segments. When all the forces acting upon an object balance each other, the object will be at equilibrium; it will not accelerate. The term balance is defined in mechanics as the state of an object (static or movement) when the resultant load actions (forces) acting upon it are zero and as such there is no acceleration (Newton's First Law). The control of the upright posture can be well described based on the mechanics of the inverted pendulum. In this model, the

movements of the center of mass (CoM) or gravity (CoG) and of the center of pressure (CoP) are important measures of postural stability. The ability of an object to balance in a static situation is related to the position of the CoM and the area of the base of support (BoS) of that object. In an oversimplified inverted pendulum model of the upright human posture, the center of body mass (CoM) is the single controlled variable (Winter et al., 2003). CoP oscillates on either side of CoM to keep it in a fairly constant position between the two feet (Ivanenko et al., 1999). Since the center of body mass (CoM) is located relatively high (in the trunk, ~1 m above the ankles, which determines the length of the inverted pendulum) and the base of support is relatively small, the posture is inherently unstable. The forces produced at the level of the feet by the body to control the movements of the center of mass are known to define the process of maintaining body balance (Gage et al., 2004). The center of pressure (CoP) is the point where the total sum of a pressure field acts on a surface, resulting in a force to act through that point where the pressure passes. The CoP tends to move around the center of mass constantly to maintain the balance of the body. The displacement of CoP and its dynamic parameters are used to indicate the postural control. Therefore, if the displacement of CoP increases, it is likely to yield an unstable state leading to increased risk of falls (Berger et al., 2005; Maki et al., 1994; Ferni et al., 1982). Center of pressure displacement is controlled by the ankle muscles and the hip muscles along the anterior-posterior axis and the medio-lateral axis (Winter et al., 1996; Day et al., 1993). Despite this inherently unstable feature of human upright posture, humans are quite adept at maintaining stability during quiet stance or body movement due to a relatively complex neurobiological system evolved to optimize balance control (Peterka, 2002). As such, balance control allowed for the evolution and consolidation of bipedalism, which possibly played a large role in the pathway of human evolution (Schmitt, 2003).

1.1.1.2 The Neurophysiology of Postural Control

Postural control, the regulation of body position for stability and orientation, is a complex neurophysiological process involving sensory integration, central neural processing, and motor output (Horak, 2006; Shumway-Cook & Woollacott, 2007). Intentional movements originate from motor commands in the cerebral cortex and are transmitted through descending pathways in the brainstem and spinal cord. These voluntary actions are accompanied by automatic postural adjustments, essential for maintaining balance during movements such as reaching or walking (Gurfinkel & Lipshits, 1977; Jacobs & Horak, 2007).

The central nervous system continuously integrates proprioceptive, vestibular, and visual sensory inputs to regulate postural stability. Proprioception provides detailed information about limb position and muscle tension through muscle spindles and Golgi tendon organs, enabling precise motor control and balance maintenance (Proske & Gandevia, 2012; Goble et al., 2009). Age-related declines in proprioceptive sensitivity can compromise postural control, increasing reliance on visual and vestibular inputs (Goble et al., 2009).

The vestibular system, comprising the otolith organs and semicircular canals, detects head position relative to gravity and rotational movements, providing crucial feedback for postural adjustments and visual stabilization (Fitzpatrick & Day, 2004). Vestibular sensitivity also diminishes with age, making older adults more susceptible to balance disturbances, particularly under conditions of limited sensory feedback such as low lighting or uneven surfaces (Fitzpatrick & Day, 2004).

Visual input further supports postural control by offering environmental cues crucial for spatial orientation and anticipatory adjustments to changing conditions (Guerraz & Bronstein, 2008). Integration of visual information with vestibular and proprioceptive signals occurs primarily within cortical and subcortical structures, including the sensory and parietal cortices, cerebellum, and brainstem nuclei (Kavounoudias et al., 1998).

The cerebellum integrates sensory and motor signals, coordinating precise postural adjustments and motor execution. Sensory inputs from spinocerebellar tracts and cortical signals through pontocerebellar pathways allow the cerebellum to continuously refine balance and movement control (Massion, 1994; Horak & Macpherson, 1996). Additionally, the basal ganglia modulate movement initiation and smoothness, with neurotransmitter systems such as dopamine and gamma-aminobutyric acid (GABA) playing crucial roles in motor planning and execution (DeLong & Wichmann, 2007; Takakusaki et al., 2008). Dysfunction in these neural circuits underpins movement disorders characterized by impaired postural control, such as Parkinson's and Huntington's diseases (Nutt & Wooten, 2005; Bunner & Rebec, 2016).

Higher cognitive functions, including attention, executive control, and information processing speed, also influence postural stability. Cognitive resources are necessary for adaptive responses to environmental demands and maintaining balance during dual-task situations, such as walking while conversing (Woollacott & Shumway-Cook, 2002). The interaction between cognitive and motor systems becomes increasingly significant with age, potentially exacerbating fall risk in older populations.

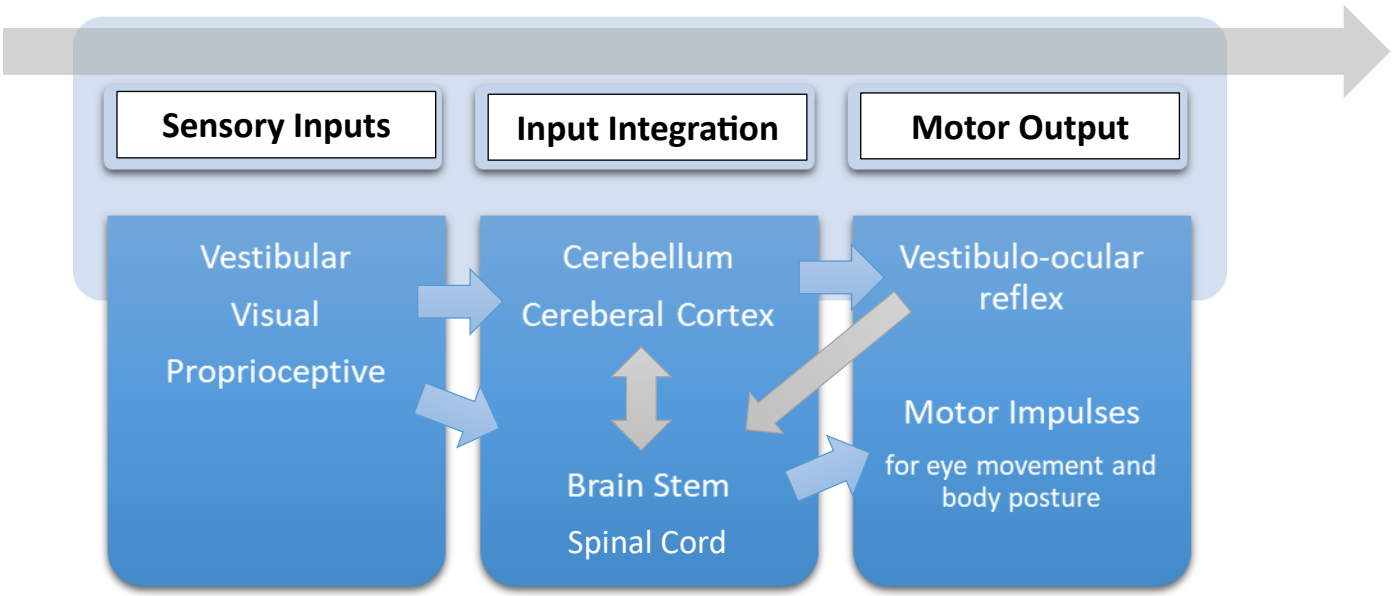


Figure 1. Balance Control in Human Body (modified from Zeng and Zhao, 2011)

1.1.1.3 The Measurement of Postural Control

Assessing postural control involves both objective measures, which provide quantifiable data, and subjective measures, which capture individuals' perceptions and confidence regarding balance. A critical appraisal of available methods, their psychometric properties, and their suitability for specific research or clinical populations is essential.

1.1.1.3.1 Objective Measures

Objective measures of postural control quantify static and dynamic stability through precise, reproducible assessments. Commonly employed methods include force plate posturography, accelerometry, and motion capture systems. Force plates, the most extensively used tool, measure variations in the body's center of pressure (COP), reflecting subtle adjustments required to maintain balance (Prieto et al., 1996). Key COP-derived metrics such as sway area, path length, and sway velocity provide sensitive indicators of balance stability and are highly reliable for detecting subtle impairments, particularly in older adults or clinical populations (Raymakers et al., 2005; Ruhe et al., 2010).

More advanced analyses, including frequency-domain and entropy-based measures, can elucidate the underlying control mechanisms and sensory integration strategies (Collins & De Luca, 1993; Donker et al., 2007). While highly informative, these complex measures require specialized analysis and interpretation skills, limiting their routine clinical application.

Other objective approaches, such as accelerometers and motion capture systems, offer valuable insights into dynamic postural control during functional tasks (Winter et al., 1996). Electromyography (EMG) additionally provides information about muscle activation patterns underlying balance maintenance, valuable for understanding neuromuscular contributions to stability (Winter et al., 1996).

1.1.1.3.2 Subjective Measures

Subjective assessments include self-report questionnaires such as the Falls Efficacy Scale (FES) and the Activities-specific Balance Confidence (ABC) Scale. These instruments measure individuals' perceived balance confidence and fear of falling, aspects not fully captured by objective assessments alone (Tinetti et al., 1990; Powell & Myers, 1995). The FES, validated extensively among older adults, is effective for identifying those at increased risk due to fear-induced activity restriction (Kempen et al., 2007).

Observation-based scales, notably the Berg Balance Scale (BBS) and Timed Up and Go (TUG) test, provide reliable, clinically feasible assessments of functional balance. The BBS involves direct observation of tasks assessing multiple aspects of balance and is strongly predictive of fall risk in older adults and neurological populations (Berg et al., 1992). The TUG test, a timed functional mobility measure, is similarly predictive and simple to administer clinically (Podsiadlo & Richardson, 1991).

However, despite clinical utility, these measures can suffer ceiling or floor effects, limiting sensitivity in higher-functioning or very impaired individuals. Thus, combining subjective and objective measures provides the most comprehensive evaluation of postural control and fall risk.

1.1.1.3.3 Balance Assessment in the Clinical Setting

Clinicians, including general practitioners, physiotherapists, and occupational therapists, use both observational and instrumented methods to assess balance impairments. Objective measures such as force plates are valuable for precise diagnosis and monitoring, particularly for conditions like Parkinson's disease or stroke, where detecting subtle changes can significantly influence treatment decisions (Horak et al., 1992; Norrie et al., 2010). Subjective tools (e.g., ABC and FES) are equally critical for understanding

psychological components influencing balance confidence and activity levels, essential for personalized intervention planning (Powell & Myers, 1995; Tinetti et al., 1990).

1.1.1.3.4 Differentiation Between Diagnostic Tools and Research Tools

Diagnostic tools such as the BBS and TUG tests are widely used clinically due to their simplicity, low cost, and practicality. Research-oriented measures (force plates, motion capture, EMG) provide greater precision and detailed mechanistic insights but require specialized expertise and resources, limiting their broader clinical application. Selecting appropriate measures involves considering the specific context, population, purpose of assessment, and available resources, thereby ensuring accuracy, relevance, and clinical utility.

1.1.1.3.5 Critical Rational for Measures Selected

Given the multidimensional nature of balance, this thesis combined quantitative COP assessments with validated self-report instruments to provide a comprehensive evaluation of postural control. COP metrics allowed for precise detection of physiological balance adaptations, while the FES captured participants' perceptions and concerns related to falls, which themselves are predictive of actual fall incidents (Hatch et al., 2003).

The decision to prioritize these tools was informed by their established psychometric properties in older adults and relevance to the thesis objectives. The Berg Balance Scale (BBS), although robust, was considered potentially prone to ceiling effects in higher-functioning participants and thus was not the primary measure. Instead, the integrated approach employed here was designed to align with both clinical perspectives and experimental rigor, optimally suited to elucidate the interplay of sleep, circadian factors, and postural control in this population.

1.1.1.3.6 Limitations of the Assessment Methods of Postural Control

There are numerous subjective and objective methods developed to assess balance control. The validity and reliability of these measures are critical for their effective application. Internal validity, particularly in the case of questionnaires, such as construct validity, ensures that the measures accurately reflect the underlying concept of postural control. All listed questionnaires, including the Berg Balance Scale (BBS), have acceptable internal consistency (Berg et al, 1992; Berg & Norman, 1996; Mancini & Horak, 2011).

External validity, including criterion and predictive validity, ensures that the findings are generalizable and can accurately predict real-world outcomes (Peterka, 2002). Indeed, most questionnaires, particularly the Berg Balance Scale, have been used to predict clinical outcomes.

While objective measures provide precise, quantifiable data on postural control, they also come with significant limitations. High costs and the need for specialized equipment and trained personnel can limit their accessibility and widespread use (Raymakers et al., 2005). Moreover, objective methods can provide highly sensitive and reliable information on a person's static or dynamic balance control, they are not necessarily used for clinical diagnosis but mostly for research purposes. Static measures, such as those obtained from force plates during quiet standing, provide reliable and reproducible data on postural stability. However, they may not fully capture dynamic postural control scenarios, such as during walking or sudden perturbations. Dynamic assessments, which involve movement and response to environmental challenges, are more complex and may provide additional insights into functional balance abilities (Peterka, 2002).

Sensitivity refers to the ability of the measure to correctly identify those with balance impairments, while specificity refers to correctly identifying those without impairments. These measures need high sensitivity and specificity for their clinical use to make sure they are both precise and dependable (Collins & De Luca, 1993). Even with its limitations, the plus side of objective assessments is that they give detailed data which can be reproduced. This allows it to spot slight changes in balance control as time goes by and makes them extremely useful in both medical applications or research. The tests may not suit all patients though; those who have serious mobility issues making standing on a force plate unsafe, or those with inserted devices messing up EMG readings might find these unsuitable.

The personal perspective methods of assessment might be influenced by emotions, thinking processes and individual beliefs about health. As a result, the assessments may not always be accurate (Tinetti et al., 1990). If these techniques were out side by side with objective ones, they may lack sufficient precision to capture complex body balance movements. Instead, they just show broad tendencies rather than slight alterations. For observational scales like BBS model rely on the person who is evaluating which might bring inconsistency thereby impacting its trustworthiness (Berg et al., 1989).

Usually, subjective measures are simple to handle and they do not need special equipment or a lot of training. This makes them easy to use in many different places (Powell & Myers, 1995). They help understand the patient's own views about their balance and confidence which is very important for

complete care. Moreover, these types of measures can save money, particularly in areas with no advanced technology available for objective measurement (Berg et al., 1992).

People with serious cognitive issues might find it hard to correctly fill self-report questionnaires and this can lead to data that are not reliable. Language issues, hearing troubles or speaking disorders may make it hard for proper filling of subjective measures leading to data that could be incorrect or incomplete. People who experience feelings such as depression or anxiety could possibly alter the results of self-assessments too. They may state that their balance is poor and they have a great fear of falling, even though their physical abilities do not support these statements (Tinetti et al., 1990).

The connection between keeping body balance and the growing chance of falling can be intricate. This might involve various elements such as side effects from medicines, misuse of substances, occupational health concerns, and problems with sensory functions. These dangers could arise in any age category which underlines the importance to conduct all-round evaluations and develop unique methods for reducing risks of falls while enhancing steady body control across diverse groups.

1.1.1.4 Factors Impacting Postural Control and Risk of Falls

As mentioned before, the ability to maintain a certain posture (PC) is an elaborate function that requires the well-coordinated interaction of different body systems. These may include your balance sense from inner ear, sight and hearing capabilities, movement control system as well as higher-level motor coordination functions (Horak, 1997). Therefore, problems with maintaining balance can have multiple causes like various health issues such as drug abuse or natural factors including age and sex; even lifestyle aspects like one's occupation choice or sleep quality. All these elements could disturb our balancing capability either alone or together. If someone struggles with postural control this could negatively affect their daily life in many ways but especially due to a heightened risk of having falls.

Falls are considered a public health problem with causes ranging from medicinal side effects (e.g., Z-drugs), environmental factors (e.g., trip hazards at home), and multiple health conditions (e.g., concussion, vertigo, stroke, neurodegeneration) leading to balance deficits (Barrett-Connor et al., 2009) to the fear of falls itself (Murphy et al., 2003). Research indicates that exercises designed to improve postural control can mitigate the risk of falls by up to 35%, offering a compelling rationale for focusing on this particular aspect of aging (Sherrington et al., 2008).

Given the focus of this thesis on healthy adults, the following section will discuss how age, sex, and occupational factors impact postural control and subsequently influence the risk of falls, without getting into the effects of medical conditions and substance abuse, which are also known to affect balance control.

The interplay of age, sex, and occupational factors with postural control clarifies the complex nature of fall risk. Older adults are particularly vulnerable to falls due to age-related declines in sensory and motor systems (Sturnieks, St George, & Lord, 2008; Rubenstein, 2006). Women may face additional risks due to physiological differences and longer lifespans (Ivers et al., 2001; Stevens et al., 2008). Occupational hazards further compound these risks, especially in work environments that limit sensorial feedback, do not provide a fully stable platform, demand high levels of physical activity and restrict sleep duration and/or disrupt sleep quality (Folkard & Tucker, 2003; Gander et al., 2011).

1.1.1.5 Postural Control and Aging

1.1.1.5.1 Age-Related Changes in Postural control and risk of falls

Age-related changes in postural control are well-documented, with older adults commonly experiencing declines in postural stability and balance (Lord & Ward, 1994). These alterations make the risk of falling in older adults higher, which can lead to serious health problems and loss of self-reliance (Pinter et al., 2009). Population studies show about one-third of individuals who are more than 65 years old fall every year. This number goes up to half for those aged over 80 (Rubenstein, 2006). Physiological reasons that add towards this downward trend consist of decreased muscle power and suppleness, delayed motor reaction times, as well as sensory weakening in visual system and balance-related senses (Melzer et al.,2010).

The after-effects of having weak control on body posture (PC) are very extreme for older adults. In this age group, falling is a major reason behind both fatal and non-fatal injuries. After falling, there can be broken bones which might need hospital treatment - that often results in long-term inability to move around normally, significant decrease in life quality or sometimes even death (Sterling et al., 2011). Each year about one out of three older individuals suffer from falls; this includes one fourth Americans who are above the age limit of 65 who fall every year (Bergen et al., 2014; Kakara et al., 2023). Apart from the physical harm, repeated falls can instill a fear of falling once more which results in reduced movements and seclusion socially. This forms a society that relies heavily on others and is detached within itself, impacting profoundly the life standard for person involved, their relatives as well as healthcare mechanism (Bertera & Bertera, 2008; Scheffer et al., 2008).

1.1.1.5.2 Physiology of age-dependent decline in postural control

Many different physical elements lead to the decrease in balance maintenance with growing age. Changes in posture control and coordination of sensory input and motor output due to aging are a result of alterations within musculoskeletal structures, changed nerve-muscle control as well as mental changes, plus other factors (Horak, 2006; Mezler et al., 2004; Melzer et al., 2010).

a. Muscle Strength, Flexibility, and Passive Extensibility: Muscle strength, flexibility, and passive extensibility are crucial for generating and regulating the forces required for effective postural adjustments. With advancing age, significant physiological changes such as reductions in muscle mass (sarcopenia) and associated decreases in muscle strength commonly occur. These age-related changes reduce the capacity to produce adequate muscular force, impairing the body's ability to initiate rapid corrective movements essential for preventing falls (Seidler et al., 2010). Furthermore, age-associated changes in neuromuscular control, such as reduced motor unit recruitment and slower reaction times, contribute further to impairments in postural stability (Tieland et al., 2018).

b. Deterioration in Sensory Functioning: The deterioration of sensory in the sight, balance, and body position systems also has an effect on the physical orientation and stability (Horak, 2006). Older adults go through a slow reduction across many sensory functions such as the balance system that gives details about head movements and spatial direction leading to issues with maintaining balance (Ho et al., 2021). Sight is very important for controlling posture and it can work together with other sensory inputs to keep up good balance. The decline in visual perception associated with getting older, such as lessened sharpness of vision, contrast sensitivity and depth recognition has a significant effect on balance and heightens the risk of falling (Tinetti & Williams, 1998; Lord & Menz, 2000; Lord & Dayhew, 2001). The decrease in proprioception that comes with aging impacts the body's capability to detect and react to changes in position. This contributes to increased postural movement and instability (Sturnieks et al., 2008). Deterioration of the vestibular system results from reduced sensitivity towards head movements and spatial orientation which further intensifies balance problems among older adults (Horak et al., 1990).

c. Neuromuscular and Cognitive Factors: The age-related decline in neural processing speed, owing to reduced nerve conduction and synaptic efficacy, slows down the body's adaptive responses (Melzer et al., 2010). Cognitive functions also deteriorate with aging, influencing postural control.

Maintaining postural control and balance requires the integration of several cognitive processes (Horak, 2006; Woollacott & Shumway-Cook, 2002). Perception across multiple sensorial modalities is essential component; accurate sensing of the environment and awareness of one's spatial orientation within it are

crucial for maintaining balance (Wade & Jones, 1997). Functional brain connectivity, affected by aging, can prevent the effective integration of sensory information from different neural regions and the coordination of complex responses (Geerligs et al., 2014). Attention is critical, as sustaining balance, particularly in dynamic conditions, demands sustained attention to one's body and environment (Woollacott & Shumway-Cook, 2002). Executive functions linked to the prefrontal brain region, including planning, inhibition, and working memory, are invoked to adapt to changing environmental conditions and respond effectively to challenges that could compromise stability. The act of balance involves considerable motor planning, where the brain efficiently plans and executes the necessary motor commands for maintaining or regaining balance (Bolton, 2015). Age also modulates the impact of cognitive load on postural control. For example, younger adults tend to be stiffer when performing a balance task simultaneously with a cognitive task (Vuillerme et al., 2000; Dault, Frank & Allard, 2001; Dault et al., 2001; Andersson et al., 2002; Siu & Woollacott, 2007), whereas older adults might exhibit more relaxed balance (Maylor and Wing, 1996; Redfern et al., 2001; Melzer et al., 2001; Huxhold et al., 2006).

d. Sleep and Postural Control: Sleep is a key physiological function that maintains the day-to-day energy and neural homeostasis of the organism, and its deprivation can affect numerous functions, including cognition and postural control (Shumway-Cook and Woollacott, 2000). Sleep impairment is common among older adults which has potential implications for the increased falls risk associated with aging. Sleep deprivation has been shown to affect postural control, with this detrimental effect modulated by concurrent cognitive tasks (Schlesinger et al., 1998; Robillard et al., 2011). In older adults, sleep deprivation, combined with limited visual input, has a more pronounced destabilizing effect on postural control, which is exacerbated by the additional cognitive load (Robillard et al., 2011). Chronic lack of full sleep, frequently seen in older adults who have issues with sleep that result in a slow decrease in both the amount and quality of their rest (Mander et al., 2017), can lead to continuous negative effects on how they control their body position. This could also escalate the possibility of them falling down (Carrier & Bliwise, 2003). Morning grogginess when waking up and side effects from certain medications used for sleeping disorders {e.g., Z drugs) are associated with increased risk of falls among individuals aged sixty plus years old (Brandt & Leong, 2021; Treves et al., 2018; Roth, 2007; Neubauer, 2007).

Knowing the hidden processes of posture control declines connected to aging is vital. This knowledge assists in crafting treatments and tactics to reduce risk of falling, as well as enhancing general functioning abilities in older individuals. Recognizing the multifactorial decline in postural control with aging encompassing sensory, neuromuscular, and cognitive dimensions highlighted a critical gap in

understanding how these factors, alongside sleep and circadian disruption, may collectively influence fall risk. This directly informed the formulation of the research questions explored in this thesis

1.1.1.5.3 Falls Prevention Among Older Adults

For minimizing the risk of falls in older adults, a range of programs based in communities have been established. These initiatives usually encompass multiple disciplines such as physiotherapy, support technology, lifestyle adjustments and surveillance. Physiotherapeutic measures which aim at improving balance and muscle strength are crucially important; these include exercises particularly focused on strengthening muscles, enhancing coordination and optimizing balance to diminish fall risks (Gillespie, 2013). Exercise plans that involve groups, like tai chi for instance, are seen to markedly enhance balance and decrease instances of falling (Wolf et al., 2003).

Utilizing helpful tools such as sticks and walking aids can provide balance for people and stop them from falling. New advancements in wearable technology offer non-stop monitoring of movement patterns and stability, giving instant feedback while making caregivers aware if a fall happens (Delahoz & Labrador, 2014). Motivating older individuals to participate consistently in physical activities, keep up with good eating habits, and effectively handle long-standing health issues can lower the danger of falls significantly. Programs in the community frequently offer knowledge and aids to support people in making these changes in lifestyle (Stevens et al., 2018).

Falls prevention is quite important and should start with regular health checks for things like vision and hearing. At home, it is good to make sure there are no trip hazards, grab bars are installed, and lighting is sufficient so as many falls can be avoided (Lord et al., 2006). Health service providers have a significant role in this by focusing on community-level activities. In dealing with the complex nature of fall risks such as improving balance control among older adults ultimately helps increase their life quality while putting less strain on healthcare systems.

For the prevention of falling hazards and to improve body posture in older adults, many scientifically proven clinical guidelines suggest a comprehensive method. This process involves incorporating balance training practices, strengthening workouts along with changing surroundings according to individual's requirement. Studies have shown that exercises focusing on maintaining balance can bring about substantial enhancements in postural steadiness thus diminishing fall risks. These workouts test the body's capacity to keep balance and adjust to different sensory inputs, which in turn better the effectiveness of the system controlling posture (Wolf et al., 1996; Shumway-Cook & Woollacott, 2001).

Training for strength, especially emphasizing on the muscles of lower body parts, is a vital part of planning to prevent falls. It enhances the ability of muscles responsible for postural changes and this way, old adult can react better when their balance is disturbed and keep stability. The exercises that focus on quadriceps, hamstrings, gastrocnemius and soleus muscle groups are found really beneficial (Liu & Latham 2009; Orr et al., 2008).

On top of doing exercises, making changes to the surroundings is very important in cutting down chances of falling. Small adjustments like enhancing lightings, getting rid of objects that could cause trips (for example, rugs not attached properly or wires), and adding handrails can make home safer for older adults. Furthermore, it is necessary to keep having regular eye and ear tests so as older adults get the best information through their senses which helps a lot with keeping balance (Lord et al., 2006; Gillespie, 2013).

For making fall prevention methods as effective as possible, it is often suggested to use a team of different healthcare professionals. Physical therapists have the knowledge to create and apply plans for balance and strength training. At the same time, occupational therapists can examine and change parts of a home place to lower dangers connected with falls. When these experts come together, they make thorough methods for preventing falls that attend to each older person's individual demands (Sherrington et al., 2019).

1.1.1.6 Sex Differences in Postural Control and Fall Risk

Sex differences in postural control and fall risk have been observed, with women generally experiencing a higher incidence of falls compared to men. Epidemiological studies show that women over 65 have a 30-50% higher rate of falls than men of the same age (Lord et al., 2000; Stevens & Sogolow, 2005). Additionally, questionnaire-based studies and objectively measured assessments consistently indicate that women report more falls and demonstrate poorer balance performance (Stevens & Sogolow, 2005).

Several factors are thought to contribute to these observed sex differences. One key factor is the lower muscle mass and strength observed in women compared to men, which may reduce their ability to recover from balance perturbations (Faulkner et al., 2007). Balance perturbations refer to external or internal forces that challenge an individual's ability to maintain postural stability. Examples of such perturbations include sudden trips or slips, unexpected changes in the surface underfoot, rapid changes in direction while walking, or being bumped in a crowded environment (Maki & McIlroy, 1996; Pai & Patton, 1997). These perturbations require rapid and effective neuromuscular responses to maintain balance, and insufficient muscle strength can impair these responses, leading to falls.

Hormonal changes, especially the decline in estrogen levels during menopause, can also play a critical role in balance impairment and associated adverse health consequences. Estrogen positively influences muscle and bone health, and its decline leads to decreased bone density and muscle function, contributing to an increased risk of falls and fractures in older women (Iolascon et al., 2014). Furthermore, osteoporosis, more prevalent in women, exacerbates the risk of fractures from falls, further complicating postural stability (Cummings & Melton, 2002).

Older men may experience greater declines in proprioceptive sensitivity as they age. This could partly be attributed to a higher prevalence of co-existing conditions such as diabetes, which negatively impacts peripheral nerve function and thus impairs proprioception and balance (Nawroth et al., 2011). Given that effective postural control relies significantly on cognitive processes, sleep disturbances might pose particular challenges. Older women, who typically report higher rates of sleep disturbances and insomnia compared to older men, could therefore face increased risk of falls due to exacerbated cognitive and motor deficits arising from poor sleep (Mander et al., 2017).

Research on the effects of sleep deprivation on balance has yielded with various results; however, evidence indicates that younger adults, particularly women, might be more affected. For example, a study demonstrated that young females face greater cognitive problems from lack of sleep and adverse circadian phases compared to males (Santhi et al., 2016). This cognitive impairment may indirectly impact their balance ability due to the strong connection between brain activity and postural control. Conversely, other studies have shown that young males may experience more difficulties in controlling balance when sleep-deprived, potentially due to factors like an elevated pressure center (Ołpińska-Lischka et al., 2021). These differences show the complexity of interactions among age, sleep deprivation, sex, and body sway, highlighting the need for further research to fully comprehend these relationships.

To investigate these complex interactions, pursuit tracking task or pursuit rotor task (PTT), can be used as valuable tool for assessing motor coordination and cognitive function under varying conditions, including sleep deprivation and circadian influences. Research has shown that both partial and total sleep deprivation adversely affect performance across multiple cognitive domains, which suggests the sensitivity of tasks like the PTT to sleep-related changes (Smith et al., 1994). Furthermore, studies have explored sex differences in the circadian regulation of sleep and cognition, revealing distinct patterns in cognitive performance between men and women relative to circadian phases (Santhi et al., 2016). By employing the PTT in research, it becomes possible to examine how postural control and motor coordination are modulated by sex differences, particularly in response to sleep deprivation and circadian rhythms.

Moreover, brain issues like Alzheimer's disease, Parkinson's disease and different kinds of dementia deeply affect the control over one's stance. These ailments can reduce the capacity of the brain to supervise sensory information and regulate movements resulting in enhanced instability and higher risk of falling (Yogev-Seligmann et al., 2008). Also, certain medicines used for these mental disorders may create sensations such as dizziness or sleepiness that then cause fall accidents by triggering orthostatic hypotension (Hartikainen, Lönnroos & Louhivuori, 2007).

The increased sensitivity may relate to the stronger association between sleep disturbances and mental health observed among women. Insomnia tends to be more prevalent in females (Zhang & Wing, 2006; Mallampalli & Carter, 2014), and women generally exhibit greater susceptibility to the negative impacts of inadequate sleep on cognitive performance and emotional stability (Lo et al., 2016; Muzni et al., 2021). However, the precise relationship between these sleep-related factors and postural control in older adults remains poorly understood and requires further investigation.

Knowing the differences between men and women in terms of balance control and risk of falls is very important. Such understanding helps to make detailed plans and proactive steps for lessening falls, improving steadiness among older adults. Balance problems can be caused by many factors like side effects from medicine, drug misuse issues connected with work health or sensory deficits need total strategies specifically built for individuals, with the goal to lessen risks of falling while increasing posture stability across different groups.

1.1.1.7 Occupational Factors and Postural Control

The work field of occupational health is very important. It pays attention to the physical, mental, and social good condition of workers in many different industries. Making sure that the working environment is safe and healthy is extremely necessary because it influences directly how well employees can do their jobs safely and effectively. Occupational health mainly looks at keeping good postural control which helps a lot in avoiding accidents at work like falls especially. In the working environment, there are numerous elements that can affect balance control and related falls risk.

Falls represent a significant occupational safety issue. Data from the National Institute for Occupational Safety and Health (NIOSH) indicate that a substantial proportion of workplace injuries and fatalities result from falls. In the United States, 880 workplace fatalities occurred in 2019 due to falls, slips, or trips, making these incidents the second leading cause of occupational fatalities. Additionally, according to the Bureau of Labor Statistics (BLS), there were approximately 244,000 non-fatal workplace injuries resulting from

same level falls in 2020, highlighting the widespread nature of these incidents across various occupational sectors.

Certain business sectors are especially susceptible to injuries related to falls. For example, the building industry regularly records a significant number of fall incidents and accidents from high places happen to be the top cause of death in this area. As indicated by Occupational Safety and Health Administration (OSHA), 33.5% of all deaths in construction was due to falls in 2018 - highlighting that it is extremely important for effective strategies preventing such cases be put into place. Moreover, medical caregivers who frequently work in swift and physically challenging conditions are also at a raised danger. Research conducted by Pompeii et al. (2015) discovered that medical caregivers suffered injuries due to falls with a proportion of 5.8 per hundred full-time workers, which is considerably above the mean for every private sector.

Job related aspects such as working for extended periods, rotating shifts, and engaging in tasks that require physical exertion augment the risk of falls. To illuminate this point further, when people work long hours or during nighttime their sleep pattern along with circadian rhythms get disturbed resulting to increased tiredness which affects maintaining a stable posture (Folkard & Tucker, 2003). Feeling excessively tired negatively impacts mental processing and motor operations - both vital elements for keeping balance thus preventing falls. Mariners, especially, find this to be accurate. They generally have the duty of working extended hours in nighttime and are involved in special work circumstances. These situations include activities that need a high degree of balance and control over body posture (Gander et al., 2011).

a. Physical Work Environment:

The place where physical work is done has a big impact on how well someone controls their posture. When the setup of the workstation is not good in an ergonomic way, it can cause bad posture and make conditions affecting muscles and skeleton more likely to happen. The goal of interventions based on ergonomics is to improve compatibility between workers and their duties, which reduces stress and makes postural balance better (Norman & Wells, 1998). Furthermore, the kind of floor and shoes used at work can greatly affect balance. Risky falls, slips, or trips are more likely with slippery or irregular floors coupled with unsuitable shoes (Cham & Redfern, 2002).

Problems with seeing clearly are very important in work places. If light is insufficient, it may be difficult for the workers to safely navigate. This might possibly affect their balance and heighten the chance of having

accidents (McBean et al., 2016). Making sure to provide good lighting where all things can be seen clearly may help workers keep better steadiness and lessen occurrences of falls.

Platforms that are not stable can greatly affect a person's ability to maintain balance at the work place. If employees have to perform tasks on surfaces that move or are uneven, their sense of stability and balance may face difficulties. These situations require better coordination between nerves and muscles, causing tiredness and also raise the possibility of falls if it is not handled correctly (Punakallio et al., 2005). For minimizing these dangers, we are able to supply robust workplaces and teach workers on managing tasks in unpredictable surroundings.

b. Work-Related Fatigue and Sleep Deprivation:

Shift work jobs or unstable work hours might disrupt body's internal timer, causing lack of sleep and tiredness. Studies have shown that workers who lack adequate sleep exhibit lesser control over balance, increased physical movement, and a higher risk of slipping or falling (Sadeghniiat-Haghighi & Yazdi, 2015; Magnavita et al., 2021).

c. Physical and Mental Workload:

Work that needs you to lift, bend or carry heavy things repeatedly, can put pressure on your body's musculoskeletal system. This might affect the control of posture and raise chances of sustain injury (Kamijantono et al., 2024). If a person is under much mental workload or stress this could impact focus and steadiness in their posture. Stressful work conditions can lead to distraction of thoughts, making it difficult for the body to maintain balance (Freitas et al., 2005).

d. Sensorial Feedback Restriction:

Limited sensory feedback, like bad visibility, dim light or moving platforms can seriously affect balance control. Doing tasks with low visibility conditions may disturb a worker's skill to keep balance and move safely which escalates the chance of falling (Marras et al., 1999). In the same way, working on shifting platforms or in situations where ground surface is not steady tests body’s mechanisms for maintaining posture causing more demand on muscles and nerves and higher risk of fall (Punakallio et al., 2005). Implementing measures to improve visibility and stabilize work surfaces can help mitigate these risks.

1.1.1.8 The Role of Sleep and Circadian Rhythms in Age, Sex, and Occupational Risk-Related Vulnerability of Postural Control and Risk of Falls

Factors such as age, sex, and occupational demands independently and interactively affect postural control and falls risk, with sleep serving as a critical mediator of these relationships. Poor sleep quality and disrupted sleep patterns negatively impact postural stability, increasing fall risk particularly among older adults and individuals working irregular or extended hours (Magnavita et al., 2021; Sadeghniiat-Haghighi & Yazdi, 2015).

Sleep timing, duration, and quality profoundly influence physiological and cognitive functions, including gene expression (Archer et al., 2014), immune responses (Gomez-Gonzalez et al., 2012), metabolic regulation (Morselli et al., 2010), psychological wellbeing (Lo et al., 2012), and neural connectivity (Cho, 2001). One significant consequence of insufficient or disrupted sleep is compromised postural control. With aging, decreases in both sleep duration and quality have been consistently reported, which likely contribute to elevated fall risk observed among older populations (Schlesinger et al., 1998; Goldman et al., 2007; Formiga et al., 2008). Hita-Contreras et al. (2018) demonstrated that poor sleep quality and shorter sleep duration independently predicted impaired postural control, while other factors, such as anxiety and higher BMI, predicted heightened fear of falling.

The risk of falls is notably higher among older adults compared to younger populations, due in part to age-related cognitive decline and decreased mobility associated with reduced activity levels (Ambrose, Paul, & Hausdorff, 2013; Rubenstein, 2006). Cognitive impairments from poor sleep, such as reduced attention and slower reaction times, can directly affect balance and stability (Blackwell et al., 2006; Schwartz et al., 2017). Additionally, disruptions in circadian rhythms influence motor function and reaction times, crucial factors in maintaining postural stability (Cajochen, 2007). Thus, disturbances in sleep or misalignment of circadian rhythms complicate fall prevention strategies, particularly among older adults.

Sex differences significantly influence balance control and fall risk. In women, fluctuations in hormone levels, particularly during menopause, are associated with decreased bone mineral density, increasing the risk of osteoporosis (Greenspan et al., 1994). Osteoporosis negatively impacts skeletal integrity, thereby exacerbating vulnerability to falls. Given women's generally longer life expectancy compared to men, this susceptibility accumulates with age. Differences in muscle mass, strength, body composition, and joint flexibility between sexes also influence balance control (Ivers et al., 2001). Additionally, higher fear of falling among women often results in reduced physical activity, further impairing postural stability and increasing falls risk (Zijlstra et al., 2007). Understanding these sex-specific vulnerabilities, especially the osteoporosis-related risk post-menopause, was integral to developing the research questions of this

thesis, guiding the investigation of sex differences in postural control under sleep and circadian disruption conditions.

Occupational environments that require extended or irregular work hours, particularly night shifts, disrupt normal sleep patterns and circadian rhythms, increasing susceptibility to balance impairment and occupational falls (Folkard & Tucker, 2003; Tucker et al., 2003). Maritime workers exemplify this risk, often undertaking prolonged night shifts in environments demanding high levels of sustained postural stability and precise motor coordination (Gander et al., 2011). The unique occupational setting of maritime workers provided a rationale for exploring occupational impacts on sleep disruption and subsequent balance impairments as part of this thesis.

In conclusion, many factors such as drugs, various changes in the body related to age and decrease in sleep quality and circadian rhythms influence balance ability especially for older adults. The less control over posture is a primary cause why this group experiences frequent falls. Risk of falling also grows higher across different work industries where inadequate or poorly timed sleep can further disrupt balance management along with other circumstances conditions.

1.1.2 Sleep, Circadian Rhythms, and Aging

Given that we live in a society in which getting the physiologically required sufficient sleep duration and quality is becoming more and more problematic, understanding the complex interplay between sleep and postural control is important. This becomes even more crucial as individuals age provided both sleep and postural control, are known to be affected by the aging process (Olpińska-Lischka et al., 2021; Riemann et al., 2012). Importantly, alterations in these domains can contribute to an increased risk of falls among the older adults population, which is a major public health concern (Ambrose, Paul, & Hausdorff, 2013; Blackwell et al., 2006; Rubenstein, 2006).

1.1.2.1 Definition, Function, and Basic Concepts of Sleep Regulation

Human beings spend, on average, one-third of our life asleep, highlighting its important contribution to health and well-being (Kryger, Roth, & Dement, 2010). Unless essential for life, this well-conserved behavior present across the animal kingdom, characterized by increased vulnerability to external threats, would not have evolved (Vandewalle, 2021). Indeed, sleep has been shown to have a major impact on the human brain and the body, ranging from core molecular processes related to gene expression (Archer et al., 2014; Moller-Levet et al., 2013), to growth, immunity, and metabolism (Garcia-Garcia et al., 2014; Leproult et al., 2014; Tasali et al., 2009; Vidal et al., 2022), to emotional control and mental well-being (Groeger et al., 2022; Muzni et al., 2021), cognitive functions (Lo et al., 2012), as well as the underlying neural plasticity and brain connectivity (Skelin et al., 2021; Tononi & Cirelli, 2014; van den Berg et al., 2023).

Sleep is essential for learning and memory, and its insufficiency exerts a strong negative effect across multiple domains of cognition and can lead to permanent neural brain damage (Krause et al., 2017). Specifically, sleep drives the recovery process from the deleterious effects of wakefulness on the brain, including energetic replenishment, synaptic recalibration, neural repair, and clearance of toxic waste products that accumulate during wake and can harm the neurons (Tononi & Cirelli, 2014; Vyazovskiy & Harris, 2013). Sleep supports learning by facilitating branch-specific dendritic spine formation (Yang et al., 2014), regulating synaptic strength (Tononi & Cirelli, 2014), and promoting the transfer of representations initially encoded in the hippocampus to the distributed neocortical circuitry for long-term storage (Westermann et al., 2015). Despite all these facts, the functions of sleep are far from being fully unveiled. Epidemiological studies establishing an association between insufficient or disrupted sleep with an increased risk of chronic conditions such as cardiovascular disease, diabetes, obesity, mental health

disorders, and neurodegeneration, as well as accidents and all-cause mortality, provide further support for the central role of sleep for health and everyday life (Dijk, 2012).

Besides its role in recovery and restoration, the cognitive function of sleep has been at the forefront of decades of research with a particular focus on memory and executive functions. Memory processes, including both short-term and long-term memory, are known to be affected by sleep (Stickgold, 2005; Walker & Stickgold, 2006). Sleep plays a crucial role in memory consolidation, facilitating the transfer of information from temporary storage (e.g., hippocampus) to more permanent storage represented by the distributed neocortical networks in the brain (Walker, 2005). This is orchestrated by the coalescence of brain electric oscillations, including hippocampal ripples, sleep spindle, and slow waves (Diekelmann & Born, 2010).

Executive functions, encompassing cognitive processes such as working memory, inhibitory control, and cognitive flexibility, are essential for successful postural control (Diamond, 2013). Sleep loss and circadian misalignment can negatively impact executive functions, impairing individuals' ability to plan and execute motor responses required for maintaining postural stability (Killgore, 2010). Reduced working memory capacity resulting from sleep disturbances may hinder the ability to process and integrate sensory information for accurate postural adjustments (Harrison & Horne, 2000).

Sleep is a complex phenomenon characterized by distinct stages and cycles, each serving unique functions in the restoration and regulation of various physiological and cognitive processes (Carskadon & Dement, 2011). Sleep is composed of alternating periods of rapid eye movement (REM) sleep and non-rapid eye movement (NREM) sleep, with NREM sleep further divided into three stages: N1, N2, and N3 or slow-wave sleep (SWS) (Carskadon & Dement, 2017).

The regulation of sleep is intricately tied to the circadian rhythm, an internal timing system that operates on a roughly 24-hour cycle. The "master clock" of the body, alternatively called suprachiasmatic nucleus (SCN) and located in hypothalamus, manages circadian rhythm. The SCN engages with external surroundings primarily via light exposure and modulates various physiological as well as behavioral tasks to coincide them with 24-hour day-night cycle (Duffy & Czeisler, 2009; Hastings et al., 2007).

The sleep-wake cycle and the rhythms of day and night are managed by a complex operation in the brain. The balance between sleep and wakefulness is greatly affected by different neurotransmitters such as adenosine, serotonin, and gamma-aminobutyric acid (GABA). Adenosine contributes to our need for sleep; its amount increases when staying awake then it gradually decreases during sleeping that results into an

equal management of the necessity for rest (Porkka-Heiskanen, 1999; Basheer et al., 2004). Serotonin and GABA also have important functions in controlling sleep and wakefulness. Serotonin has an effect on REM sleep while GABA encourages sleep by putting a stop to neurons that promote alertness (Brown et al, 2012; Monti, 2011; Saper et al., 2010; Siegel, 2005). There are dedicated neurons in the hypothalamus (e.g., Ventrolateral preoptic nucleus, VLPO) that actively promote sleep but inhibit the activity of the wake-promoting neurons in the hypothalamus (hypocretin/orexinergic cells) and various brainstem nuclei contributing to the ascending arousal system (Saper & Fuller, 2017).

1.1.2.2 The Assessment of Sleep

Sleep, as a complex physiological function, is assessed using multimodal approaches. In general, we differentiate between subjective reported and objectively measured sleep assessments. While subjective reported measures represent proxy measures of sleep features, they are broadly used in both basic human and clinical research due to practical reasons (Buysse et al., 2006).

1.1.2.2.1 Sleep Questionnaires

Numerous sleep questionnaires are used to assess sleep duration, quality, insomnia symptoms, daytime sleepiness, and various disturbances related to breathing and movement. While many of the questionnaires have good psychometric properties (Gonçalves et al., 2023; Buysse et al., 1989), their concordance with objectively measured sleep features varies to a great extent (Trimmel et al., 2021). This is particularly true for questionnaires related to sleep quality and insomnia. It is thought that aspects of mental well-being and emotional disposition represent major confounds of self-reported sleep quality (Krystal & Edinger, 2008). Therefore, the way people judge their sleep quality will be interlinked with their emotional well-being without a clear causality between the two. Interestingly, self-reported sleep duration and chronotype (habitual sleep-wake timing and diurnal preference) are much less associated with emotions and mental well-being compared to sleep quality (Muzni et al., 2021).

1.1.2.2.2 Actigraphy

Actigraphy is a widely utilized non-invasive objective technique for investigating sleep and rest-activity patterns. It presents a cost-effective and ecologically valid approach to assess sleep and circadian rhythms by capturing habitual rest-activity rhythmicity within a participant's natural everyday life (Ancoli-Israel et al., 2003; Martin & Hakim, 2011). Outcome measures derived from the recorded actigraphy data have demonstrated a robust correlation with entrained endogenous circadian rhythms (Ancoli-Israel et al., 2003).

From a medical perspective, actigraphy offers insights into potential circadian disorders (e.g., delayed sleep phase disorder or non-24-hour circadian rhythm disorder), insomnia, and nocturnal awakenings (Meyer et al., 2022). However, it is not used as a medical device for diagnosis (Cistulli & Grunstein, 2005). Actigraphic data are acquired through the use of an actiwatch device (Natale et al., 2014). Typically worn on the non-dominant wrist, this device incorporates a light sensor and an accelerometer to track major motor movements (Gao et al., 2021). Recording can span from several hours to several days and weeks, facilitating the visualization of daily rest and activity patterns (Figure 2). It can estimate the amplitude and the phase of the day-to-day activity-rest rhythmicity (Thomas & Gamble, 2022).

The actigraphy data are often complemented by a sleep diary, including details of bedtime, wake-up time, frequency of awakenings, pre- and post-sleep levels of drowsiness, sleep quality, dream recollections, and physical activities (Ramlee et al., 2017). While actigraphy overestimates sleep by being unable to differentiate between quiet wakefulness (Sansom et al., 2023), it is still one of the preferred methods of assessing sleep where polysomnography is not feasible (Rösler et al., 2023).

In addition to objective sleep duration and quality estimation, the non-parametric measures derived from actigraphy, such as intra-daily variability and inter-daily stability, have been shown to be predictive of various health conditions and even mortality (Zuurbier et al., 2015). Actigraphy-measured sleep duration and quality have been found to be predictive of various mental health conditions (Henning et al., 2020).

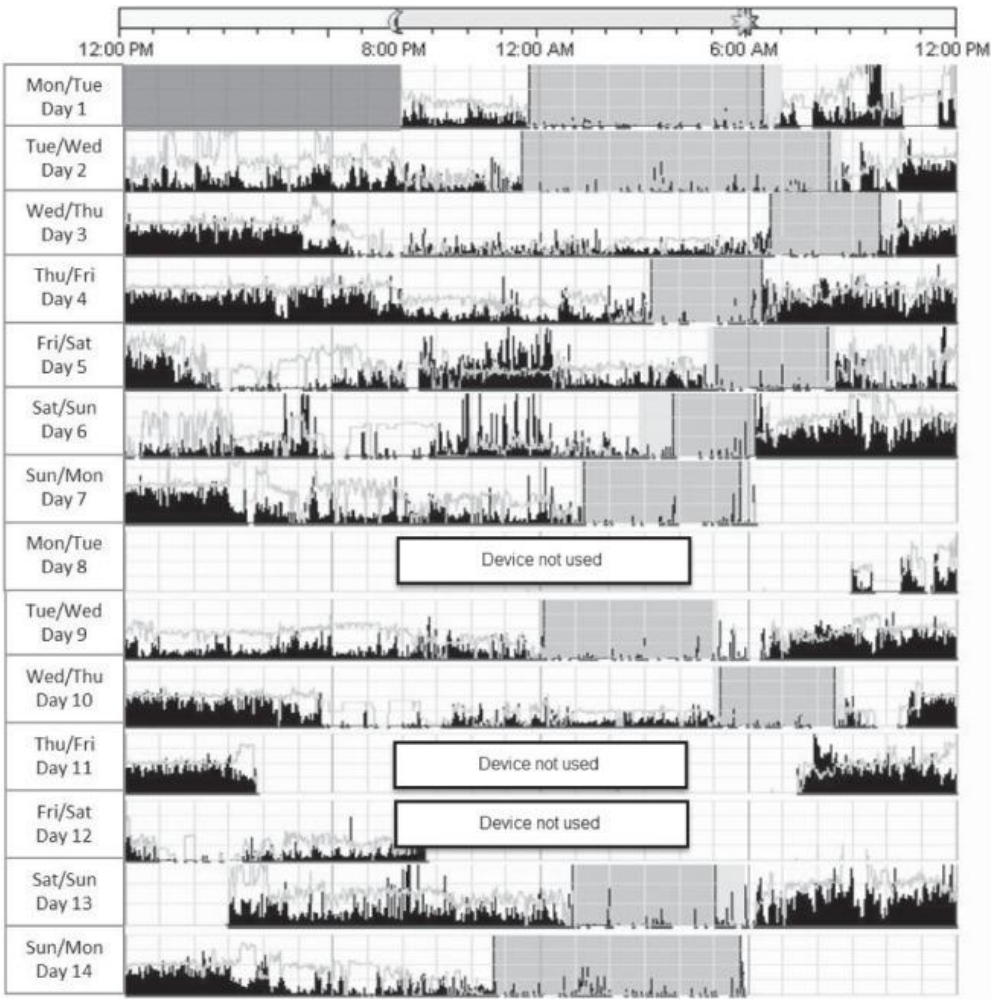


Figure 2. Example a multiday actigraphy assessment of a patient with an abnormal sleep-wake profile. Horizontal think black line indicates activity levels. The light grey lines indicate light levels. The shaded areas in between periods of activity indicate rest episodes. The irregularity of sleep-wake timing and the elevated activity are apparent (Lewis et al., 2015).

1.1.2.2.3 Polysomnography

The gold standard method of assessing the objective features of sleep is polysomnography (PSG). This comprises the simultaneous monitoring of multiple physiological variables. Via electrodes placed at the surface of the scalp (electroencephalogram or EEG), PSG provides data about the dynamic patterns of electrical activity of the brain. These key EEG measures are complemented by other polygraphic features related to the tone of muscles (electromyogram or EMG), the movements of the eyes (electrooculogram or EOG), as well as respiration and the electrocardiogram (ECG) (Berry et al., 2012; Iber et al., 2007). The simultaneous inspection of these signals can reveal the changes that take place in the brain and body when we transition from wakefulness to sleep (Dijk & Lazar, 2012). Importantly, the integration of EEG measurements with EOG and EMG permits the classification of sleep stages. This classification adheres to

globally recognized guidelines outlined in manuals like "A Manual of Standardized Terminology, Techniques, and Scoring System for Sleep Stages of Human Participants" (Rechtschaffen & Kales, 1968) and standards established by the American Academy of Sleep Medicine (Berry et al., 2020). PSG, beyond being a scientific tool for objective sleep investigation, is also an authorized medical procedure for the diagnosis of sleep disorders.

PSG allows for the objective characterization of sleep, encompassing general features of the sleep architecture such as the time to sleep onset (i.e., sleep latency), total duration of sleep, sleep efficiency (ratio between sleep duration and time spent in bed), the time spent in various NREM sleep stages (e.g., N1, N2, N3 or Slow wave sleep) and REM sleep, along with other qualitative factors such as the number of awakenings and the number of arousals. Additionally, the assessment of the EEG power spectrum through the analysis of specific frequency bands offers more intricate insights into sleep quality (Berry et al., 2012; Iber et al., 2007; Rechtschaffen & Kales, 1968). Exploring EEG topography allows for the examination of localized sleep-related phenomena like K-complexes, sleep spindles, and slow waves (e.g., Ioannides et al., 2019; Laurino et al., 2019; Alfonsi et al., 2019).

During the sleep episode, when this happens during the circadian night, other physiological and hormonal changes occur that are normally not measured as part of routine clinical polysomnography but can be measured as part of the multimodal sleep assessment with research purposes (Figure 3). These changes include the rising and falling limb of the blood melatonin concentration, the gradual decline in the core body temperature, and an increase in the blood cortisol levels, as well as a pulsating release of growth hormone during slow-wave sleep (Dijk & Lazar, 2012). It has been shown that hundreds of genes across the human genome present sleep-wake-dependent expression profiles that can be tracked via regular blood tests and dedicated molecular biology methods (Archer et al., 2014).

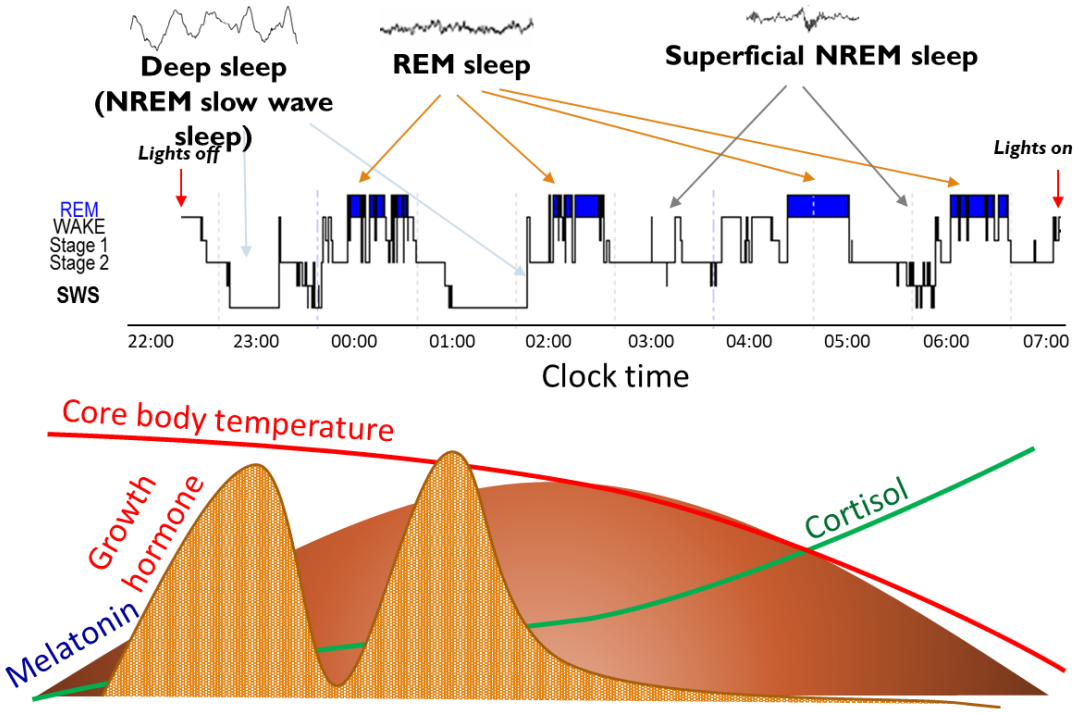


Figure 3. The overnight sleep architecture (i.e., hypnogram) of a healthy adult and illustration of associated physiological/hormonal changes.

1.1.2.3 Sleep Stages and Architecture

The architecture of sleep is a fascinating interplay of non-REM and REM sleep stages, cycling through the night in a somewhat predictable pattern. Non-REM sleep can be sub-categorized into various stages, often described as N1, N2, and N3, or slow-wave sleep (SWS), depending on the classification system used. As soon as we fall asleep, the neural activity of the brain slows down, transitioning into deep sleep or SWS, followed by an abrupt increase in neural brain firing rate leading to REM. This circular process of brain activity deceleration and subsequent acceleration represents a sleep cycle that lasts around 90 minutes, and depending on the length of the sleep episode, adults have about 5 sleep cycles a night (Carskadon & Dement, 2005; Siegel, 2005; Brown et al., 2012) (Figure 2.2).

Non-REM and particularly SWS are mainly associated with cellular and metabolic restoration, as well as neural plasticity linked to learning and memory. REM sleep is a unique state characterized by rapid eye movements, increased brain activity, and muscle paralysis (Walker, 2009; Stickgold & Walker, 2013). This stage is thought to be essential for emotional regulation (Carskadon & Dement, 2017) but also contributes to memory consolidation. However, the mechanisms by which those two vigilance states contribute to memory-related processes are thought to be quite different (Diekelmann & Born, 2010).

We spend, on average, 80% of sleep in NREM and about 20% in REM sleep. SWS also presents a proportion of 10-20% of total sleep time (Chokroverty, 2010). These distributions show marked changes across development and aging and in various mental health conditions and brain disorders. Most commonly, SWS and REM sleep decrease with aging (Diekelmann & Born, 2010).

1.1.2.4 Changes in Sleep Patterns and Architecture with Advancing Age

Epidemiological studies have established that sleep disorders and insufficient sleep are common in older adults, with around 50% of those aged above 65 experiencing chronic sleep problems (Crowley, 2011). Importantly, these sleep problems are associated with many poor physical and mental health outcomes (Cohen et al., 2022; Kerkhof, 2017). Sleep dysfunction is highly prevalent across the spectrum of mental health disorders and neurodegenerative conditions, with a potential bidirectional relationship with the underlying disease process (Freeman et al., 2020; Voysey et al., 2021). For patients with mental health disorders, dementia, or other age-related chronic conditions, the presence of sleep disturbances represents an additional burden to the impaired function and quality of life directly attributable to the disease and may also escalate the rate of global deterioration predicting a poorer prognosis (Ishak et al., 2012). Effective assessment and management of sleep dysfunction in aging and neurodegeneration are therefore of paramount importance, and new interventions are needed to address these issues (Greene et al., 2022).

The gradual decline in overall sleep quality is, however, not necessarily paralleled by similar changes in sleep duration. The sleep length recommendation remains relatively constant from middle-aged adulthood, and adults over 65 are still advised to get seven to eight hours of sleep each night (Hirshkowitz et al., 2015). According to a recent large sample size study (N > 700,000) performed across 63 countries, age-dependent changes in self-reported sleep duration segment the adult human life course into three distinct phases. While self-reported sleep duration decreases with age in early adulthood (19-33 yrs), and there are no changes in mid-adulthood (34-53 yrs), sleep duration increases in late adulthood (54+ yrs). In this third phase, sleep duration shows an inverted U-shape relationship with cognitive performance, with the optimal performance peaking at 7 hours of reported sleep (Coutrot et al., 2022). This is in line with another large sample size study showing that seven hours of self-reported sleep is optimal in middle and old age, for both cognition and mental health (Li et al., 2022). That said, both short and long sleep durations have been associated with worse outcomes for older adults, such as greater amyloid-beta (Aβ) burden, greater depressive symptoms, higher body mass index, and cognitive decline (Winer et al., 2021).

Importantly, objectively measured changes in sleep quality have been shown to statistically forecast the longitudinal trajectory of cortical Aβ deposition in the human brain (Winer et al., 2020).

Various factors contribute to the age-related changes in sleep architecture and quality. Neurotransmitter systems involved in sleep regulation, such as the melatonin and GABA systems, undergo alterations with aging (Maldonaldo, 2018). These changes can disrupt the balance between sleep-promoting and wake-promoting mechanisms, leading to sleep disturbances (Vitiello, 2006).

Despite this connection, sleep complaints in older adults are not all due to the physiological aging process but due to primary sleep disorders or secondary to other health conditions (Crowley, 2011). The frequency of primary sleep disorders such as insomnia, obstructive sleep apnea, restless leg syndrome, REM sleep behavior disorder, and advanced sleep phase disorders are all more common in older adults (Foley et al., 2004). Some of these sleep disorders are often secondary to other medical conditions, ranging from chronic pain disorders to mental health and neurodegeneration (Mander et al., 2017; Patel et al., 2018).

The effects of sleep changes linked to aging go further than just night rest. Sleep troubles in older adults relate to a series of negative results (Schmidt et al., 2012). Reduced mental ability, including problems with memory, focus, and management function are connected with disturbed sleep (Mander et al., 2017). Mood disturbances, such as depression and anxiety, are also more prevalent in older individuals with poor sleep quality (Ohayon et al., 2004). Moreover, sleep disturbances have been implicated in increased falls risk, cardiovascular disease, metabolic dysfunction, and overall reduced quality of life (Ancoli-Israel & Cooke, 2005).

1.1.2.5 Sleep-wake Regulation and the Nature of Sleep Alterations in Aging

The timing, duration, and quality of sleep are defined by two distinct but dynamically interacting biological timekeepers: sleep-wake homeostasis and circadian rhythmicity (Borbely et al., 2016).

1.1.2.5.1 The Two-Process Model of Sleep Regulation

During the 24-hour sleep-wake cycle, the two timekeepers are timed to oppose each other. That is, the gradually amounting sleep propensity during wake-up time is compensated by a monotonically increasing circadian arousal signal that peaks about two hours before habitual bedtime (Figure 4). This time interval is also called the wake maintenance zone associated with the maximal core body temperature and the initial phase of melatonin release. Subsequently, the circadian arousal signal enters its descending phase along with the declining core body temperature and waxing melatonin concentration that opens the physiological time window for sleep to take place. Driven by the elevated homeostatic propensity (i.e.,

process S), sleep is initiated and consolidated throughout the night. In the early morning hours when homeostatic sleep pressure (process S) is mostly dissipated due to slow-wave sleep dominating the first part of the night, the circadian sleep-promoting signal associated with the trough of the core body temperature reaches its maximum and keeps the brain asleep. This is called the sleep maintenance zone (Borbely et al., 2016; Dijk & Lazar, 2012). Mathematical simulations show that age-dependent changes in sleep timing, duration, and quality during adulthood can be explained either as a consequence of a simultaneous reduction in the amplitude of the circadian sleep/wake-promoting rhythm and/or the learning-dependent build-up of homeostatic sleep pressure during wake (Skeldon et al., 2016).

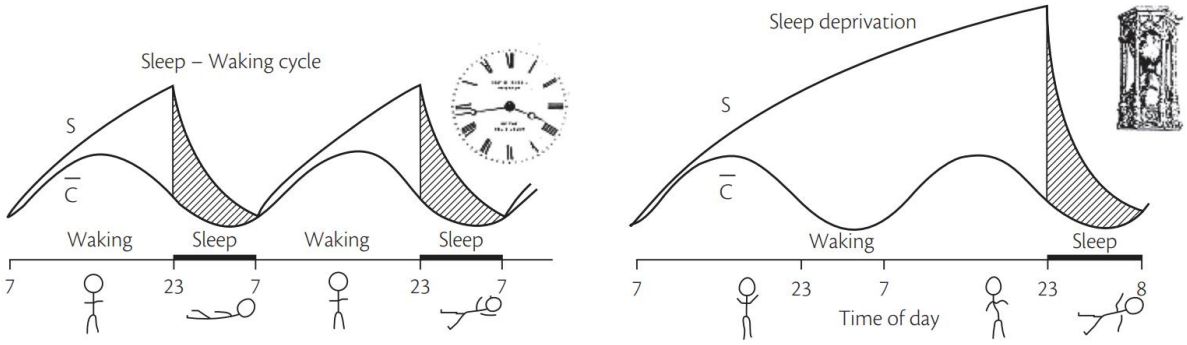


Figure 4 The two-process model of sleep regulation (from Dijk and Lazar, 2012 and originally published by Borbely, 1982).

1.1.2.5.2 Sleep-wake Homeostasis

Sleep-wake homeostasis (i.e., process S), linked to cellular energy metabolism and synaptic strength, tracks the relative amount of sleep and wakefulness similar to an hourglass (Figure 2.3). Sleep latency (time needed to fall asleep) and slow-wave sleep (i.e. NREM stage 3) are key markers of homeostatic sleep propensity. The longer we stay awake, the greater sleep propensity we accumulate, and therefore, the more restorative sleep we need to recover (Vyazovskiy & Harris, 2013). Increased sleep propensity upon bedtime is associated with overall better sleep quality, the reason why one of the central elements of CBTi is sleep restriction/consolidation. To reduce the time to fall asleep and boost sleep quality, patients with insomnia are encouraged to curtail their nightly time spent in bed in a controlled manner. In this way, the

residual sleep propensity carried over to the following day helps gradually improve sleep quality (Morin et al., 2006).

Evidence highlights that the homeostatic process S is use-dependent. That is, the more we learn during wake (i.e., learn), the more restorative deep sleep we need afterward. This is reflected in the relative increase of slow-wave activity (i.e., delta: 0.5 – 4 Hz) and sleep spindles (11 – 15 Hz) during NREM sleep as measured by EEG (Nir et al., 2011; Vyazovskiy et al., 2009). This suggests that sleep is the price the brain must pay for learning and memory (Tononi & Cirelli, 2014). Interestingly, this use-dependent sleep modulation happens in a topographical manner, producing the phenomenon called local sleep. That is, different brain regions express differential amounts of slow-wave activity and sleep spindles, depending on the synaptic strength induced by the preceding learning (Huber et al., 2004; Tononi & Cirelli, 2014). This phenomenon renders sleep and particularly sleep-dependent EEG activity the potential to become a sensitive early biomarker of age-dependent cognitive decline (Mander, 2020). A decrease in slow-wave activity has been associated with aging and has been shown to mediate the effect of the age-related medial prefrontal cortex (mPFC), gray-matter atrophy (Mander et al., 2013), and mPFC beta-amyloid pathology (Mander et al., 2015), which, in turn, impacts medial temporal lobe integrity - one of the first cortical regions affected in Alzheimer's (Mander et al., 2015; Mander et al., 2013).

Although older adults report more frequent naps and increased daytime sleepiness, this is probably due to disrupted sleep quality or other comorbidities. Experimental studies show that healthy aging is associated with a reduction in daytime sleep propensity, sleep continuity, and slow-wave sleep, which may reflect a lessening in the homeostatic sleep requirement (Dijk et al., 2010; Klerman & Dijk, 2008). That is, healthy older adults without sleep disorders are expected to be less sleepy during the day compared to young adults. Therefore, daytime naps later during the day will likely worsen insomnia symptoms. This is because the accumulated sleep pressure will partially dissipate before bedtime, which will further increase sleep latency and time spent awake during the night and reduce slow-wave sleep.

1.1.2.5.3 Circadian Rhythmicity

There is much more to sleep than an hourglass-type homeostatic response to time awake and learning experiences. It is gated by the other biological timekeeper, the circadian system, which can either facilitate or prevent sleep from happening (Vandewalle, 2021). The fact that human life is characterized by alternating cycles of sleep and wakefulness, with a period of 24 hours, suggests the existence of a biological clock machinery tracking the daily light-dark cycle. Indeed, this cycle is associated with a molecular clock that "ticks" deep in the cells of our body and is synchronized across tissues into

physiological-level circadian rhythms by a tiny nucleus in the hypothalamus called the suprachiasmatic nucleus (SCN) or master clock (Mohawk et al., 2012). This endogenous master clock anchors circadian rhythmicity to external time cues, most importantly light, by its monosynaptic connection to the photosensitive retinal ganglion cells (Foster et al., 2020). By modulating multiple physiological systems, including the levels of brain arousal through a range of neural and hormonal effects, the SCN creates optimal time windows for the brain and the body to rest and excel (Vandewalle, 2021). This is referred to as process C. The optimal circadian time window for sleep coincides with the nighttime characterized by elevated blood melatonin concentration and decreasing core body temperature (Dijk & Czeisler, 1994; Lazar et al., 2013). The circadian sleep-promoting signal is maximal during the early morning hours, overlapping with the nadir of the daily cycle of the core body temperature (Dijk & Lazar, 2012). This adverse circadian phase negatively impacts emotional well-being and cognitive performance, as well as the underlying brain activity, with implications for jet lag and shift work (Cajochen et al., 2002; Groeger et al., 2022; Lazar et al., 2015; Santhi et al., 2016). Similarly, the quality of sleep mistimed relative to the optimal circadian phase for rest is impaired and can disrupt normal human physiology from gene expression to metabolism, immunity, and autonomic function (S. N. Archer et al., 2014; Leproult et al., 2014; Morris et al., 2015; Qian et al., 2019; Sletten et al., 2020). The unfavorable phase relationship between sleep-timing and the intrinsic circadian rhythms (e.g., melatonin phase) is associated with insomnia symptoms, and this association has been shown to be stronger in women (Lazar et al., 2013).

The circadian phase is interlinked with habitual sleep-wake timing (chronotype) and has been linked to both physical and mental health, most likely due to its interaction with sleep quality and duration (Lazar et al., 2012). Aging is associated with a physiologically advanced sleep phase (early bedtime and wake-up time), which in extreme cases is considered an advance-sleep-wake disorder interfering with the quality of life. Eveningness and delayed sleep phase syndrome – less common among the older adults - have been associated with lower sleep quality, poor sleep habits, depression, including seasonal affective disorder (SAD), and increased substance dependence (Simon N. Archer et al., 2014; Kivela et al., 2018). Light impacts the circadian phase by delaying or advancing its phase depending on the timing of the light exposure. Morning light exposure advances, whereas early evening exposure will delay the circadian phase (Blume et al., 2019). Besides the impact of aging on circadian rhythmicity by advancing its phase, it also reduces its amplitude (Duffy et al., 2015). To understand how these age-dependent changes in sleep-wake homeostasis and circadian rhythmicity affect sleep and waking vigilance in aging, this should reviewed in the interaction between process S and process C.

1.1.2.6 Experimental Protocols Used to Study Circadian Rhythmicity vs. Sleep Homeostasis

Sleep homeostasis (process S) and circadian rhythmicity (Process C) present a dynamic interaction in how they define the timing, duration, and quality of sleep and waking neurobehavioral functioning. Processes C and S synergistically promote sleepiness and wakefulness. The constant routine protocol, where participants remain awake for at least 24 hours in a controlled environment with fixed conditions (e.g., room temperature, light intensity, standardized meals), serves as the gold standard for circadian rhythmicity assessment, determining circadian phase and amplitude. During constant routine protocols, alertness and neurobehavioral functioning gradually deteriorate due to increasing homeostatic sleep pressure (process S). Consequently, the circadian pattern of cognitive performance, with lower performance in the early morning and higher in the evening hours, becomes overshadowed by the accumulating sleep pressure. This is evident in a general deterioration of subjective and objective measures of vigilance, such as the increased Karolinska Sleepiness score (KSS), the increased reaction time, or the elevated number of attentional lapses on the Psychomotor Vigilance Task (PVT) (Gabehart & Van Dongen, 2017). However, this gradual increase in homeostatic sleep pressure is still modulated by the circadian arousal signal that ticks in the background. As such, the effect of total sleep deprivation is worse during the early morning hours when the core body temperature reaches its nadir and becomes nearly normal in the wake maintenance zone (evening hours) of the subsequent day when the body temperature reaches its peak. As such, in an acute sleep deprivation experiment such as the presented constant routine, the two processes are confounded.

The only way to experimentally disentangle Processes C and S is to employ a forced desynchrony (FD) protocol in which the sleep-wake cycle is desynchronized from the intrinsic circadian clock by shifting the sleep-wake schedule by several hours every day. A commonly used FD protocol comprises 28-hour days, including 18 hours and 40 mins of wake and 9 hours and 20 mins of sleep (Lazar et al., 2013). In this way, the sleep-wake timing is shifted by 4 hours every day. Given that the experiment is run in dim light conditions, the central clock cannot synchronize with such a magnitude change in the sleep-wake cycle and will start free running. That is, it will lose anchor to both the light and the sleep-wake cycle and will be driven by the intrinsic circadian pacemaker. This will allow the researchers to study the independent effect of time spent awake as well as the circadian phase.

Another frequently employed protocol is the napping protocol (multi-nap protocol), designed to keep homeostatic sleep pressure (Process S) at a constant level to unveil the effects of Process C. Multiple naps elevate sleep pressure, thus maintaining Process S at a relatively constant level. These experimental designs effectively highlight the wake maintenance zone, corresponding to peak daily alertness rhythms,

and the sleep-promoting zones characterized by declining alertness, driven by the circadian oscillator's promotion of sleep. Circadian researchers often opt for a between-subject design, randomly assigning participants to either sleep deprivation (SD) or nap protocols (Graw et al., 2004, Reichert et al., 2017, Cajochen et al., 2001). In the SD protocol, individuals remain awake for an extended period, typically around 40 hours, while the nap protocol involves receiving multiple brief sleep opportunities at regular intervals (usually 9-10 naps over a 40-hour protocol).

1.1.3 Interrelationship between Postural Control, Sleep and Circadian Rhythmicity: Age-Related Changes in Sleep and Postural Control

Sleep, a vital part of human health, changes significantly as we age. Investigation indicates that typically older adults sleep less and not as good when compared to younger individuals. According to the National Sleep Foundation, usually adults who are above 65 years old get around 7-8 hours of sleep per night whereas those at a younger age generally have about 7-9 hours (Blackwell et al., 2006). Apart from sleeping lesser, older adults also tend to be awake more during nighttime causing their overall quality of sleep efficiency to reduce (Ancoli-Israel et al., 2003). Sleep problems like insomnia are more common in people older than 65 years (Foley et al., 1995; Ohayon, 2002).

Simultaneously, the capacity for keeping equilibrium and managing our stance changes as we grow older. Researches discover that older individuals appear to wobble more when standing steady compared to younger ones (Horak, 2006). This decline in postural control is a major factor in the increased risk of falls among older adults.

Based on experimental evidence it is likely that age dependent sleep quality decline contributes to the age dependent decline in postural control. However, the relationship between sleep changes and postural control in aging is complex and not well understood. Nonetheless as our society grows older, it becomes increasingly important to understand how age affects both sleep patterns and our ability to maintain balance. Sleep problems, which are common in older adults, can worsen balance issues (Schwartz et al., 2017) and both independently and in interaction can significantly impact quality of life and healthy longevity. Looking to the future, we can expect these issues to become even more pressing. Demographic shifts underscore the need to address age-related health challenges proactively.

1.1.3.1 Effects of Sleep Deprivation on Postural Control

Sleep plays a crucial role in maintaining optimal postural control. Acute sleep deprivation, characterized by a complete or partial sleep restriction, has been consistently found to impair postural stability potentially elevating the risk of falls (Robillard et al., 2011, Patel et al., 2008; Avni et al., 2006; Fabbri et al., 2006; Gribble & Hertel, 2004; Liu et al., 2001, Nakano et al., 2001). Beyond these immediate effects, chronic sleep problems or sustained periods of poor sleep quality including various sleep disorders can potentially undermine healthy postural control, affecting muscle coordination and reaction times, both of which are vital for maintaining postural stability (Kirshner et al., 2022; Hita-Yañez et al., 2013).

There are a significant number of experimental studies that have investigated the immediate effects of sleep deprivation, with sleep restriction periods ranging from 4 to 36 hours, on postural control across various age groups. In these experiments, postural control is commonly measured through metrics such as center of pressure (CoP) variability, sway velocity, and sway area as non-linear measures of sway dynamics (e.g. sample entropy) using posturography. Additionally, these studies often incorporate cognitive assessments, such as reaction time tasks, various attentional tasks, and dual-task paradigms, to evaluate the interplay between cognitive function and motor control under conditions of sleep deprivation. And indeed, the decline in postural stability following extended wakefulness becomes even more salient when additional tasks demand attentional engagement (Schlesinger et al., 1998). This is in line with the well-established evidence that sleep loss affects brain function as measured by cognitive test in a dose dependent manner explained by an excess of homeostatic sleep pressure proportional with the time loss of sleep (Van Dongen et al., 2003).

Robillard et al. (2011) ran an important study to see the effect of sudden loss of sleep on balance control, including any possible issues this could cause for risk of falling. In their comprehensive research, participants were made to stay awake for a total length of 25 hours after a plan lacking sleep was implemented as part of a detailed design format. The experiment involved healthy young adults. This ensured that the consequences of insufficient sleep on balance control were clearly visible and not confused with any existing health conditions or age-related alterations in balancing ability. To examine their body equilibrium, a force platform was utilized; this apparatus notes down the shift at what we refer to as center of pressure (CoP). This is a reliable method to see if someone has good balance or not. Precisely, these researchers examined various factors like CoP sway area, quickness and variability under different circumstances - such as when eyes are open compared to when they are closed. They aimed to find out more about whether visual feedback can reduce the impacts brought on by insufficient sleep. The research indicated that not having enough sleep because of severe sleep deprivation led to a significant alteration in preserving bodily equilibrium. In particular, there was an evident increase in CoP sway area and speed, suggesting that individuals struggled more to maintain stable posture. This effect became even more apparent when visual assistance was eliminated, underlining the reliance on vision as compensation for insufficient body control during situations with inadequate sleep. In addition, the research pointed out that there is a direct connection between poor posture stability and increased sleep pressure. This situation worsens sensorimotor weaknesses and decreases cognitive processing speed. These results are very important because they show short-term lack of sleep can greatly raise the likelihood of falling down, mainly in places where there aren't many visual signs or when people need to keep balance under hard

situations. The research also indicates enough rest is necessary for maintaining balance and preventing falls, especially among groups more likely to be affected by loss of sleep.

Additionally, visual feedback is critical for motor control, including postural balance, as it allows muscles to adjust their movements accordingly (Peterka, 2002; Massion, 1994). However, the integration of visual sensory information with the motor and vestibular systems involved in maintaining postural control might be impaired by sleep deprivation as alertness reduces (Gomez et al., 2008; Nielson et al., 2010). Sleep deprivation may also increase musculoskeletal stiffness and reduce the effectiveness of postural control, as shown in studies of altered muscle function following sleep deprivation (Moldofsky et al., 1975; Kato et al., 2000; Robillard et al., 2011).

Furthermore, studies by Nakano et al. (2001) and Avni et al. (2006) highlighted that sleep restriction not only disrupts motor control and/or visuo-motor integration but also exacerbates the difficulty of maintaining balance during tasks that require simultaneous cognitive engagement. For example, in dual-task conditions where participants were required to maintain balance while performing a secondary cognitive task, those who were sleep-deprived exhibited significantly greater postural instability compared to well-rested controls. This dual-task impairment is thought to arise from the reduced cognitive resources available for motor control when sleep is restricted, leading to a compromised ability to maintain postural stability during cognitively demanding tasks.

However, some studies suggest that the relationship between sleep deprivation and postural control is not entirely straightforward. For instance, Gomez et al. (2008) observed that, contrary to expectations, some participants exhibited improved postural control following sleep deprivation and repeated balance perturbations. This improvement was speculated to arise from increased compensatory efforts (i.e., resilience to sleep loss) or the specific nature of the tasks. Similarly, Pham et al. (2014) found that under less challenging conditions—such as standing on a firm surface with eyes open—the expected impairments in postural control were not as pronounced. This implies that the body can adjust in some situations, which might hide the negative impact of lack of sleep on maintaining balance. In addition to this, Aguiar and Barela (2014) mentioned less clear effects of insufficient sleep on controlling posture in activities requiring lesser thinking or physical effort. The discoveries they made show that level of difficulty may fluctuate based not only on task complexity but also sensory system participation. These researches together show that though lack of sleep typically worsens balance control, the seriousness of this weakening can be managed by task situations, personal variances and balancing adjustments. This results in a range of outcomes based on different testing scenarios.

The majority of previous research has mainly concentrated on younger adults, with only a handful looking into the impact of sleep deprivation on balance and stability control in older individuals. However, there are hints that age can influence how much sleep loss affects postural control. To illustrate, it seems like older adults might be especially susceptible to lack of sleep effects demonstrating more issues with balance and stability when compared to young adults (Przybylski et al., 2014). The higher risk might be because of the decrease in sensory processing and motor control as one gets older, which sleep loss makes even worse (Demanze Laurence & Michel, 2017). Also, younger adults can use certain methods to keep their balance after not sleeping enough - they may rely more on what they see or sensations from within the body. Yet, these methods may not perform effectively for older adults (Redfern et al., 2001). As a result, even minimal sleep disruption can significantly influence the ability of old individuals in preserving their posture. It underlines the necessity to concentrate on diminishing such risks (Fabbri et al., 2006; Nakano et al., 2001; Gribble & Hertel, 2004). Additionally, these age-related differences put emphasis on the need for specific sleep habits guidelines and recommendations according to different age groups. It assists in preserving a healthy physical equilibrium and preventing fall injuries among older individuals (Berger & Doherty, 2010).

The study conducted by Patel et al. (2008) indicated that restricting sleep to just 4 hours considerably increased the inconsistency of CoP (center of pressure) and resulted in challenges for young adults to stand steady, implying a reduction in balance control. Likewise, in the research conducted by Gribble and Hertel (2004), they noticed an effect on older adults. These individuals had difficulty keeping a suitable posture, alongside doing mental tasks when deprived of sleep for one entire day. It was evident from increased swaying related to CoP and slow reaction times in activities requiring attention. This study suggests that inadequate sleep can have a direct and notable impact on body balance particularly amongst senior citizens who might not have as robust balancing systems (Smith et al., 2012; Robillard et al., 2011).

It is unsurprising to discover that the influence of sleep deprivation on balance control can vary based on age. It is common for younger adults to outperform older adults in maintaining their balance, possibly because they are able to utilize improved stiffness techniques (Lajoie et al., 1993; Kerr et al., 1985). This adaptability in posture regulation could be one factor explaining why young adults handle lack of sleep more effectively than their older counterparts. The ability to maintain balance with less sleep is often shown more in younger individuals (Liu et al., 2001). In contrast, older adults usually struggle more to keep body stability after reducing their sleeping hours. Nielson et al suggest that this might be due to the decline

related to age in sensory processing, motor coordination and cognitive reserve (Fabbri et al., 2006). A study observed that usually, younger adults change their posture when they partake in study activities (Nielson et al., 2010). This could be connected to an intentional increase of mental concentration and focus which is required for keeping balance. The function of sleep, particularly its quality and duration, might assist these balancing strategies (Alhola & Polo-Kantola, 2007; Durmer & Dinges, 2005). Younger adults who normally have more rejuvenating sleep cycles might be better prepared to use such compensation methods during periods of sleep deprivation as the cognitive and motor systems are less affected than those seen with older adults or because they possess greater brain reserves to activate (Hirshkowitz et al., 2015). This suggests that the resilience observed in younger adults could be partly attributed to the better quality of sleep they typically experience, which in turn supports their ability to maintain postural control under challenging conditions.

Nonetheless, the age-dependent effects of sleep loss on postural control are not entirely intuitive given that the existing literature also shows that younger adults can be more vulnerable to sleep loss from a vigilance state perspective (Phillip et al., 2004; Robillard et al., 2011). That is, one could expect older adults outperform younger adults in tasks requiring sustained attention following acute sleep restriction. This is because aging is associated with a physiological decline in homeostatic sleep pressure accumulation during wakefulness (Dijk et al., 2001; Mander et al., 2017). These effects are further modulated by a decreased circadian amplitude of vigilance characteristic of older age resulting in reduced vigilance during the early evening hours (i.e., wake maintenance zone) but increased arousal in the early morning hours in older adults as compared to their younger peers (Duffy et al., 1998; Monk, 2005; Carrier et al., 2001).

Despite these predictable age-dependent effects, experimental data, as summarized above, show that older adults are more affected by acute sleep loss in their balance control. This suggests that the age-dependent decline in cognitive/brain reserve may be critical for the adverse effect of sleep loss on balance control in older adults (Stern et al., 2019). For example, Robillard et al. (2011) conducted a study that explored how aging interacts with sleep deprivation to influence postural stability in healthy adults. The study included a sample of younger (aged 20-30 years) and an older (aged 55-65 years) group of healthy adults. Participants in both age groups were subjected to a total sleep deprivation protocol, where they were kept awake for 25 hours, during which time their postural control was assessed at various intervals. The findings revealed that while both younger and older adults exhibited impaired postural control following sleep deprivation, the older adults were disproportionately more affected. The older participants showed a more pronounced increase in CoP sway area and velocity, particularly in the eyes-closed condition, indicating a significant deterioration in balance. This suggests that the absence of visual

feedback further exacerbated the balance deficits in the older group, highlighting their increased reliance on visual cues to maintain postural stability. Robillard et al. (2011) also noted that older adults exhibited a slower recovery of postural control after sleep deprivation ended, implying that aging not only worsens the immediate effects of sleep loss but also prolongs the recovery process. The study's results suggest that the combined effects of aging and sleep deprivation could contribute to a higher risk of falls and accidents in older populations, especially in situations where visual information is compromised or unavailable.

In summary, it can be stated that even a single night of sleep deprivation can lead to increased postural sway and a reduced ability, and these effects may be stronger in older adults, and in conditions with added attentional task and/or limited sensorial feedback (Fabbri et al., 2006; Nakano et al., 2001; Avni et al., 2006; Robillard et al., 2011). Nonetheless, the mechanism by which sleep loss affects balance control and also interacts with age, cognitive load, and sensorial feedback is still unclear. Some of these effects may be attributed to deficits in attention, reduced muscle strength, impaired coordination, and compromised sensorimotor integration (Alhola & Polo-Kantola, 2007; Mignot et al., 2002; Van Dongen et al., 2003; Van Dongen et al., 2019).

Functional imaging studies have shown that brain regions such as the thalamus and pre-frontal cortex, which regulate key cognitive functions like attention, alertness, and executive functions, become deactivated following even one night of sleep restriction (Thomas et al., 2000). This could contribute to impairments in postural control. Lack of sleep results in an overall decrease in cognitive capacity, which negatively influences a variety of functions when awake, such as maintaining balance. Other research suggests that the effects on posture are associated with daily rhythmic changes; alertness and vigilance vary throughout the day due to our body's internal biological clock (Nakano et al., 2001; Gribble & Hertel, 2004). This variation implies that during certain times—usually early morning and late night—the body is naturally less aware and more susceptible to imbalance issues. As a consequence, it heightens chances for falls or mishaps (Cajochen, 2007; Schmidt et al., 2007).

Research indicates that not having enough sleep can lead to outcomes comparable to being drunk, including reduced coordination, poor judgment and slower response times (Williamson & Feyer, 2000). There are many studies showing the negative influence of fatigue and alcohol on tasks such as driving. Williamson and Feyer (2000) found that performance after 17–19 hours of wakefulness was worse compared to that of individuals with a blood alcohol level of 0.05%, the legal driving limit in most Western European countries.

Despite significant advances in understanding the relationship between sleep deprivation and postural control, key research gaps remain. First, while numerous studies have explored these effects in young adults, the impact of sleep deprivation on postural control in older adults is less well-studied, despite evidence suggesting they may be more vulnerable. Second, it is unclear how the adverse effect of sleep loss is modulated by biological sex given that there is evidence suggesting and increased cognitive vulnerability to sleep loss in women compared to men. Third, it is also unknown how sensorial feedback of different modalities (e.g. visual, tactile) interacts with sleep loss in modulating postural control. Fourth, it is unclear how the time of the day modulates the effect of sleep loss on postural control. Additionally, the specific neural mechanisms linking sleep loss to impaired motor control, especially under dual-task conditions, are not fully understood. Future research should investigate how age-related sensory declines, cognitive reserve, and compensatory strategies modulate these interactions, and develop targeted interventions to mitigate fall risk in older populations.

1.1.3.2 Chronic Sleep Disturbances and Postural Control

Our society is struck by chronic sleep disturbances, such as insomnia sleep apnea, restless legs syndrome, and periodic limb movement disorder (Stuck et al., 2021). These sleep problems become even more frequent with advanced age which could all potentially contribute to the age-dependent decline in health and cognitive performance but also to the increased risk of falls reported in the third age group. For instance, sleeping pills like Z drugs which are given for sleeplessness have been found to raise the chance of falling in older adults (Trevens et al., 2018; Allian et al., 2005). Yet, it is hard and mostly based on observation studies to systematically look into how continuous sleep issues affect balance control and increase risk of falls. These observational studies cannot determine cause-effect relationship.

Many research studies have found a connection between bad sleep quality and higher chance of falling. For example, a study showed that poor quality of sleep - as tracked using actigraphy - can raise the risk of falls in older adults (Furtado et al., 2016). Similarly, another study found a link between poor self-reported sleep and the increased chance of falls (Patel et al., 2008). Also, a carried out a comprehensive review has confirmed that issues related to sleep, such as insomnia and sleep apnea, can notably raise the risk of falls in older individuals (Knechel et al., 2022).

For understanding effects of persistent sleep issues on body posture, it is crucial to know the distinctions between cross-sectional studies and longitudinal studies. These two research methods offer varied viewpoints. For example, examining the cross-sectional study done by Furtado et al. (2016) or Patel et al. (2008), they give significance to identifying the connections between issues of sleep and risk of falling at a certain point in time. However, they do not set cause-effect connection. Therefore, longitudinal studies are for following individuals over a time period that permits more detailed study of how ongoing sleep disturbances change and their possible long-term impacts on standing balance control. The research carried out by Yaffe et al. (2007), which was longitudinal style of study showed that the probability for functional drop off and incidents of falling increase in older adults who constantly have issues with their sleep. This technique is more preferable to monitor modifications occurring overtime regarding maintaining body posture, while considering other probable confusing elements like use of drugs, variations in health condition and the regular aging progression.

In the studies, a big problem is different tools being used to judge sleep quality and how people control their body posture. This makes it hard to compare one study with another. Often, they look at sleep problems by using both methods where people tell about themselves (like self-reports) and where things are measured in an exact way. For instance, when looking at the person's own reports of sleeping well or

not so well we often use Pittsburgh Sleep Quality Index (PSQI) and writing down daily notes on their sleep patterns that have been seen in several researches done previously (Patel et al., 2008; Buysse et al., 1989; Backhaus et al., 2002; Carney et al., 2012). Examples for techniques which measure exactly include actigraphy – observing physical movements - polysomnography– studying someone during their time of sleeping, as used in Furtado et al. (2016) as well as Stone et al. (2008). Moreover, postural control has been evaluated using multiple methods ranging from balance tests (Horak et al., 2009; Maki et al., 1991) to more sophisticated force platform assessments that measure sway and balance instability (Paillard & Noe, 2015).

Thus measurement of sleep quality and postural control varies between studies, influencing the reported outcomes. Objective measures such as actigraphy and polysomnography offer a more reliable characterization of the true sleep patterns (e.g., sleep onset, duration, and fragmentation). Research such as Furtado et al. (2016) show that objective ways can notice sleep problems often not fully told in subjective evaluations. Thus, simpler and less expensive methods like self-told surveys or sleep logs are still commonly used because they straightforwardly impact clinical diagnosis (Patel et al., 2008). Nevertheless, subjective reports of sleep quality may be influenced by the participants' mood (Krystal & Edinger, 2008) and mental health (Muzni et al., 2021) and in that sense may be confounded by psychological factors and may underestimate or overestimate the severity of sleep problems, leading to potential biases. A study by Stone et al. (2006) found discrepancies between self-reported and objectively measured sleep quality in older adults, which could influence the conclusions regarding the risk of falls.

Various sleep disorders have been connected to a higher risk of falls in older individuals. Insomnia, which is recognized by the troubles it causes in starting or continuing sleep, has received a lot of attention for its connection with body balance and falling over. This becomes particularly important since the frequency of insomnia tends to grow significantly as people age (Ohayon, 2002; Foley et al., 1999). A study by Liu et al (2021) verified that insomnia largely increases the possibility of falls in older adults. Persistent insomnia can cause feeling sleepy during day, tiredness, and less alertness (Morin et al., 2015), which all negatively impact balance and movement.

Also, other sleep problems such as obstructive sleep apnea (OSA) have been linked to an increased possibility of falling. This is probably because of the mental and physical effects caused by repeated nighttime low oxygen levels (Stevens et al., 2020). People who suffer from sleep apnea frequently show extreme tiredness during daytime and damaged cognitive function like focus, executive function), along with decreased muscle strength. All these factors can impact balance control (Liu et al., 2021).

Medications prescribed for insomnia, particularly Z-drugs (e.g., zolpidem, zopiclone), have been implicated in falls among older adults due to their sedative effects. These medicines are frequently given to make the sleep better for people having chronic insomnia. However, they might affect motor coordination and reaction time that can cause more instability in posture (Wang et al., 2001). In a research conducted by Allain et al. (2005), it was discovered that Z-drugs notably worsen balance and boost the probability of falls, specifically in older adults who may already have some level of cognitive impairment. Moreover, it is understood that these medicines can result in sleepiness the following day and slower response times, thereby increasing chances of falls during daytime tasks. Older individuals are generally more susceptible to sedative medications because aging impacts drug metabolism and removal from the body; this often amplifies balance-related side effects among them (Glass et al., 2005).

Studying the connection between ongoing sleep issues and body position control is hard because many scientific studies rely on observational data, making it difficult to determine cause-effect relations. However, studies that observe have always found a connection between low quality sleep and worsened control of body posture (Furtado et al., 2016). Lack of sleep or insomnia - hard time starting or keeping asleep - has been connected with more swaying in standing position and less stability while maintaining posture (Morin et al., 2015). Often, these situations can cause broken sleep. This results in lower motor coordination, alertness and sensory process - all very important to keep balance (Lim & Dinges, 2010).

When a person does not get enough sleep or their rest is interrupted, it can mess up the involuntary nervous system. This could change how heart rate and blood pressure are controlled, both needed for adjusting body posture (Tobaldini et al., 2017). On top of that, problems with sleep may harm production of hormones like cortisol and growth hormone; these factors have a part in muscle power and coordination (Van Cauter et al., 2000; Balbo et al., 2010).

Chronic sleep disturbances, that result in cognitive deficits, also have a hand in impairing postural control (Alhola & Polo-Kantola, 2007; Lim & Dinges, 2010). This means poor sleep can affect reaction time negatively and hamper attention levels and speed of processing information. These are crucial for sensing changes in balance or starting corrective measures (Alhola & Polo-Kantola, 2007). There is more: complex cognitive functions like executive function and working memory which become affected due to chronic lack of good night's rest can further impact one’s ability to maintain body posture (Fastame et al., 2022).

The effects of chronic sleep disturbances on postural control may be more pronounced in older adults due to age-related declines in sensory processing and motor coordination (Paillard, 2023). While younger individuals may be more resilient to short-term sleep loss, older adults with chronic sleep disturbances are at a heightened risk for postural instability and falls.

Although, young women have been shown to be more susceptible to the negative effects of sleep loss and adverse circadian phase on vigilance and cognition (Santhi et al., 2016), with regard to postural control, young men have been shown to be more affected by sleep loss (Ołpińska-Lischka et al., 2021). This may be due to the higher center of pressure (CoP) in men. The effect of sleep loss on postural control is modulated by the time of the day, suggesting a role of the circadian clock in physiological functions associated with postural control and indicating that one can be more vulnerable to falls at certain times of the day.

Circadian misalignment such as shift work, jet lag and circadian sleep difficulties make the link between sleep and body balance more complex. Those who are shift workers, particularly those on night shifts endure continual disturbance to their normal wake-sleep cycle which leads to poor quality of sleep, mental performance issues as well as lower physical coordination (Smith & Eastman, 2012). Research has proven that a higher risk for falls or accidents is associated with these shift workers likely because of changed sleeping routines along with less alertness during working hours (Wright et al., 2012). Jet lag, a temporary mismatch between the body's internal clock and external time signals, also impacts control over posture. When people cross many time zones, they commonly have weakened mental performance and balance because of disturbed sleep patterns and disruption to their circadian rhythm (Steinach, & Gunga, 2020). This is especially significant for sports people or those who travel often as they are more likely to suffer from accidents or falls when their circadian rhythms are out of sync. Chronotype is about an individual's natural inclination towards sleep-wake hours. For instance, some people are "morning individuals" while others are "evening birds". This factor also influences posture control. People who prefer evenings might face more instability in posture during the early morning times. On the other hand, those who prefer mornings might suffer from greater impairment as day progresses due to poor alignment with their circadian rhythm (Facer-Childs & Brandstaetter, 2015). Disorders related to circadian sleep like delayed sleeping pattern and irregular rhythms of awake-sleep can increase risks associated with postural control deficits because they continuously distort internal body clocks relative to environment surrounding us. Often, these disruptions result in poor and broken sleep. This worsens the functioning of motor, cognitive, and sensory systems necessary for maintaining balance which heightens the fall risk (Dijk & Lockley, 2002).

In summary, sleep is a phenomenon that has many aspects with direct and indirect impacts on postural control, particularly in older adults.

1.1.3.3 Influence of Circadian Rhythms on Postural Stability and Balance Control

1.1.3.3.1 The Circadian Clockwork and its Influences on the Organism

Humans are diurnal species with a clear 24-h period of rest and activity episodes known as circadian rhythmicity. Circadian rhythms are endogenous, approximately 24-hour cycles of physiological processes that govern various aspects of biology and behavior, including sleep-wake cycles (Dijk & Lazar, 2012). Such rhythms arrange the timing as well as harmonization of bodily functions like temperature control, hormone release, brain function etc., all participating in keeping posture stability. Circadian rhythms' function gets more fascinating when considered together with postural control. This is very important for physical independence and preventing falls, particularly in the older adults (Langeard et al., 2022; Paillard, 2023; Jorgensen et al., 2012). Comprehending how circadian rhythms affect postural control and seeing this relation's progression as people age could be crucial to create plans for avoiding falls and bettering life quality in older persons.

Circadian rhythmicity is generated by a molecular clockwork present in most cells, based on a transcriptional-translational feedback loop involving core clock genes (e.g., PER and CRY) and transcription factors (e.g., BMAL1 and CLOCK). These are all cell-autonomous peripheral clocks. However, there is also a central clock, the master clock, located in the suprachiasmatic nucleus (SCN) of the hypothalamus. The master clock is synchronized to external time cues, most importantly light via signals transmitted from the intrinsically photosensitive retinal ganglion cells (ipRGCs). It is also synchronized by physical activity and feeding. The master clock orchestrates and synchronizes the peripheral cellular clocks and a host of physiological processes in the organism. These rhythms not only dictate sleep patterns but also influence hormone production, body temperature, brain activity, synaptic plasticity, and cognitive performance (Mohawk et al., 2012; Lazar et al., 2015). The phase, amplitude, and period (i.e., length) of circadian rhythmicity are key in the regulation of various physiological processes, including sleep-wake timing and activity rest-rhythmicity (Czeisler & Gooley, 2007).

1.1.3.3.2 The Circadian Modulation of Postural Control

The biological timekeeping system, known as the circadian clock, also plays a role in physical abilities and coordination (Yalcin et al., 2022). Studies suggest that the way posture is controlled can change depending

on the time of day (Bougard et al., 2017; Mylonas et al., 2023). This is probably because of the body's daily cycles affect muscle work and brain processing operations. For instance, during parts when people usually feel sleepy (like late at night or really early in morning), one may have reduced balance or less stable posture (Langeard et al., 2022). Furthermore, Halpern et al. (2022) have reviewed the broader impact of time in a day on how body posture and walk are controlled. They emphasize the importance of circadian rhythms for balance while standing still or moving.

Circadian rhythms govern postural control via several methods. A significant method is the influence of circadian rhythms on muscle tension and coordination. Alterations was observed in muscular strength and joint stiffness related to these cycles, with peak values occurring during daytime hours and bottom levels at night (Martin et al., 1999; Guette et al., 2005). These fluctuations in muscle characteristics can affect postural adjustments and stability.

Circadian rhythms also contribute to sensorimotor integration methods that help in regulating posture (Bougard et al., 2011). Organizing and timing of sensory inputs such as visual, vestibular, and proprioceptive information is crucial for accurate motor reactions when there are changes in the body's position (Speers et al., 2002; Loram, 2015). The circadian variations can be observed affecting how we process sensory data which could influence both the synchronization and efficiency of these motor reflexes. This would then affect stability of posture (Zouabi et al., 2016).

Numerous studies are done to grasp how circadian rhythms influence posture control. Observations show that subtle balance-maintaining movements, also known as postural sway, increase during uninterrupted periods of wakefulness, particularly when our bodies prepare for sleep such as in the afternoon (Son, 2017). In a similar manner, changes in body's alertness cycles affecting postural controls and notable fluctuations in sway during long durations of being awake have also been discussed (Liu et al., 2001; Cardoso, 2021). This implies that stability of posture changes throughout the day, probably because of daily rhythms affecting muscle activity and sensory processing.

Zouabi et al. (2016) examined if postural control and perception of verticality have a circadian rhythm. They confirmed that both elements fluctuate following this cycle. This implies the internal clock not only affects balance but also influences how people perceive their body's positioning within space. Thus, the feeling of being vertical changes with the body's daily clock. It is more correct in morning time (10 a.m.) than at night (10 p.m.). On the other hand, controlling our posture stays constant all day and this could be because adjustments are made within our brain and spinal cord system. The research also found that when there is a decrease in vertical feeling during daytime, it gets back to normal while sleeping which shows

how important sleep can be for keeping balance and understanding where we are spatially. In general, although postural control remains steady, the body's internal clock influences how we perceive verticality.

Circadian rhythms' influence on how we maintain balance can change when comparing young adults to seniors. In older grown-ups, maintaining an upright posture is more affected by what time it is in a day. Some parts of the circadian cycle make them less stable (Jorgensen et al., 2012). This aligns with other research looking at the connection between these body clocks, feeling sleepy and perceiving uprightness in old-age individuals — revealing that disruptions to their daily biological cycles can worsen problems with keeping balanced (Langeard et al., 2022). Studies also back the idea that postural control is influenced by time-of-day among diverse age categories. It suggests that even though both young and older adults exhibit these impacts, their intensity and type can fluctuate (Gribble et al., 2007; Mylonas et al., 2023).

The management of body position, or postural control, is influenced by the circadian rhythm through a variety of methods. Research implies that balance can be affected by disturbances in the circadian rhythm as it changes aspects like the intensity of circadian cycle and rate at which homeostatic build up happens (Forsman & Hæggström, 2013). On top of this, fluctuations in somatosensory inputs throughout daily life have an impact on how well one maintains their balance; variances between morning and evening ability to control posture are noted (Bougard et al., 2011). A comprehensive study that brings together results from various studies further emphasizes how the time of day and lack of sleep can affect our balance (Izadi et al., 2022). This is backed up by research demonstrating the considerable impact on balance due to prolonged periods without sleep and disruption in our internal body clock (Smith et al., 2012; Bougard, 2011).

The link between the risk of falling, body clock rhythms and melatonin offers more understanding into how misalignment in our body clocks and shifts in hormones like decreased levels of melatonin as we grow older, affect stability when standing (Goswami, 2020). Melatonin is a hormone connected to controlling sleep. Evidence shows it plays a role in maintaining balance especially with senior individuals (Amstrup et al., 2015). Nonetheless taking too much or ill-timed supplementation could disrupt equilibrium leading to higher probability for falls.

The connection between circadian rhythms and the sleep-wake cycle helps regulate postural control (Czeisler & Gooley, 2007). Sleep patterns are closely intertwined with this circadian system, as sleeping mainly takes place during biological night times (Czeisler & Gooley, 2007; Duffy & Czeisler, 2009). If there is a misalignment between the natural circadian rhythm and the sleep-wake cycle like what happens in shift work or trans-meridian travel scenarios it can drastically affect factors like sleep quality, functioning

of brain cognitive capacity and even gene expression (Lazar et al.,2013; Lazar et al.,2015; Santhi et al.,2016; Archer et al.,2013).

The intricate relationships between sleep, circadian rhythms, and cognitive performance are increasingly recognized as pivotal in understanding human behavior and health (Spiegel et al., 2009; Borbély, 1982). Good sleep has been shown to bolster various aspects of cognitive performance, including memory, attention, and problem-solving abilities (Payne et al., 2012; Walker & Stickgold, 2006). On the flip side, disrupted sleep patterns can lead to cognitive deficits, impairing the same domains that are enhanced by adequate rest (Spiegel et al., 2004; Walker, 2008). Cognitive performance also doesn't remain constant throughout the day; it peaks during certain times, generally aligned with individuals' internal circadian rhythms (Dijk & Lockley, 2002). This circadian influence on cognition extends to tasks that require substantial cognitive resources, such as maintaining postural control, which could potentially be compromised during 'off-peak' circadian phases.

Shift work, which is defined by not regular or work during night times, has a connection with increased mental problems like less attention, decreased memory that works and affected abilities to make decisions (Akerstedt & Wright, 2009). Jet lag from quick travel through many time zones can disturb cognitive processes. This leads to short-term disturbances in cognition until the circadian rhythms adjust again (Reichert et al., 2017; Waterhouse et al., 2007). The difference between sleep-awake cycle and internal clock phase also has link with damaged control of body posture and high risk of falling down too (Goswami et al., 2020).

The complex connection between circadian rhythms and control of posture is linked to intricate neurobiological mechanisms. This involves the suprachiasmatic nucleus (SCN), which acts as the main pacemaker for circadian rhythm, along with parts of brain that are responsible for controlling posture such as basal ganglia, cerebellum, and motor cortex. These specific regions in our brain get information from SCN which they then employ to combine signals related to timing of circadian rhythm with commands concerning movement thus affecting how we adjust our posture and maintain stability (Videnovic & Hogl, 2015).

Additionally, the daily regulation of cognitive processes can have a secondary effect on maintaining balance. Cognitive functions such as attention, working memory and executive function show regular changes throughout the day which could affect how we focus our resources or handle sensory information that helps us adjust our posture (Woollacott & Shumway-Cook, 2002). Disruptions in circadian rhythms can lead to cognitive impairments, potentially compromising postural stability. The circadian modulation

of cognition has been shown to present a sex difference, with women presenting higher vulnerability to extended wakefulness in the early morning hours (Santhi et al., 2016). This may have implications for sex differences in the vulnerability of postural control and an adverse circadian phase to sleep loss.

Circadian rhythm is interlinked with the pineal hormone melatonin, produced by the pineal gland and contributing to sleep regulation by regulating core body temperature (Macchi & Bruce, 2004). Melatonin production decreases with aging (Zhdanova et al., 1998), and for older adults, melatonin can help improve sleep (Amstrup et al., 2015). In some countries, small amounts of melatonin are part of dietary supplements. Amstrup et al. (2015) showed that melatonin treatment is safe for older adults, provided it does not cause drowsiness or dizziness, which can decrease postural balance and muscle strength, increasing fall risk. They suggested a safe daily dose of 1 to 3 mg for postmenopausal women with osteopenia, improving sleep quality without long-term adverse effects on balance.

Summary: The Association of Sleep, and Circadian Rhythmicity with Falls Risk and Postural Control in Healthy Adults: Effect of Age, Sex and Work Environment

Sleep and circadian rhythms play a significant role in various physiological and cognitive functions critical for maintaining postural control and balance. Age has an impact on sleep, circadian rhythms, sensory-motor integration, coordination, and cognition. There are also sex differences in both the risk of falls and vulnerability to sleep loss and adverse circadian phase. The complex interrelationship and their modulation by age most likely drive the age-dependent decline in postural control and increased risk of falls. Therefore, interventions targeting sleep and circadian rhythm disturbances have the potential to reduce falls risk in older adults. Addressing sleep disorders, optimizing sleep-wake patterns, and improving sleep quality may help enhance postural control via a positive effect on daytime alertness, cognitive functions, sensorial integration, and motor function (Morin et al., 1999). Strategies to minimize the disturbance of circadian rhythms, such as keeping a regular schedule for sleep and wake times and getting natural light, can also help decrease the risk of falls by improving quality of sleep and brain function when awake (Figueiro et al., 2006). It is very important that multidisciplinary practices are taken into account with healthcare experts including those who specialize in sleep disorders, older adults care physicians, and physical therapists. They play key roles in creating well-rounded plans for preventing falls which take into consideration how interactions between sleeping patterns, biological clocks ('circadian' rhythms), and other factors may affect risks. These plans may propose ideas such as instructing beneficial habits related to productive bedtime routines or cognitive behavioral therapy specifically tailored for those troubled with insomnia. It can also include scheduling activities centered on balance training and strength enhancement,

modifying environments to lessen fall risks (Rubenstein 2006; Morin et al.,1993). However, a deeper comprehension of the complex cause-and-effect association between sleep, phases of circadian rhythm, sensory feedback along with postural control and their modulation by sex is needed in order to effectively address the risk of falls among older adults.

Overall Conclusion

This thesis exhibits a complicated connection between sleep, day-night cycles, and body balance control. This is more significant in the perspective of aging aspect. While there has been substantial research devoted to each factor individually, efforts that integrate these elements are still not enough. It is common for older adults to experience changes in their sleeping habits and bodily equilibrium stability which increases their chances of tripping or falling over.

Keeping proper balance control is necessary for healthy aging because it assists with daily tasks such as walking and standing. The chance of falling increases as people age, making falls a common source of injury, disability, and death among the older adults. Poor posture control plays an important role in this risk factor and can lead to not only physical harm but also limited movement, loss of self-reliance, and emotional stress. The fear of falling usually leads to decreased activities, which in turn worsens the physical and cerebral deterioration. Getting older is also related to bad sleep quality and interruptions in our body's internal clock. Studies show that these factors might influence how aging affects the risk of falls.

Doing usual physical and social activities is very important for total good health, especially when people get older. Physical activity assists in keeping muscle strength, flexibility and balance strong, while being socially active supports mental and emotional wellness. However, if control of posture becomes compromised it often causes individuals to pull back from these activities which leads to a cycle where they are inactive leading their health to worsen.

With the growing number of old adult, it is crucial to comprehend the link between sleep, body clock rhythms and balance control. Falls lead to chronic health problems, boosted healthcare expenses and may cause early death. To stop these falls and encourage good stability are main elements of public health tactics for maintaining healthy aging.

Further research is essential to comprehensively understand how sleep, circadian rhythms, and postural control interact. This knowledge could inform real-world interventions, such as exercise programs or therapies targeting sleep disorders, ultimately reducing fall risk and enhancing the quality of life for older

adults. While progress has been made in studying these factors separately, a more integrated approach is urgently needed.

Research Gap: Postural Control, Sleep and Circadian Rhythmicity in Aging

The reviewed evidence highlighted, sleep and circadian rhythmicity have an impact on postural control, and this effect is modulated by age and sensorial (e.g., visual) input. However, the existing experimental studies in this field are limited in their ability to establish the differential effect of sleep loss and time of the day or circadian phase on postural control in older adults. This is because there are no studies that included multiple assessments of postural control covering the full circadian cycle and simultaneously contrasted high sleep pressure conditions with a similarly controlled low-pressure condition where participants were allocated in a random manner. Also, most experimental studies have been performed in younger adults.

Furthermore, it is also not known to what extent the effect of the two sleep-wake regulatory mechanisms (i.e., Sleep-wake homeostasis or Process S and the circadian cycle or the Process C) on postural control is modulated by key sensorial feedback conditions (e.g., visual and haptic/light touch input) known to be critical for postural control.

It is also unclear to what extent these sleep and circadian effects simultaneously modulate sensory-motor integration as measured by visuomotor coordination, a key neurophysiological mechanism underlying postural control, in the same participants.

Finally, evidence shows that there are sex differences in the risk of falls as well as in vulnerability to sleep loss and adverse circadian phase. However, it is not known to what extent these sex-based vulnerabilities extend to the negative effect of restricted sleep and adverse circadian phase on postural control.

Moreover, it is also not known how self-reported risk of falls is associated with self-reported measures of sleep quality, chronotype as well as physical and mental well-being and how these relationships are modulated by sex in older adults.

Scientific Context and Significance

Maintaining postural control relies on complex interactions among sensory, motor, and cognitive systems. Disruptions to these systems, through aging or disease, can increase instability and elevate the risk of falls. Increasing evidence indicates that sleep and circadian processes play critical roles in supporting the neural

integration required for balance, yet the precise mechanisms by which sleep pressure and circadian timing influence postural control remain poorly understood.

Most existing studies on sleep and balance have focused on observational correlations with habitual sleep duration or self-reported sleep quality. While informative, such approaches do not allow for causal inferences about how changes in sleep pressure or circadian phase directly alter balance performance. To address this gap, this thesis makes a key scientific contribution by experimentally manipulating both sleep pressure and circadian timing through controlled total sleep deprivation and multi-nap protocols, in combination with systematic variations in the time of day. This approach enables the direct examination of how acute sleep restriction and circadian misalignment affect postural stability, which has not been explicitly tested in prior research.

Furthermore, although habitual sleep reflects real-world patterns, it does not permit precise control over sleep timing, intensity, or circadian phase and as such cannot establish causality. For this reason, total sleep deprivation and multi-nap paradigms were employed in this thesis as the only viable experimental methods to induce sufficient variation in sleep pressure and circadian alignment, thereby allowing for robust assessment of their causal impacts on balance and sensorimotor integration.

The Putative Mechanisms to be Investigated

The general hypothetical model of the interactions between sleep and circadian rhythmicity in real-life contexts postulates that circadian disruption, whether caused by shift work or aging, has a direct effect on the brain (e.g., vigilance, cognitive performance, and sensorimotor integration), but can also indirectly impact brain function through the disruption of restorative sleep. Aging will also have an independent effect on restorative sleep. Postural control can be affected by a generally reduced vigilance, attention, and cognitive performance, as these are affected independently by sleep and circadian phase, but also by a deficit in sensorimotor integration driven by sleep loss and adverse circadian phase, somewhat independent of vigilance and other cognitive functions (see Figure 5).

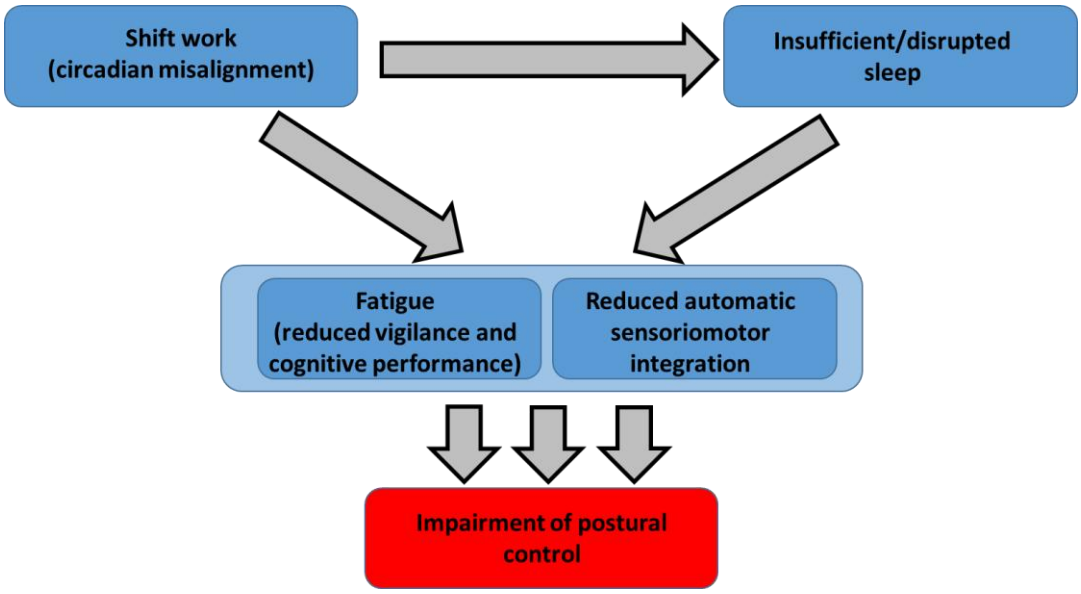


Figure 5. The potential mechanistic relationship between circadian misalignment (shiftwork) and insufficient sleep on postural control.

Specific Contribution of this Thesis

This thesis contributes to the existing literature by experimentally manipulating sleep pressure and circadian timing, an approach not previously explored in relation to postural control. The study shows that, unlike prior research that primarily relied on observational analyses of habitual sleep patterns, an experimental design enables causal interpretation of how sleep and circadian disruptions directly impact balance. The study design was based on an experimental protocol that contrasted high sleep pressure condition induced by total sleep deprivation with low sleep pressure condition induced by a multi-nap schedule, a methodological innovation not present in earlier experimental work in this field. The multi-nap protocol reset homeostatic sleep propensity repeatedly across the day, rather than only during a single nightly sleep episode, thereby allowing direct examination of balance control under systematically altered sleep pressure across the 24-h cycle.. The multiple assessments embedded across the protocol further allowed the estimation of circadian phase effects under both high and low sleep pressure conditions, providing a novel insight into the interaction of homeostatic and circadian processes on postural control.

By integrating both observational analyses of habitual sleep patterns and health correlates with rigorous experimental manipulation of sleep pressure and circadian phase, this thesis uniquely advances understanding of how sleep and circadian physiology interact to influence balance control. This work provides novel evidence of sex-specific vulnerabilities, highlights the moderating role of sensory

conditions, and extends these insights to occupational populations such as mariners who routinely face sleep disruption and irregular work schedules.

1.2 : Aims and Objectives

1.2.1 Aims:

1. Investigate the associations of self-perceived risk of falls with self-reported sleep and diurnal preference (i.e. chronotype), and the way these associations are modulated by sex in cognitively healthy older adults as controlled for age, lifestyle, physical and mental well-being.

2. Clarify the effects of sleep restriction (i.e., experimentally induced homeostatic sleep pressure) and circadian phase (i.e., time of day) on both objective and subjective measures of balance control under varying sensory feedback conditions and examine the way sex modulates these effects through a specialized experimental design.

3. Investigate the effects of sleep restriction and circadian phase on visuo-motor coordination, as another cognitive function underpinned by sensorimotor integration similar to balance control, and the way sex modulates these effects through a specialized experimental design.

1.2.2 Research Questions and Hypotheses:

- What is the association of self-reported sleep duration, sleep quality, and sleep-wake timing/chronotype with self-reported fall risk in older men and women without cognitive impairment, and how are these associations modulated by sex?

    - *<u>Hypotheses:</u> Shorter sleep duration, worse sleep quality and more delayed chronotype will be associated with poorer postural control. This association will be stronger in women compared to men.*

- What are the effects of sleep restriction and circadian phase (i.e., time of the day) on objectively and subjectively measured postural control in healthy adults, and how are these effects modulated by sex and sensorial feedback?

    - *<u>Hypotheses:</u> Sleep restriction will significantly impair postural control, with the greatest effects observed during the circadian night. Women will exhibit greater vulnerability than men. Sensory feedback will mitigate the negative effects of sleep loss and adverse circadian phase on postural control, with the most pronounced impairments occurring in conditions with eyes closed and no haptic feedback.*

- To what extent do sleep restriction and circadian phase (i.e., time of day) affect sensorimotor integration, as measured by a visuo-motor coordination task, and is this effect influenced by sex?

- *<u>Hypotheses:</u> Since the neurophysiological substrate of postural control relies heavily on sensorimotor integration, sleep restriction is expected to negatively affect visuo-motor coordination as well. This adverse effect will be most pronounced during specific circadian phases, particularly the biological night compared to the biological day. Additionally, sex will modulate the impact of sleep restriction and circadian phase on sensorimotor integration, with women exhibiting greater impairment in visuo-motor coordination under sleep restriction, especially during the biological night, compared to men.*

1.3 : METHODS

The study investigated the role of sleep in self-reported and objectively measured falls efficacy and postural control in healthy adults.

1.3.1 Sleep and postural control in healthy older adults

Funding Statement

The study was funded by the Wellcome trust given to Dr. Alpar Lazar (207799_Z_17_Z) with the primary objective to assess the effect of the APOE-ε polymorphism on the individual cognitive vulnerability to sleep loss and adverse circadian phase in cognitively healthy older adults.

Ethics Statement

The research study was approved by the University of East Anglia's Faculty of Medicine and Health Sciences Research Committee and in compliance with the General Data Protection Regulation and the Data Protection Act 2018 (Reference: 2017/18-135).

Procedures

The study had multiple phases that followed each other in a consecutive manner starting with recruitment, through screening and the field session to the in-lab experimental study (Figure 6).

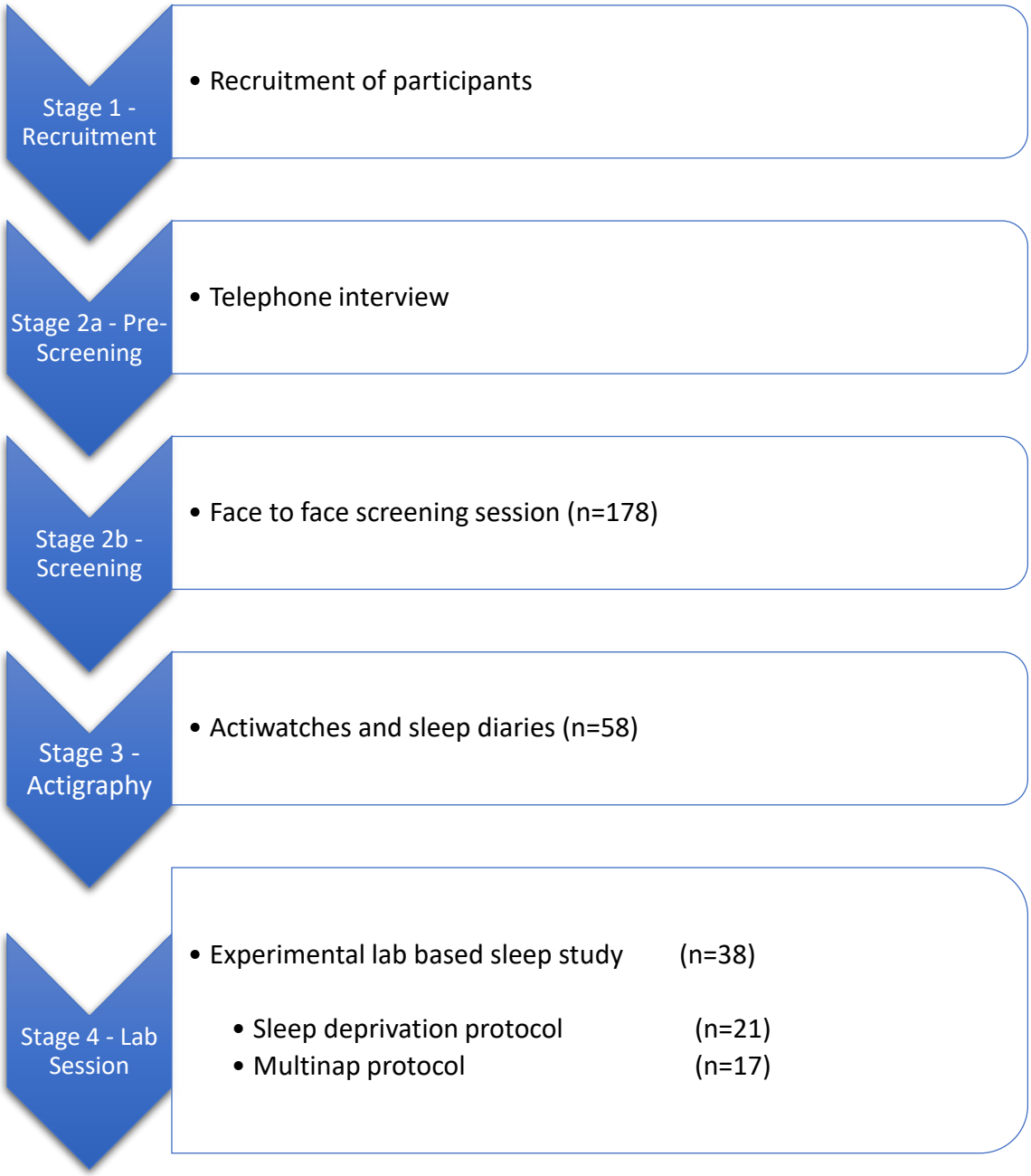


Figure 6. Study Stages.
Note: Lab participants were selected after actigraphy session which is not included in this thesis

Compensation and Reimbursement of Research Participants

Participants were compensated for their time and expenses, including travel, parking during screening sessions, and a £50 payment for the field session and £250 for the sleep laboratory session. It is important

to note that the payment was intended to compensate participants for their time, rather than as an incentive for them to participate in the study.

Recruitment

Participants were recruited from various databases, including the UEA intern APOE-e participant database, the University of Third Age, the Joint Dementia Research JDR, media coverage from schools, radio, and national TV news broadcasts, as well as advertisements. The sleep study team conducted phone interviews to recruit healthy adults between the ages of 40-90. Exclusion criteria were applied during the phone interviews as follows:

- Pregnancy
- Acute infections or diseases
- Psychiatric disorders or chronic neurological disorders including diagnosis of dementia, mild cognitive impairment MCI / prodromal Alzheimer disease
- Learning, sensory or physical impairment / disabilities that could have an impact on the cognitive tests and considered as a disadvantage
- Chronic pain conditions
- A current diagnosis of malignant tumors / cancers
- Shift work
- Alcohol intake of more than 14 units per week and / or taking illicit substances / alcohol dependency
- Smoking tobacco including e-cigarettes and / or vapes

Screening Session

Participants who were eligible were invited to a screening session, which involved a face-to-face interview in the Sleep and Brain Research Unit located in the Queen's Building at the University of East Anglia (UEA). Each individual was provided with patient information sheet multiple days before their visit

as well as an invitation letter that included directions to the interview location. Instructions for car parking and other transportation methods were also provided.

Upon arrival, a team member greeted the participant and provided a car park permit if needed. The participant was then given a tour of the sleeping lab and monitor room, followed by a short presentation about the stages and processes they would go through in the study. The participant had the opportunity to ask any additional questions during a question session.

After the presentation and discussion, the participants were invited to sign the consent form. This was followed by a paper-based and computerized cognitive assessment and the completion of multiple questionnaires on self-reported health, sleep and falls risk. A buccal swab (cheek swab) for genetic testing was taken during the short break in between the two sessions to characterize the APOE-e in line with the objective of the main research.

Assessment tools and outcome measures

During the screening session, participants were asked to complete multiple questionnaires called priority questionnaires and tests which provided a comprehensive picture of their subjective sleep quality, rest-activity patterns/chronotype, cognitive decline, as well as mental and physical health. The Addenbrooke's Cognitive Examination (ACE-III) was used for assessing general cognitive status and ruling out Mild cognitive impairment and dementia in line with the inclusion/exclusion criteria.

In addition participants were asked to fill out in the SBRU or at home questionnaires called non-priority questionnaires, which included forms such as the Edinburgh Handedness Inventory, the Dimensional Apathy Scale, the Empathy Quotient, the Barratt Impulsivity Scale, the Big Five Inventory, the Positive and Negative Affect Scale, the Short-form Health Survey, the Dutch Eating Behavior Questionnaire, and the Mannheim Dream Questionnaire, could be completed at home and sent back to the study team in a pre-paid envelope (see Appendix 2). Some outcome measures (e.g. Short-form Health Survey) assessing self-reported physical and mental health are also included in the current thesis.

Questionnaire	Range of Scores	Description
Demographics Questionnaire	-	The Demographics Questionnaire is a comprehensive survey that collects essential information about an individual's background, including age, sex, education, marital status, occupation, and other demographic details. It serves as the foundation for understanding the participant's personal characteristics and is often used as a basis for further research analysis.
General Medical Questionnaire	-	The General Medical Questionnaire is an extensive assessment designed to gather detailed information about a participant's medical history, current health status, and any pre-existing medical conditions. This questionnaire is typically evaluated by a medical doctor or healthcare professional to ensure a thorough understanding of the participant's health before conducting medical studies or assessments in sleep lab sessions.
Epworth Sleepiness Scale (ESS) (Johns, 1991)	[0-24]	The Epworth Sleepiness Scale (ESS) is a self-report questionnaire that measures an individual's daytime sleepiness. It consists of questions that assess the likelihood of falling asleep or dozing off in various everyday situations. The ESS is widely used in sleep medicine and research to evaluate the level of daytime sleepiness, which can be indicative of sleep disorders or insufficient sleep.
Pittsburgh Sleep Quality Index (PSQI) (Buysse et al., 1989)	[0-21]	The Pittsburgh Sleep Quality Index (PSQI) is a questionnaire that assesses an individual's sleep quality over the last month. It covers various aspects of sleep, including sleep duration, disturbances, sleep latency, and daytime dysfunction. The PSQI provides insights into the overall sleep quality and can be a valuable tool for identifying sleep problems.
Insomnia Severity Index (ISI) (Bastien et al., 2001)	[0-28]	The Insomnia Severity Index (ISI) is used to evaluate the severity of perceived nocturnal and diurnal symptoms of insomnia over the last two weeks. It assesses the impact of insomnia on an individual's daily life, including issues like difficulty falling asleep, staying asleep, and the satisfaction with sleep. The ISI helps in diagnosing and monitoring insomnia.

Morningness- eveningness questionnaire (MEQ) (Horne & Östberg, 1976)	[16-86]	The Morningness-Eveningness Questionnaire (MEQ) measures an individual's diurnal preference and chronotype. It assesses whether a person is naturally inclined to be a "morning person" or an "evening person." The MEQ helps researchers and clinicians understand an individual's circadian rhythms, which can influence sleep patterns and daily activities.
Patient Health Questionnaire (PHQ-9) (Kroenke et al., 2001)	[0-27]	The Patient Health Questionnaire (PHQ-9) is a screening tool used to assess depressive symptoms and their severity over the last two weeks. It asks individuals about various symptoms associated with depression, such as low mood, fatigue, changes in appetite, and sleep disturbances. The PHQ-9 helps in identifying and monitoring depression.
Generalized Anxiety Disorder Questionnaire (GAD-7) (Spitzer et al., 2006)	[0-21]	The Generalized Anxiety Disorder Questionnaire (GAD-7) is a self-report measure used to assess the initial symptoms and severity of anxiety over the last two weeks. It asks about common anxiety-related symptoms, including excessive worry, restlessness, and physical tension. The GAD-7 aids in identifying and evaluating anxiety disorders.
Falls efficacy (Yardley et al., 2005)	[0-64]	A questionnaire designed to assess concern about falling during a range of activities of daily living. It consists of 16 items regarding concerns about falling when performing various activities inside and outside the home, such as cleaning, walking, and visiting friends. Each item is rated on a 4-point Likert scale from 1 (not at all concerned) to 4 (very concerned). Total scores range from 16 to 64, with higher scores indicating greater concerns about falling.

Table 1. Priority questionnaires. *This table provides an organized view of the questionnaires, their scoring ranges, and a brief description of each.*

Sleep Laboratory Session

Eligible and interested participants took part in the laboratory session as they were selected after the two weeks actigraphy session including sleep diaries. Participants stayed at the Sleep and Brain Research Unit (SBRU) laboratory for two and a half consecutive days, including three nights. The laboratory session comprised two randomized protocols: either 40 hours of sleep deprivation or 40 hours of multi-nap sessions. These protocols were commonly used to challenge sleep-wake homeostasis and study the effects

of high versus low sleep pressure on brain activity, cognitive performance, sleep, and emotional state during wakefulness. Each protocol started with 8 hours of baseline and ended with a recovery night's sleep, during which the participant had the opportunity to sleep for 8 to 12 hours. Cognitive assessments and balance tests were conducted every 4 hours for approximately an hour, including EEG recordings.

Data Collection

Qualified participants were encouraged to participate in a controlled laboratory session. This session, held at the SBRU, spanned roughly 2.5 days, encompassing three continuous nights. The primary focus of this session was two distinct experimental approaches designed to manipulate sleep pressure: one involved 40 hours of continuous wakefulness, and the other, a 40-hour multinap regime. Such methodologies are frequently employed to evaluate the impact of varying sleep pressures on cognitive functions, brain activity, emotional states during alert periods, and subsequent recuperative sleep, as evidenced by studies such as those by Graw et al. (2004) and Cajochen et al. (2001).

Upon initiation of the laboratory phase, participants were allotted time to settle in, acclimatize to the surroundings, and familiarize themselves with the facility's layout and procedures. Subsequently, a medical practitioner scrutinized the previously filled General Medical Questionnaire and conducted a physical examination to confirm the participant’s health suitability for the upcoming activities. Following this medical evaluation, dinner was served as per the participant's preference. Following dinner, participants engaged in a trial run of all cognitive tasks (COGT). Typically, post-trial, participants enjoyed leisure activities such as watching shows, reading, or interacting with the research staff. Both experimental approaches began with a baseline sleep opportunity assessed using polysomnography (PSG) to detect any primary sleep anomalies which represented an exclusion criterion. This was done by the principal investigator. Sleep timings for these sessions mirrored the participants' habitual patterns, as discerned from the home-based assessments. Participants were also instructed to maintain consistent sleep routines in the three days leading up to the laboratory session. Each experimental approach culminated with a recovery sleep opportunity that varied between 8-12 hours based on the participant's preference.

Each experimental protocol entailed a series of cognitive assessments (detailed in the 'Cognitive Evaluation – Lab Session' section) conducted every four hours, accompanied by EEG recordings and a subsequent Static Posturography task. Melatonin levels, indicative of the body's internal circadian rhythms, were periodically measured between the 9th and 31st hours of the experiment. To maintain consistent environmental conditions, lighting was kept dim (below 10 lux) throughout the extended wake periods,

ensuring no disruption in melatonin production or alertness levels and eliminating any potential light-induced time cues.

During downtime, participants had the option to engage in recreational activities, such as watching shows, reading, working on puzzles, light physical activities, or conversing with the researchers. Nutritional needs were addressed with periodic snacks, calibrated at 150 kcal for females and 200 kcal for males. These snacks included a mix of fruits, vegetables, dairy, and bread. Water was readily available, while caffeine-free fruit teas were provided during snack times. Each session was exclusively conducted with one participant at a time.

The day after the recovery night offered participants an optional, supplementary cognitive evaluation. This included tests such as the Raven Progressive Matrices (Court & Raven, 1998), the Digit Span task (Kaufman & Lichtenberger, 1999), and the Reward prediction error test (Sambrook & Goslin, 2014, 2016).

Sleep Deprivation Protocol

Following the baseline night sleep episode, the participant was requested to stay awake for 40 consecutive hours for this protocol. However, if the participant could not cope with the forty hours and requested to rest, a 4-hour sleep time was allowed, and the protocol changed to become partial sleep deprivation. During this procedure, sleep pressure was increased, allowing for the investigation of the effect of the circadian rhythm on cognition (see Figure 7).

Multi-nap Study Protocol

In this protocol, following the baseline sleep episode, participants were given regular nap opportunities every 4 hourly intervals, maintaining the 1/3 sleep-wake ratio by 80 minutes of nap and 160 minutes of wake duration, respectively. This protocol was uniquely suited to keep the sleep pressure relatively low and constant through the study period, allowing for the evaluation of circadian effects on the studied outcome measures (see Figure 7).

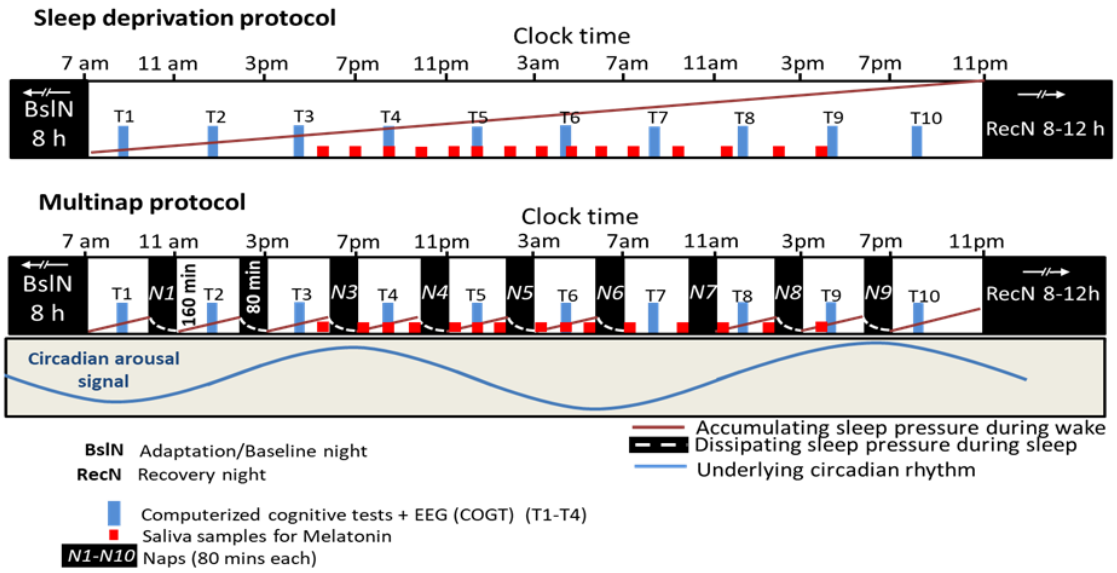


Figure 7. Experimental Sleep Study Protocols. *In the research setup, participants were involved in a 70-hour-long laboratory session. Initially, they had a baseline night (BsIN), and then they were randomly assigned to one of two conditions: either 40 hours of total sleep deprivation (upper panel) or a multi-nap experimental condition (lower panel). Following these conditions, there was a recovery night (RecN). Cognitive assessments were conducted every 4 hours (represented by blue bars labeled T1 to T10), and saliva sample for melatonin profiling were collected at specific intervals (indicated by red bars). While sleep pressure, expected to increase continuously in the sleep deprivation protocol, it was anticipated to remain at lower levels in the multi-nap condition. Nine naps were scheduled, each occurring every 160 minutes and lasting 80 minutes (labeled N1 to N9). The time of day effect, driven by underlying circadian rhythmicity (bottom panel), was expected to modulate the outcomes in both experimental conditions.*

Measurements

Cognitive Measurements

The laboratory sessions for cognitive assessment followed a specific sequence of tasks. Each session began with the Karolinska Drowsiness Task (KDT) by Kaida et al. (2006), followed by the Psychomotor Vigilance Task (PVT) developed by Dinges and Powell in 1985. Afterward, they engaged in the Pursuit Tracking task (as per Lo et al. 2012, Frith 1973, and Maquet et al. 2003). Further to that was the static posturography test (PCT), followed by a 10-minute break (Figure 8). To conclude each cognitive session, participants revisited the Karolinska Drowsiness Task (KDT) (Figure 8).

Prior to the baseline night, a training session was conducted to ensure that participants were familiar with all the cognitive tasks, understood the instructions, and felt comfortable with them.

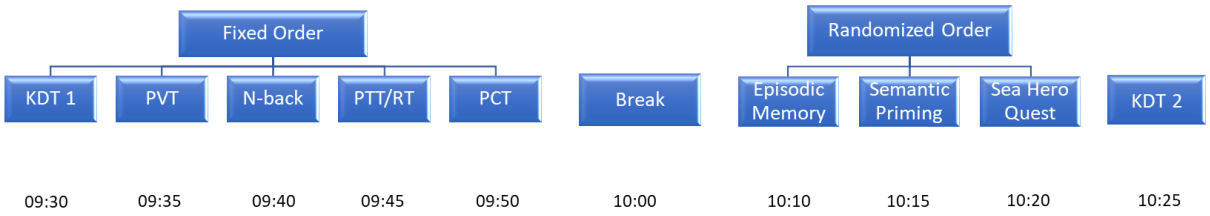


Figure 8. The structure and timing of a cognitive test battery (COGT). *The COGT consisted of various cognitive tasks as well as the postural control assessment (PCT), each with a designated duration, which were part of the sleep lab protocol. The initial block of tasks was consistently administered in a fixed sequence. However, the tasks that followed the break were randomized for each participant. Notably, Karolinska Drowsiness Test 2 was consistently administered at the conclusion of each session. The clock time under each test is a representative example of a morning test session.*

Psychomotor Vigilance Task PVT

The Psychomotor Vigilance Task, adapted from the work of Dinges & Powell (1985), serves as a reputable measure for gauging sustained attention using a basic reaction time task. In this 5-minute exercise, participants are directed to concentrate on a white fixation cross centered on a dark screen, while positioning the index finger of their predominant hand on the response key (specifically, the spacebar). The task's main challenge arises when the fixation cross intermittently transforms into a red dot, appearing at unpredictable intervals ranging from 2 to 10 seconds (Figure 9). Upon the dot's appearance, participants are prompted to swiftly press the spacebar. The speed of their response, termed reaction time (RT), is then showcased on the screen for a duration of 1 second. Any RT surpassing 500ms is categorized as an attentional lapse (Table 1). Conversely, if the RT is below 100ms, it's considered a premature response. Thus, for a PVT response to be deemed valid, the RT should lie above 100ms, in line with findings by Basner & Dinges (2011). The key metrics assessed in this task are derived from prior research, including studies by Basner & Dinges (2011) and Thomann et al. (2014). This task was constructed using the E-Prime® 3 software, dedicated to psychological research.

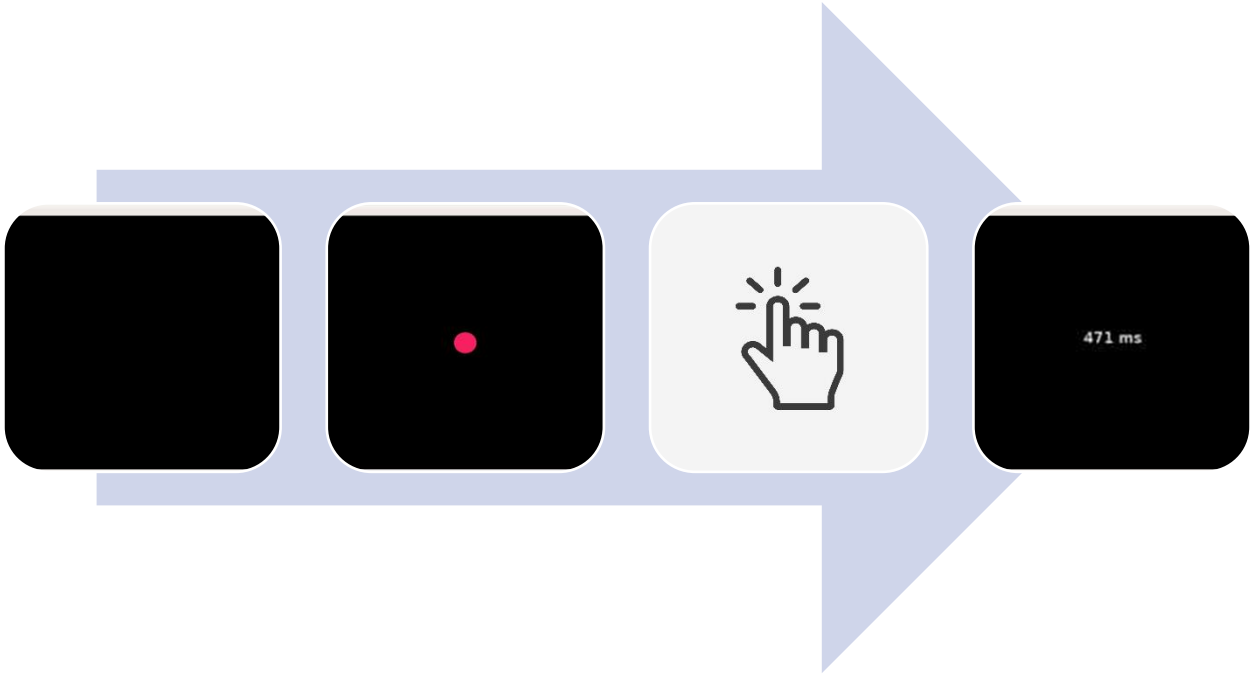


Figure 9. The psychomotor vigilance test (PVT) process steps.

Pursuit Tracking Task

This task was designed to assess visuo-motor coordination. The program used was PEBL, pursuit tutor (Figure 10), and the participant indicated their dominant and non-dominant hand. A computer mouse was used to control the cursor, which was used by the participant to trace a red dot that circled clockwise. After the program was set up for the participant, they used their dominant hand twice and non-dominant hand twice, for a total of four tests. The participant clicked on the screen, and a red dot appeared, circling clockwise on the presented route. The participant needed to trace the red dot with the cursor, using a computer mouse to control it for a full complete circle on the route (Figure 10). The test was performed again with the dominant hand and then moved twice to the non-dominant hand to monitor attention and alertness (Makeig & Jolley, 1995). It also measured motor skill or motor learning, through the detailed feedback, time on target for each trial was recorded along the 15 seconds. The distance in pixels was shown once the cursor was away from the red dotted target due to the recording of the coordinates of the cursor (X and Y coordinates) (Table 2).

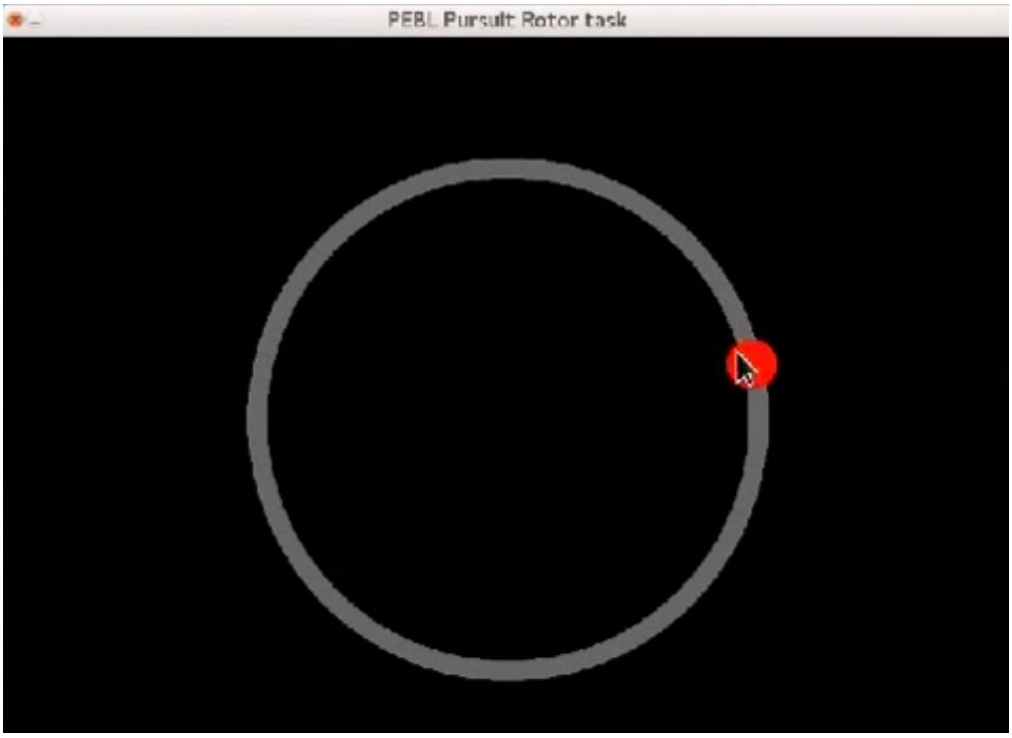


Figure 10. PEBL Pursuit Tracking Task

Outcome Measures for cognitive assessments in the lab

TEST TYPE	OUTCOME MEASURE
PSYCHOMOTOR VIGILANCE TASK PVT	Sustained attention and alertness/reaction time - mean RT lapses included [ms] - mean RT lapses excluded [ms] - fastest 10% RT [ms] - slowest 10% RT lapses excluded [ms] - number of lapses laps = RT > 500 ms
KAROLINSKA SLEEPINESS SCALE	A widely used self-reported measure of subjective sleepiness, scored on a 9-point Likert scale ranging from 1 (“extremely alert”) to 9 (“extremely sleepy – fighting sleep”). It is broadly employed in sleep deprivation (SD) research and has been validated against objective

	electroencephalographic (EEG) measures, making it a robust tool for assessing perceived levels of sleepiness in experimental and clinical settings.
PURSUIT TRACKING TASK	Cognitive function of attention and alertness with coordination of hand and vision -Time on target (dominant / non-dominant hands) -Deviation from target in pixels (dominant / non-dominant hands)

Table 2 Outcome Measures

Posturography

The balance test was used as a technique to quantify postural control on a static force plate (Figure 11). The central nervous system was quantified, including its adaptive mechanism to maintain a certain posture and balance. The force plate was used to measure the forces and the moment to find the center of pressure (CoP) among the cycle of the circadian rhythm during the protocol. The integration of postural control was a complex of variables such as position, angles, and velocity. The test included the following conditions of eyes open, eyes closed, light touch, and no touch for the torque/force device sensor (Wrisley et al, 2007; Ford-Smith et al, 1995). In this way participants had four 20-sec sessions along the 4 sensorial feedback conditions (Eyes Open – Light Touch, Eyes Open – No Touch, Eyes Closed – Light Touch, Eyes Closed – No Touch) run twice for each condition. That is 20 sec/ session * 4 conditions * 2 trials = 160 sec in total.



Figure 11 The Force Plate used in the study.

The test of postural control balance focused on obtaining the center of pressure (COP) time series properties. It was represented in the point location on the ground where reaction of force vectors integrated on the horizontal plane axis or along the two orthogonal perpendicular vertical axes. These axes were fixed to the platform and known as the anterior-posterior (AP) and medial-lateral (ML) (Directions, 1983). The balance control process and movements of the center of mass of the entire body, both were reflected by this single variable; therefore, posture control was measured. The center of pressure (COP) in both anterior-posterior and medial-lateral planes proved to be a significantly reliable metric output measurement (Harris et al, 1993). For instance, path length, sway area, and ranges also proved to be effectively monitored the parameters of postural sway. The center of pressure (COP) analysis could be used as a cost-effective alternative to estimate the movement of the center of gravity (COG) of the participant to get a more accurate projection of the brain's ability to enhance balance (Palmieri et al, 2002).

The balance test used a static posturography paradigm (Figure 12). In this static paradigm, the participant stood on a flat, horizontal, stable surface with the following conditions of eyes open (EO) or eyes closed (Romberg's test). The spontaneous sway movements were recorded through the center of pressure (COP) on the support force plate surface they parameterized according to the requested posture. These stimuli were used to evaluate the relative contribution of the visual, vestibular, and sensorimotor systems in maintaining posture (Duarte et al, 2010). This test method was combined with a torque/force device sensor to be light touched (LT) using a pointing finger or with no touch (NT) to better understand the process of feedback in achieving postural stability. Posturography analysis with the force plate platform showed that participants attempted to adjust their posture accordingly, especially in the anterior-posterior (AP) and vertical directions (Martin et al, 2009). Researchers investigating posturography focused on studying balance control maintenance and body sway movements with the center of pressure (COP) oscillations.

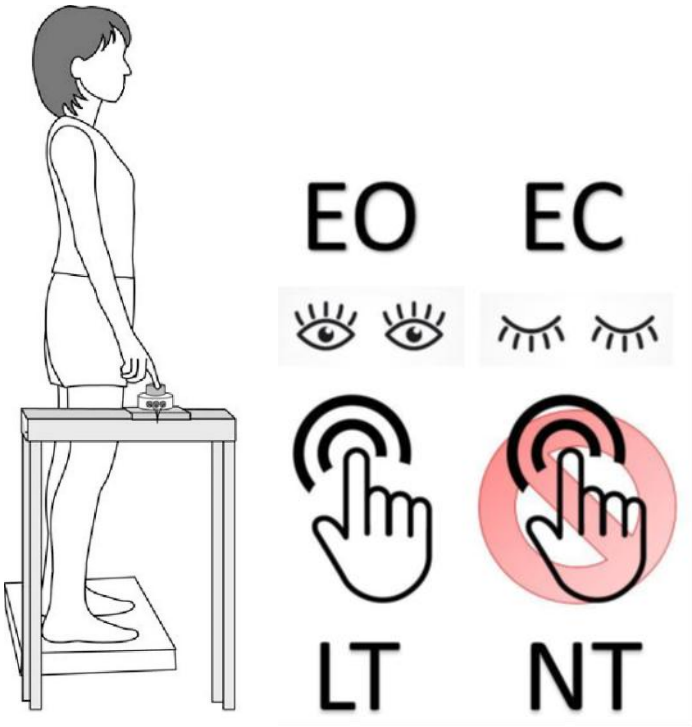


Figure 12. Illustration of a study participant standing on the force plate with light touch on the force torque sensor. *Displayed visual and haptic sensorial feedback conditions (eyes open/closed – light touch/ no touch). The participants undertook a nearly 20 min posturography session 11 times throughout the protocol with each session having 4 conditions including the combinations of the two sensorial feedback conditions (i.e., eyes open – no touch, eyes open – light touch, eyes closed – no touch, eyes closed – light touch).*

Torque/Force Device Sensor

This device was used to measure the actual force used by light touch to help maintain balance. The sensor used silicon strain gauges designed to convert pressure loads into forces and torques. The measuring principle of this network torque/force transducer was the six components of force and torque. Throughout the sensor, vertical and horizontal forces and torques were measured. A spring element was used to convert displacement into force, and a damping element was used to convert velocity into force. Furthermore, an inertial element was used to convert acceleration into force. This transducer was light touched via pointing finger of the participant while on the balance test to receive the haptic feedback characteristics.

Outcome Measures of Posturography

Outcome Measures for Postural Control (PC):

1. **Circumference**: The measurement of the total distance traveled by the center of pressure (COP) during a specific postural control task. This metric provides insights into the extent of postural sway.
2. **Ellipse Area**: The area enclosed by the ellipse that represents the COP displacement in the anterior-posterior (AP) and medial-lateral (ML) directions. It quantifies the spatial extent of postural sway.
3. **Pathlength**: The total length of the COP trajectory during a postural control task. It reflects the overall postural sway or the distance traveled by the COP.
4. **PC VAS (Visual Analog Scale)**: A subjective measure in the form of a visual analog scale where participants rate the perceived difficulty of each tested condition (e.g., eyes open, eyes closed, light touch, no touch) in terms of postural control. Participants indicate their perceived level of difficulty on a continuous scale.
5. **Sample Entropy (X and Y)**: Sample entropy is a statistical measure used to quantify the irregularity or complexity of the COP time series data in both the AP (X) and ML (Y) directions. It assesses the unpredictability of postural control and can reveal subtle changes in stability.

Subjective Effort of Balance Control

In addition to the objective measurement of postural control parameters, a Visual Analog Scale (VAS) was administered to capture participants' perceived effort in maintaining balance during each posturography session. This VAS ranged from "no effort at all" to "very high effort," enabling a quantitative assessment of subjective exertion.

1.3.2 Statistical Analysis Plan

All statistical analyses were performed in SAS 9.4 (SAS Inc) and SPSS 29 (IBM) and visualized in Graph Pad Prism 9.

Analyses were planned to test the formulated hypotheses set out in section 1.2 . Descriptive statistics was used to indicate centrality and dispersion in the form of mean and SD for continuous data and in the form of frequency and % for categorical data.

Sex or Protocol differences in centrality and distribution in both the screening and the laboratory dataset were analyzed via the Mann-Whitney U test and Chi-squared test. This is because normality was inspected and tested in the first step and multiple variables showed a non-normal distribution.

Bivariate correlations between variables of interest were analyzed using the Spearman rank correlation and correlation coefficients were compared between sex groups using Fisher Z transformation.

To investigate the independent effect of predictors of interest on the self-perceived risk of falls as measured by the falls efficacy scale a multivariate linear regression was used. Residuals were inspected for normality and transformations were performed where needed if needed to obtain normality.

For all the experimental data analyses a repeated measures design implemented in a linear mixed model including test number (i.e., time of the day) as within participant factor and two between participant factors including experimental condition (Sleep deprivation versus Multinap) and Sex (Males versus Females). Participants were included as a random factor. Unstructured (un), compound symmetry (cs), and autoregressive 1 (ar1) covariance structures were used in the repeated statement. The least-square means and 1 SEM was used to visualize data.

Given the large number of analyses linked to multiple datasets and analyses adjustment for multiplicity was not purposeful as it would have massively increased the type 2 statistical error. The research had well-justified *a priori* hypotheses and only the strongest effects are considered in the conclusion. For this very same reason, only significant main effects are statistically claimed whereas significant interactions are interpreted based on the least square means (e.g. figures) and in the context of the hypotheses. Post-hoc analyses following main effects and interactions are not run to avoid further inflating the type 1 statistical error.

1.4 Results

This section will present the findings from the statistical analysis of the data collected in both the in the above presented observational and experimental phases (section 1.3) of Study 1 focusing on postural control in healthy older adult individuals. The analyzed data, as described in the methods section, was collected using a comprehensive set of subjective, self-reported, and objective measures of sleep, physical and psychological well-being, cognitive function, as well as risk of falls and postural control. The presentation of the results will follow the same order as the methods section, reporting first on the screening dataset followed by the experimental laboratory-based research in healthy older adults. In the last section, the analysis of the pilot study performed on mariners will be presented.

1.4.1 Results Phase 1: Observational Study on The Association between Sleep, Chronotype and Falls Efficacy in Older Men and Women

The aim was to clarify the association between self-reported sleep quality, duration, and habitual sleep timing (i.e., chronotype) and self-reported balance control (i.e., falls efficacy) in cognitively healthy adults and the way these associations were modulated by sex.

1.4.1.1 Basic Demographics

Data collection occurred between January 2019 and July 2021, involving a total of 166 English-speaking participants who met the entry criteria outlined in the Methods-Recruitment section. These participants were initially invited to undergo a screening session, with demographics as follows: 49 males and 117 females, with an average age of 65 years (±9 years).

Out of the 166 participants, 58 completed the actigraphy session, consisting of 22 males and 36 females, with an average age of 65 years (±9 years). Additionally, 38 participants took part in the laboratory session, comprising 18 males and 20 females, with an average age of 65 years (±9 years).

It is worth noting that all participants in this study self-identified as White British, except for one participant who selected the option "White Other." Participants were asked to identify as either male or female, with the option to choose "other" also available. It is important to mention that three sleep laboratory sessions were terminated prematurely: one participant requested termination voluntarily, and two others withdrew due to experiencing claustrophobia, which prevented them from continuing the study in the sleep laboratory. These incidents were not classified as adverse medical events but rather as protocol discontinuations due to participant discomfort.

1.4.1.2 Sex Differences in Self-Reported Well-Being, Sleep, Chronotype, and Falls Efficacy

In the first step, men and women were compared across all outcome measures with a focus on demographics, self-reported psychological and physical well-being as well as sleep and chronotype. While the two sex groups had similar age and years of education and were comparable along most of the studied characteristics, as a finding women presented with significantly worse self-reported sleep quality as measured by ISI and PSQI, as well as significantly longer sleep latency and shorter sleep duration as measured by the general medical questionnaire (Table 1). There was a non-significant trend towards a higher alcohol intake and BMI in men compared to women. In line with previous research establishing the general advancement of chronotype with aging, participants in this study sample were also mostly morning and intermediate types with only a couple of participants presenting an evening chronotype. Interestingly, men also presented a non-significant trend towards higher morningness compared to women as measured by the MEQ. This was confirmed in another analysis showing that the distribution of the three chronotypes (i.e., morning, intermediate, and evening) in the two sex groups was significantly different in a way that men were more likely to be morning types than women (79.59% vs. 59.65%) (Table 3).

Variable	*Men Count*	*Men Mean (Std)*	*Women Count*	*Women Mean (Std)*	*Mann-Whitney U p-value*
Age	49	66.02 (10.08)	117	64.14 (9.11)	0.163
Years of Education		16.9		16.3	
Screening Session Time					
Morning		38 (77.6%)		41 (40.2%)	
Afternoon		11 (22.4%)		61 (59.8%)	
Lifestyle factors					
BMI	46	25.47 (4.23)	113	24.37 (3.76)	0.063
Alcohol Intake (unit)	49	5.46 (5.16)	116	3.82 (4.06)	0.068
Physical Activity (min)	45	2647.56 (2286.09)	111	2696.40 (2817.24)	0.692
Health related quality of life					
SF36 PH	47	76.54 (8.14)	105	76.18 (8.15)	0.649
SF36 MH	48	70.15 (6.00)	107	68.07 (7.79)	0.135
Psychological well-being					
PHQ-9	49	1.82 (2.48)	117	2.38 (2.78)	0.161
GAD-7	49	1.53 (2.58)	117	2.46 (3.90)	0.141
Sleep Quality					
ISI	49	5.14 (5.70)	117	6.73 (5.20)	**0.021**
ESS	49	5.90 (3.66)	117	4.76 (3.06)	0.061
PSQI	49	4.90 (3.29)	116	6.45 (3.16)	**0.001**
PSQI Sleep Latency (mins)	49	13.12 (11.32)	117	22.71 (43.24)	**0.045**
PSQI Usual Bedtime (hrs)	49	21.65 (4.55)	117	21.14 (5.36)	0.454
PSQI Wakeup Time (hrs)	49	6.98 (0.87)	117	7.11 (1.13)	0.297
PSQI Self-reported Actual (hrs)	49	6.75 (1.45)	117	6.66 (2.20)	0.092
PSQI Sleep Duration (hrs)	48	6.89 (1.07)	114	6.83 (1.94)	0.091
MEQ	49	62.84 (6.55)	115	60.28 (8.30)	0.060
General Health					
GMQ Sleep Duration (hrs)	46	7.09 (0.89)	113	6.76 (0.99)	**0.049**
Falls risk					
FES Total Score	37	2.27 (2.78)	75	4.07 (6.09)	0.018

Table 3. Sex differences in participant characteristics along continuous outcome measures. *This table provides an overview of the demographic, health, lifestyle sleep features of male and female participants, including their age, education, lifestyle factors, health-related quality of life, psychological well-being, and sleep quality. Continuous variables are presented as mean values and standard deviations for each sex group. The statistical significance of differences between male and female participants is assessed using the Mann-Whitney U test. Note: Group differences were tested with independent t tests (t(164)) and χ^2 tests ($\chi^2(1)$ for categorical variables). Abbreviations: ISI = Insomnia Severity Index; PSQI = Pittsburgh Sleep Quality Index; ESS = Epworth Sleepiness Scale; MEQ = Morningness–Eveningness Questionnaire; GMQ = General Medical Questionnaire; SF-36 PH/MH = Short-Form-36 Physical/Mental Health; PHQ-9 = Patient Health Questionnaire-9; GAD-7 = Generalized Anxiety Disorder-7; FES = Falls Efficacy Scale.*

There were significant differences in self-reported sleep quality between men and women. Women reported notably worse sleep quality as indicated by the ISI (5.14 vs 6.73) and the PSQI (4.90 vs

6.45). Additionally, women reported a longer sleep latency (~9 mins) and a slightly shorter sleep duration (~20 mins) according to the PSQI and General Medical Questionnaire, respectively.

In terms of smoking habits, most participants in both groups were non-smokers, with 61.22% of men and 67.24% of women identifying as such. The majority of participants in both sex groups were retired, with 75% of men and 67.24% of women indicating that they were retired (Table 4).

When assessing psychological well-being, there were no notable differences between men and women in terms of health-related quality of life, as measured by the SF36 Physical Health and Mental Health sub-scores.

Variable	*Men Count*	*Men %*	*Women Count*	*Women %*	*Chi2 p-value*
Smoking					
Non-smoker	30	61.22	78	67.24	ns
Smoker	19	38.78	38	32.76	
Retirement Status					
Not retired	12	25	38	32.76	ns
Retired	36	75	78	67.24	
Chronotype					
Morning	39	79.59	68	59.65	**0.023**
Intermediate	10	20.41	43	37.72	
Evening			3	2.63	

Table 4. Sex differences in categorical participant characteristics. *This table provides a detailed breakdown of categorical demographic, lifestyle and chronotype data for male and female participants in the study. The counts and percentages for each category are given, and the p-value returned by the Chi^2 test indicates the significance of differences in distributions between male and female participants for each category.*

1.4.1.3 The Bivariate Association Between Falls Efficacy and Self-Reported Measures of Sleep Quality, Sleep Duration, and Chronotype in Cognitively Healthy Older Adults

In this dataset, a wide range of variables provides a detailed view of the participants' health and lifestyle, covering demographics, physical and mental health, sleep patterns, chronotype, and health behaviors such as alcohol consumption and physical activity. Together, they offer a holistic understanding of the participants' overall demographic features and well-being.

The analysis focused on the Falls Efficacy Scale (FES), which measures individuals' concerns about falling during various activities, revealing significant relationships with other health metrics. Across the entire sample, multiple significant correlations with measured physical and mental health were observed,

showing the strongest association with FES. Additionally, significant associations were found with age, alcohol consumption, physical activity, and sleep quality, but not with other features of self-reported sleep or chronotype (Figure 13 and Table 5).

A strong positive association was found between FES and PHQ9 scores, indicating that individuals with increased concerns about falling often exhibit more conspicuous depressive features. This trend is further validated by the associations between FES and both GAD7 scores, suggesting that increased fear of falling coincides with heightened levels of generalized anxiety.

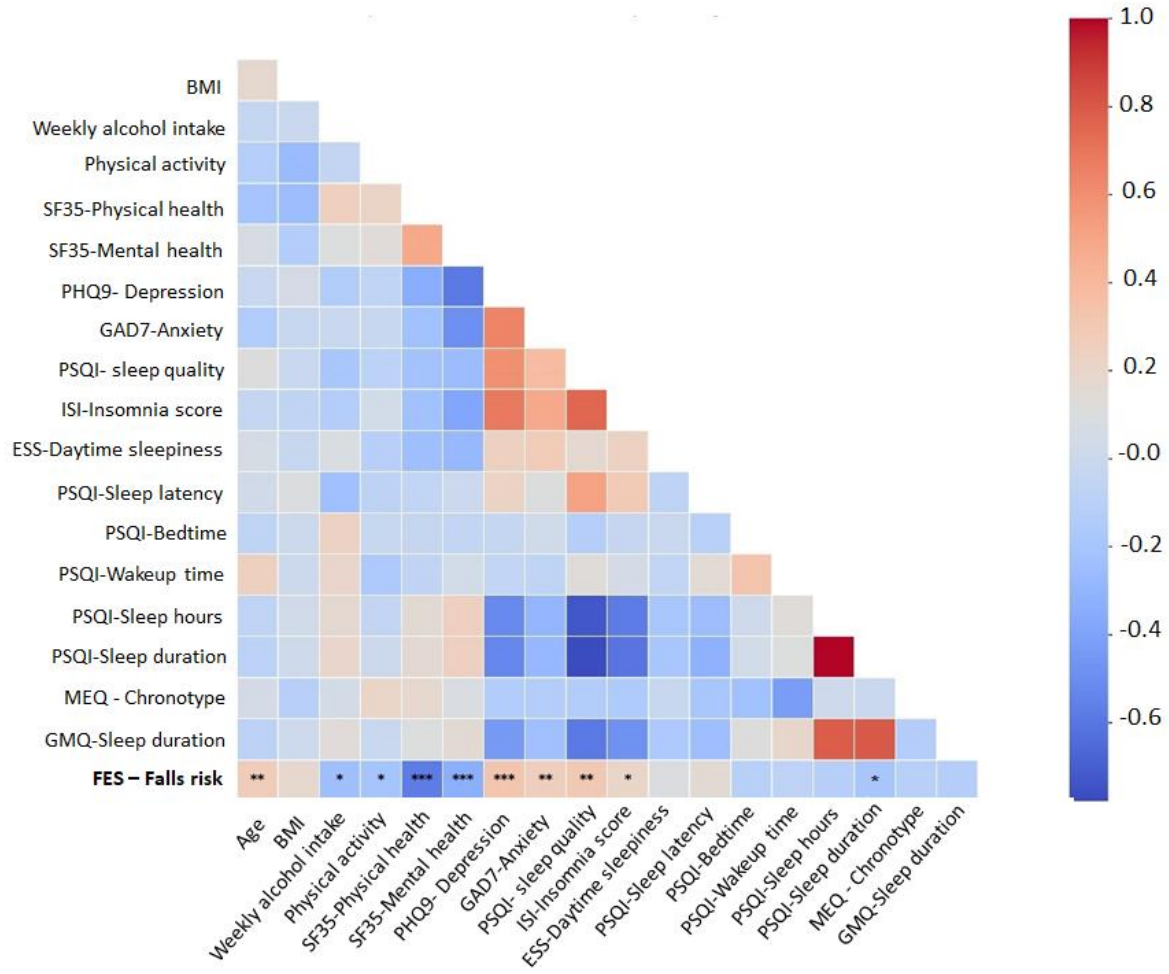


Figure 13. Heatmap of Spearman correlation coefficient (Rs) between studied variables in the entire sample. *Asterisks (*) indicate significant associations (P<0.05). Significance indicated for the target variable only (i.e., FES – falls risk).*

In a similar vein, the FES is positively linked with the PSQI and ISI, suggesting that participants with greater concerns about falling also tend to experience more compromised sleep quality with an increased likelihood of insomnia. Interestingly, sleep duration which was hypothesized in this study would be associated with falls risk did not show a significant association in the bivariate correlation. Importantly, FES demonstrates a significant strong inverse relationship with the SF36 PH. This suggests that those harboring more substantial fears of falling frequently report suboptimal physical health outcomes. This is mirrored in the relationship between the FES and the SF36 MH, where a heightened fear of falling aligns with reported declines in mental health. Moreover, the FES's negative correlation with alcohol consumption hints at a behavioral pattern: those more wary of falls may inherently be more cautious, thus limiting their alcohol intake. This cautious behavior is further evidenced by the reduced engagement in physical activities among those with higher FES scores. Furthermore, these insights illuminate the interconnected nature of the fear of falling and broader health and well-being factors.

Variables	N	Rs	P value
Age	112	0.27	**0.004**
BMI	107	0.18	0.066
Alcohol Intake unit	111	**-0.24**	**0.011**
Years Education	109	-0.12	0.233
Physical Activity	105	**-0.20**	**0.039**
PHQ-9	112	**0.32**	**0.001**
GAD-7	112	**0.26**	**0.006**
ESS	112	0.09	0.342
ISI	112	**0.21**	**0.028**
PSQI	112	**0.30**	**0.001**
PSQI Sleep Latency mins	112	0.15	0.107
PSQI Usual Bedtime hrs	112	-0.11	0.255
PSQI Wakeup Time hrs	112	-0.07	0.448
PSQI Self-reported Actual hrs	112	-0.12	0.225
PSQI Sleep Duration hrs	108	-0.19	0.051
MEQ	110	-0.11	0.261
SF36 PH	105	**-0.57**	**0.0001**
SF36 MH	106	**-0.34**	**<0.0001**
GMQ Sleep duration	107	-0.12	0.225

Table 5. Spearman correlation results between Falls efficacy (FES) and all studied variables within the entire sample. *Bolded P values indicate significant associations. Abbreviations: ISI = Insomnia Severity Index; PSQI = Pittsburgh Sleep Quality Index; ESS = Epworth Sleepiness Scale; MEQ = Morningness–Eveningness Questionnaire; GMQ = General Medical Questionnaire; SF-36 PH/MH = Short-Form-36 Physical/Mental Health; PHQ-9 = Patient Health Questionnaire-9; GAD-7 = Generalized Anxiety Disorder-7.*

1.4.1.4 The Multivariate Association between Falls Efficacy and Self-Reported Measures of Sleep Quality, Sleep Duration, and Chronotype in Cognitively Healthy Older Adults

In the following step, it was intended to clarify the extent to which the earlier presented health and sleep-related characteristics independently contributed to the variance in Falls efficacy. Therefore, multiple linear regression were used including all FES as the dependent variable in the model and the demographics, sleep and health features which showed a significant association in the earlier presented bivariate correlation analysis. Also, sleep duration as a predictor was added because there was a clear a priori hypothesis that sleep duration would predict falls risk. In the earlier bivariate analysis, the lack of significant association may have been caused by the effect of confounds linked to mental health and age that were controlled for in the multivariate model.

The model had a low effect size (R^2: 0.042, Adj. R^2: 0.006) and overall, it was not significant (F=1.156, P = 0.335) indicating that it explained an exceedingly small proportion of the variability in the Falls Efficacy Score. Surprisingly, physical health as measured by the SF36 questionnaire yielded a strong significant effect showing that self-reported physical health is a strong independent predictor of self-reported risk of falls. None of the other predictors were significant, which may have been partly due to borderline multicollinearity between some of those measures (e.g., PHQ9, ISI, PSQI, SF35 – MH) as indicated by the tolerance and the variance inflation factor (Table 6).

Variable	*DF*	*Parameter Estimate (β)*	*Standard Error*	*t Value*	*P value*	*Tolerance*	*Variance Inflation*
Intercept	**1**	**24.66**	8.75	2.82	**0.006**	.	0
Age	**1**	-0.01	0.07	-0.14	0.887	0.80	1.24
Alcohol Intake unit	**1**	0.06	0.13	0.46	0.645	0.84	1.18
Physical Activity	**1**	0.0001	0.0002	0.39	0.695	0.79	1.26
PHQ9	**1**	0.369	0.43	0.86	0.390	0.25	3.95
GAD7	**1**	0.167	0.26	0.64	0.522	0.45	2.17
ISI	**1**	-0.009	0.18	-0.05	0.959	0.26	3.75
PSQI	**1**	-0.172	0.27	-0.64	0.524	0.31	3.13
PSQI Sleep Duration (hrs)	**1**	0.074	0.31	0.24	0.810	0.70	1.40
SF36 PH	**1**	**-0.383**	0.09	-4.11	**<.0001**	0.40	2.46

SF36 MH	**1**	0.112	0.13	0.88	0.380	0.28	3.51

Table 6. Multiple linear regression including Falls efficacy (FES) as dependent variable and multiple demographic, health, lifestyle and sleep related variable as predictors. *Analysis was run among all participants. Significant effects are bolded. Multicollinearity assessment included. Abbreviations: ISI = Insomnia Severity Index; PSQI = Pittsburgh Sleep Quality Index; SF-36 PH/MH = Short-Form-36 Physical/Mental Health; PHQ-9 = Patient Health Questionnaire-9; GAD-7 = Generalized Anxiety Disorder-7.*

1.4.1.5 Sex Differences in the Bivariate Associations between Self-Reported Measures of Sleep Quality, Duration and Chronotype and Falls Efficacy in Cognitively Healthy Older Adults

In this analysis, noticeable differences arise between male and female participants when exploring how variables relate to one another. With a wealth of health and lifestyle indicators present in the dataset, a comprehensive perspective on the health profiles of the participants was gained, highlighting subtle differences based on sex.

Men's data showcases various interrelations among variables. The Falls Efficacy Scale (FES) emerges as a central focus. It displays a strong negative correlation with SF36 PH, suggesting that as men's fears of falling increase, their perceived physical health decreases. This is further supported by a moderate negative relationship with SF36 MH, indicating that this fear of falling might also be linked to their mental health perception. There are also notable positive correlations with depressive and anxiety symptoms scales like PHQ 9 and GAD 7, suggesting that as the fear of falling intensifies, these symptoms might also escalate.

In the female dataset, similar trends are observed. The FES's strong negative relationship with SF36 PH underscores the connection between the fear of falling and perceived physical health. The negative association with SF36 MH also persists, reflecting the intertwined nature of physical apprehensions and mental well-being. Positive correlations with PHQ-9 and GAD-7 suggest that women with a heightened fear of falling also tend to report more depressive and anxiety symptoms, respectively.

The sex-based analysis underscores the vital role of falls risk plays in individuals' overall health perception. While both men and women exhibit similar trends, the strength of these relationships might vary. Interestingly, some associations that were presented in one sex group were totally missing from the other. For example, age and habitual bedtime were associated with falls risk only in men. A more delayed bedtime was associated with a lower risk of self-perceived risk of falls in men.

To confirm whether there were sex differences in the bivariate associations between falls risk and the studied demographic, lifestyle, sleep, and health features, a detailed comparison was used of the two correlations by running a Fisher Z transformation. The two-tailed results indicated that the risk of falls (FES)

was significantly stronger associated with Age and bedtime in men compared to women, while the association between FES and physical health was significantly stronger in women than in men (Table 7).

FES	Men (Rs)	Women (Rs)	Z	P value
Age	**0.57**	0.12	3.02	**0.0025**
BMI	0.18	0.21	-0.17	0.865
Alcohol Intake unit	-0.08	-0.26	1.12	0.263
Years Education	-0.10	-0.16	0.39	0.697
Physical Activity	-0.11	-0.20	0.5	0.617
PHQ-9	0.27	**0.31**	-0.21	0.833
GAD-7	0.17	**0.27**	-0.6	0.549
ESS	0.12	0.08	0.2	0.842
ISI	0.10	0.16	-0.37	0.711
PSQI	0.26	**0.26**	0.02	0.984
PSQI Sleep Latency mins	0.13	0.10	0.21	0.834
PSQI Usual Bedtime hrs	**-0.41**	0.08	-2.97	**0.003**
PSQI Wakeup Time hrs	-0.30	0.01	-1.84	0.066
PSQI Self-reported Actual hrs	-0.26	0.00	-1.51	0.131
PSQI Sleep Duration hrs	-0.28	-0.09	-1.11	0.267
MEQ	0.15	-0.18	1.91	0.056
SF36 PH	**-0.36**	**-0.64**	2.18	**0.029**
SF36 MH	-0.17	**-0.39**	1.36	0.174
GMQ Sleep duration	-0.24	-0.02	-1.23	0.219

Table 7. Comparison of Spearman correlation coefficients between Men and Women. *Rs values indicate Spearman correlation coefficients between Falls efficacy (FES) and all studied variables separately for men and women. Bolded Rs values indicate significant associations (P<0.05). P values indicate two-tailed significance for the comparison between the correlation coefficients following Fisher Z transformation. Abbreviations: ISI = Insomnia Severity Index; PSQI = Pittsburgh Sleep Quality Index; ESS = Epworth Sleepiness Scale; SF-36 PH/MH = Short-Form-36 Physical/Mental Health; PHQ-9 = Patient Health Questionnaire-9; GAD-7 = Generalized Anxiety Disorder-7.*

Spearman's rank correlation analysis was conducted to assess relationships between falls efficacy and various demographic, behavioral, and psychological factors among participants. Separate analyses were conducted for men and women to investigate potential sex differences.

For age and falls efficacy, men showed a moderately strong positive correlation (Rs=0.57), indicating increasing age among men correlates with heightened concerns about falling. Among women, this association (Rs=0.12) was not observed. As such a statistically significant sex difference in how age

relates to falls efficacy was indicated by a Z value of 3.02 and p-value of 0.0025, suggesting aging men may exhibit heightened concerns about falling compared to women.

Regarding Body Mass Index (BMI) and falls efficacy, both men and women displayed weak positive correlations, indicating higher BMI values slightly elevate concerns about falling in both sexes. The correlation coefficients did not significantly differ between men and women (Z= −0.17, P=0.865).

Alcohol intake (in units) showed negative correlations for both sexes, suggesting increased alcohol consumption is associated with decreased concerns about falls. However, these weak relationships may not be clinically significant or may be confounded by other factors.

For physical activity, both men and women displayed negligible negative correlations, suggesting weak associations between increased physical activity and reduced concerns about falls. No significant sex difference was observed in this association (Z= 0.39, P=0.697), indicating physical activity slightly alleviates fall concerns regardless of sex.

Depression measured by PHQ-9 showed positive correlations for both men and women, indicating as depressive symptoms increase, concerns about falling also mildly intensify. No significant sex difference was found in this association (Z= −0.21, P=0.834).

Daytime sleepiness assessed using ESS and insomnia severity measured by ISI exhibited positive correlations for both sexes, suggesting slight positive relationships between these factors and increased concerns about falls. No significant sex difference was observed in these associations (ESS: Z= 0.2, P=0.842; ISI: Z= −0.37, P=0.711).

For sleep quality assessed by PSQI, both men and women showed positive correlations, indicating poor sleep quality is associated with heightened fall concerns. There was virtually no sex difference in this association (Z= 0.02, P=0.984), suggesting disrupted sleep may influence fall perceptions similarly regardless of sex.

Regarding specific PSQI components, men exhibited a strong negative correlation between usual bedtime and falls efficacy, while women showed a weak positive correlation, indicating differing sleep patterns may influence fall perceptions across sexes. A significant sex difference was highlighted (Z= −2.97, P=0.003).

For wake-up time, men displayed a moderate negative correlation, suggesting waking up later is associated with reduced fall concerns, while the correlation was near-zero for women. Although a trend towards a sex difference was observed, it was not statistically significant (Z= −1.84, P=0.066).

Self-reported actual sleep duration showed correlations for both sexes, but no significant sex difference was found (Z= −1.51, P=0.131). Longer sleep durations tended to be associated with slightly reduced fall concerns in men.

Additionally, the relationship between sleep duration and falls efficacy was examined, showing negative correlations for both sexes. No significant sex difference was observed (Z= −1.11, P=0.267), indicating longer sleep durations might be associated with decreased concerns about falls, particularly in men.

Regarding chronotype assessed by MEQ, men showed a positive correlation, suggesting morning preference is associated with slightly increased fall concerns, while women displayed a negative correlation. A trend towards a sex difference was observed (Z= 1.91, P=0.056), indicating potential underlying differences in daily routines or circadian preferences influencing fall perceptions.

Lastly, the relationship between perceived physical health (SF36 PH) and falls efficacy differed between men and women. Men displayed a strong negative correlation, while women exhibited an even stronger negative correlation. A significant sex difference was indicated (Z= 2.18, P=0.029), suggesting the relationship between perceived physical health and fall concerns is more pronounced in women, with better health associated with significantly reduced fall apprehensions.

1.4.1.6 Sex Differences in the Independent Association between Falls Efficacy and Self-Reported Measures of Sleep Quality, Sleep Duration, and Chronotype in Cognitively Healthy Older Adults

In the following step, the same multivariate linear regression model as presented above was conducted, but separately for men and women. FES was the dependent variable, while demographics, sleep, and health features showing significant associations in the bivariate correlation analysis were included as predictors (Table 3). However, the results were inconclusive. Both models had low effect sizes, slightly higher in men (R^2=0.156) compared to women (R^2=0.041), and neither model was significant (Men: P=0.231, Women: P=0.573).

Variable	DF	Parameter Estimate (β)	Standard Error	t Value	Pr > |t|	Tolerance	Variance Inflation
Intercept	**1**	7.903	10.748	0.740	0.470	.	0.000
Age	**1**	0.094	0.049	1.910	0.069	0.611	1.637
Alcohol Intake unit	**1**	0.082	0.077	1.060	0.300	0.731	1.368
Physical Activity	**1**	0.000	0.000	-0.810	0.429	0.771	1.297
PHQ 9	**1**	0.217	0.389	0.560	0.582	0.123	8.136
GAD 7	**1**	0.449	0.241	1.860	0.076	0.306	3.270
ISI	**1**	-0.001	0.148	-0.010	0.996	0.174	5.762
PSQI	**1**	-0.177	0.281	-0.630	0.535	0.164	6.102
PSQI Sleep Duration (hrs)	**1**	-0.391	0.698	-0.560	0.581	0.313	3.197
SF36 PH	**1**	-0.289	0.081	-3.550	**0.002**	0.314	3.187
SF36 MH	**1**	0.184	0.139	1.320	0.201	0.156	6.431

Table 8. Multiple linear regression including Falls efficacy (FES) as dependent variable and multiple demographic, health, lifestyle and sleep related variable as predictors among men. *Significant effects are bolded. Multicollinearity assessment included. Abbreviations: ISI = Insomnia Severity Index; PSQI = Pittsburgh Sleep Quality Index; SF-36 PH/MH = Short-Form-36 Physical/Mental Health; PHQ-9 = Patient Health Questionnaire-9; GAD-7 = Generalized Anxiety Disorder-7.*

The results showed that self-reported physical health (i.e., SF36 PH) was the only significant predictor of falls risk in both sex groups with the effect size being considerably stronger in women (β=-043) compared to men (β=-0.29) (Tables 8 and 9).

Variable	DF	Parameter Estimate (β)	Standard Error	t Value	Pr > |t|	Tolerance	Variance Inflation
Intercept	**1**	32.759	12.561	2.610	0.012	.	0.000
Age	**1**	-0.030	0.098	-0.310	0.761	0.790	1.265
Alcohol Intake (unit)	**1**	0.213	0.239	0.890	0.378	0.782	1.278
Physical Activity	**1**	0.000	0.000	0.450	0.657	0.747	1.339
PHQ 9	**1**	0.414	0.592	0.700	0.487	0.304	3.286
GAD 7	**1**	0.029	0.360	0.080	0.936	0.468	2.135
ISI	**1**	0.003	0.251	0.010	0.989	0.317	3.154
PSQI	**1**	-0.330	0.374	-0.880	0.382	0.366	2.730
PSQI Sleep Duration (hrs)	**1**	0.059	0.389	0.150	0.881	0.686	1.458
SF36 PH	**1**	-0.426	0.131	-3.250	**0.002**	0.396	2.527
SF36 MH	**1**	0.077	0.178	0.440	0.665	0.275	3.631

Table 9. Multiple linear regression including Falls efficacy (FES) as dependent variable and multiple demographic, health, lifestyle and sleep related variable as predictors among women. *Significant effects are bolded. Multicollinearity assessment included. Abbreviations: ISI = Insomnia Severity Index; PSQI = Pittsburgh Sleep Quality Index; SF-36 PH/MH = Short-Form-36 Physical/Mental Health; PHQ-9 = Patient Health Questionnaire-9; GAD-7 = Generalized Anxiety Disorder-7.*

Summary of Findings for Phase One (Observational Study)

The first part of the study focused on exploring the connection between sleep quality, length of sleep, chronotype self-reported by individuals and confidence in avoiding falls among healthy older adults. In this observational research, a total amount of 166 members were involved which includes 49 men and 117 women who are mostly around age 65.

In this phase, a key measure was the Falls Efficacy Scale (FES). This scale measures how much people are concerned about falling while doing different activities. The higher scores indicate higher self-assessed risk of falls. The findings showed that higher self-assessed risk of falls was associated with higher age, lower physical activity, poorer sleep quality self-perceived physical health (evaluated by SF36 Physical Health scale) and mental health also (assessed through SF36 Mental Health scale) and increase insomnia severity score within the entire sample. Surprisingly higher alcohol consumption was associated with lower self-perceived risk of falls. Importantly, more fear of falling connected with more signs of depression which is seen from PHQ-9 scores, along with increased anxiety levels shown by GAD-7 scores. These results highlight the mental aspects of risk for falls. They suggest that people who are more concerned about falling usually show stronger signs of depression and anxiety.

However, these relationships became less conclusive when controlling for all predictors of interest simultaneously within multivariate linear regression analyses. Interestingly, only physical health emerged as an independent dimension that remained significantly associated with falls risk, even when accounting for the influence of other factors. This is somewhat plausible as mental wellbeing is highly confounded with sleep quality and there is a slight multicollinearity between those. That said the strong independent relationship between a self-reported physical wellbeing and falls risk is a novel result in my view.

The research also showed significant sex differences in the association between fall efficacy and different health measurements. Though similar patterns were seen in both men and women, some relationships were specific to each sex. For example, the link between age and habitual bedtime with risk of falls was much more pronounced in men suggesting that higher age and a later bedtime represented a risk for increased self-assessed risk of falls in men but not in women. On another note, while better physical health was associated with lower risk of falls in both sex groups this relationship was much stronger among women as compared to men. These findings underline how important it is to think about differences between sexes when considering these results.

In conclusion, the discoveries from the first part of this research emphasize how closely sleep quality, health views and risk of falls are linked in older adults. These outcomes highlight differences between men and women as they show unique patterns which could guide specific measures for reducing fall risks in this age group. In general, this study phase provides important knowledge about aspects affecting falls efficacy; stressing out the need for complete comprehension of physical and psychological domains tied up with risk of falls among older adults.

1.4.2 Results Phase 2: Experimental Study on the Effect of Sleep Restriction (i.e., accumulation of homeostatic sleep pressure) and Circadian Rhythmicity (i.e., time of the day) on Objective and Subjective Measures of Balance Control and Sensorimotor Integration in Healthy Older Adults.

The aim of phase 2 was to clarify the mechanistic effect of sleep restriction and time of the day (i.e., circadian phase) on objectively measured postural control in a laboratory setting and the extent to which these effects are modulated by sensorial feedback and sex. Additionally, the effects of sleep and time of the day on sensorimotor integration were studied, along with their modulation by sex.

1.4.2.1 Participant Characteristics

The study was conducted over a span of two and a half years, from January 2019 to July 2021, and targeted English-speaking participants who met the specific criteria outlined in the Methods-Recruitment section. Out of 166 individuals who were initially approached (comprising 49 males and 117 females) a subset of 38 participants (consisting of 18 males and 20 females) were invited to attend experimental laboratory session in the Sleep and Brain Research Unit. All individuals who participated in the study identified themselves as White British, with a single exception who chose the label White Other. The study provided options for sex identification as male or female and included an additional option for those who identified otherwise. It should be noted that out of the 38 participants three participants did not complete all assessments due to personal and medical reasons.

Table 10 is a comprehensive overview of participant characteristics encompassing a wide range of variables, including basic demographics, lifestyle, mental and physical well-being, subjective sleep and chronotype, as well as self-reported risk of falls variables. Demographically, the average age of the 38 participants was 64.3 years, with a standard deviation of 9.1 years. The sample consisted of 18 males (47.4%) and 20 females (52.6%). Participants reported an average BMI of 24.39, with a standard deviation of 3.55, and an average alcohol intake of 5.3 units, with a standard deviation of 4.9. Among the 34 participants with complete data, the mean physical activity level was 3504.1 (mins), with a standard deviation of 3429.8 (mins). Regarding lifestyle factors, 26 participants (68.4%) were non-smokers, while 12 (31.6%) were smokers. Additionally, 25 participants (65.8%) reported being retired, while 13 (34.2%) were not retired. Mental well-being was assessed using the PHQ-9 and GAD-7 scales, with participants having an average PHQ-9 score of 0.68 and an average GAD-7 score of 0.58. Participants' sleep quality was evaluated using various measures. The average ISI score was 3.13, and the average ESS score was 4.05. The PSQI yielded an average score of 4.32, with an average bedtime of 21:43 hours. These scores indicate

normal sleep quality and daytime sleepiness. Participants reported waking up at an average time of 7.26 hours, with an average self-reported sleep duration of 7.04 hours. Based on 37 participants, the PSQI-Sleep Duration had an average of 7.23 hours. Chronotype was assessed using the MEQ, with an average score of 60.39. Of the participants, 63.2% were classified as morning chronotypes, 34.2% as intermediate, and 2.6% as evening chronotypes. General medical assessment, as measured by the GMQ SD, resulted in an average score of 7.13. The risk of falls assessment utilized the FES, with participants having an average FES Total Score of 1.61. Participants were categorized into two experimental sleep conditions—Sleep Deprivation (10 males, 11 females) and Multinap (8 males, 9 females). This comprehensive presentation of participant characteristics is essential for a thorough understanding of the study population and is invaluable for interpreting the subsequent results obtained across various measures, screening questionnaires, and objective sleep quality assessments using PSG (Polysomnography).

Variable	*N*	*Mean (Std)*
Demographics and lifestyle		
Age	38	64.3 (9.1)
Men	18	47.4%
Women	20	52.6%
BMI	38	24.39 (3.55)
Alcohol Intake unit	38	5.33 (4.89)
Physical Activity	34	3504.12 (3429.82)
Smoking	38	
No	26	68.4%
Yes	12	31.6%
Retired		
No	13	34.2%
Yes	25	65.8%
Mental well-being		
PHQ-9	38	0.68 (1.12)
GAD-7	38	0.58 (1.0)
Sleep quality		
ISI	38	3.13 (3.13)
ESS	38	4.05 (2.42)
PSQI	38	4.32 (2.31)
PSQI-Bedtime (hrs)	38	21.43 (5.16)
PSQI-Wakeup Time (hrs)	38	7.26 (0.89)
PSQI-Self-reported hours of sleep (hrs)	38	7.04 (2.53)
PSQI-Sleep Duration (hrs)	37	7.23 (2.28)
Chronotype		
MEQ – chronotype/diurnal preference	38	60.39 (7.91)
morning	24	63.2%

intermediate	13	34.2%
evening	1	2.6%
General medical assessment		
GMQ SD	37	7.13 (0.96)
Risk of falls assessment		
FES Total Score	33	1.61 (1.41)
Experimental sleep condition		
Sleep Deprivation	21	10 males, 11 females
Multinap	17	8 males, 9 females

Table 10. Descriptive characterization of participants who participated in the laboratory-based experimental session along the demographic, lifestyle, physical and mental health as well as sleep and chronotype features. *Abbreviations: ISI = Insomnia Severity Index; PSQI = Pittsburgh Sleep Quality Index; ESS = Epworth Sleepiness Scale; MEQ = Morningness–Eveningness Questionnaire; GMQ = General Medical Questionnaire; PHQ-9 = Patient Health Questionnaire-9; GAD-7 = Generalized Anxiety Disorder-7; FES = Falls Efficacy Scale.*

In the following step, a comparison was made between male and female participants who took part in the laboratory session along the above-presented characteristics. This was done to check for potential sex differences that could confound the results associated with the experimental sleep manipulation in this smaller sample size. As show in Table 11 and 12 none of the participant characteristics showed significant difference between men and women.

The analysis revealed that there were no statistically significant sex differences in the distribution of Smoking status, Retirement Status, or Experimental Sleep Protocol within the sleep lab study.

	Men *N (%)*	*Women* *N (%)*	*Chi-square* *P value*
Smoking			
Non-smoker	11 (61.11%)	15 (75%)	ns
Smoker	7 (38.89%)	5 (25%)	
Retirement Status			ns
Not retired	5 (27.78%)	8 (40%)	
Retired	13 (72.22%)	12 (60%)	
Experimental sleep protocol			
Sleep deprivation	10 (55.56%)	11 (55%)	ns

Multinap	8 (44.44%)	9 (45%)

Table 11. Comparison male and female participants from the laboratory experimental study along categorical demographic variables.

In the following step, a detailed comparison of various key variables measured on a continuous scale between male and female participants within the sleep lab study is provided (Table 12). These variables encompass a wide range of factors, including demographics, lifestyle, mental well-being, sleep quality, chronotype, general medical assessment, and experimental sleep conditions. The Mann-Whitney U test was utilized to evaluate the significance of the differences observed between the two sex groups.

Age: The mean age for men was 64.78 years (SD = 9.33), while for women, it was 63.80 years (SD = 9.16). There was no significant difference in age between the two groups (p = 0.861).

BMI (Body Mass Index): Men had an average BMI of 24.46 (SD = 4.00), whereas women had an average BMI of 24.32 (SD = 3.18). No significant sex-based difference in BMI was found (p = 0.977).

Alcohol Intake: Men had an average alcohol intake of 6.31 units (SD = 5.53), and women had an average of 4.45 units (SD = 4.18). The difference in alcohol intake between the two sex groups was not significant (p = 0.394).

Physical Activity: The average physical activity levels for men and women were 3532.94 (SD = 2531.39) and 3475.29 (SD = 4225.25), respectively. There was no significant sex difference in physical activity (p = 0.255).

Mental Well-being: Men had an average PHQ-9 score of 1.00 (SD = 1.37), and women had an average score of 0.40 (SD = 0.75). Similarly, men had an average GAD-7 score of 0.78 (SD = 1.17), and women had an average score of 0.40 (SD = 0.82). No significant sex differences were observed in mental well-being scores (PHQ-9: p = 0.155, GAD-7: p = 0.410).

Sleep Quality: Men had an average PSQI score of 3.56 (SD = 2.41), while women had an average score of 5.00 (SD = 2.05). This difference was statistically significant (p = 0.019), indicating poorer sleep quality in women.

Chronotype: Men averaged 62.11 (SD = 5.99) on the MEQ, and women averaged 58.85 (SD = 9.20). No significant sex-based difference in chronotype was found (p = 0.356).

General Medical Assessment: The SF36 Physical Health (SF36 PH) and Mental Health (SF36 MH) components showed no significant sex differences (SF36 PH: p = 0.915, SF36 MH: p = 0.097).

GMQ Sleep Duration: Men reported an average score of 7.43 (SD = 0.90), while women reported 6.84 (SD = 0.96) (p = 0.042), indicating a significant difference in sleep duration.

Risk of Falls Assessment: The Falls Efficacy Scale (FES) Total Score showed no significant sex differences (p = 0.335).

This comparison of men and women within the sleep lab study provides valuable insights into sex-related variations in various factors, including sleep quality and general medical assessments. While some differences were observed, such as in sleep quality and GMQ Sleep Duration, others showed no significant disparities (Table 12).

Variable	*Men (18) Mean (SD)*	*Women (20) Mean (SD)*	*Mann-Whitney U p-value*
Age	64.78 (9.33)	63.80 (9.16)	0.861
BMI	24.46 (4.00)	24.32 (3.18)	0.977
Alcohol Intake unit	6.31 (5.53)	4.45 (4.18)	0.394
Physical Activity	3532.94 (2531.39)	3475.29 (4225.25)	0.255
PHQ-9	1.00 (1.37)	0.40 (0.75)	0.155
GAD-7	0.78 (1.17)	0.40 (0.82)	0.410
ESS	3.67 (2.83)	4.40 (1.98)	0.227
ISI	2.28 (2.56)	3.90 (3.45)	0.169
PSQI	3.56 (2.41)	5.00 (2.05)	**0.019**
PSQI Sleep Latency mins	14.44 (10.69)	34.20 (98.36)	0.619
PSQI Usual Bedtime (hrs)	21.31 (5.34)	21.55 (5.13)	0.343
PSQI Wakeup Time (hrs)	7.14 (0.83)	7.37 (0.94)	0.481
PSQI Self-reported Actual (hrs)	7.39 (0.81)	6.72 (3.42)	**0.006**
MEQ	62.11 (5.99)	58.85 (9.20)	0.356
Chronotype	1.28 (0.46)	1.50 (0.61)	0.252
SF36 PH	79.99 (3.01)	79.60 (4.55)	0.915
SF36 MH	72.72 (4.04)	70.75 (4.02)	0.097
GMQ Sleep Duration	7.43 (0.90)	6.84 (0.96)	**0.042**
FES Total Score	1.44 (1.50)	1.76 (1.35)	0.335
Protocol SD0 MN1	0.44 (0.51)	0.45 (0.51)	0.986

Table 12. Demographic table for sleep lab participants comparing sex for continuous variables.

Note: Patient health questionnaire PHQ-9, General anxiety disorder GAD-7, Epworth sleepiness scale ESS, Insomnia severity index ISI, Pittsburgh sleep quality index PSQI, Morningness-eveningness questionnaire MEQ, Physical health short form survey SF36 PH, Mental health short form survey SF 36 MH, General medical questionnaire GMQ, Falls efficacy scale FES, Sleep deprivation SD, Multinap MN.

In the sleep lab study, a detailed analysis was conducted to compare participants based on the sleep experimental protocols they underwent—specifically, Sleep Deprivation and Multinap. The aim was to discern any significant differences between these protocols concerning various demographic and lifestyle factors. Chi-square tests were employed to investigate differences along categorical variables.

Regarding smoking habits, in the Sleep Deprivation group, 23.81% of participants were smokers, while 76.19% were non-smokers. In contrast, within the Multinap group, 41.18% were smokers, and 58.82% were non-smokers. The chi-square analysis showed that there were no significant differences in smoking status between the two protocols ($\chi^2 = 0.43$, $p > 0.05$).

Further exploration of retirement status revealed that in the Sleep Deprivation group, 42.86% of participants were not retired, while 57.14% were retired. Conversely, in the Multinap group, 23.53% were not retired, while 76.47% were retired. The chi-square test results indicated no significant differences in retirement status between the two protocols ($\chi^2 = 0.37$, $p > 0.05$).

Lastly, the sex distribution within the Sleep Deprivation and Multinap groups was examined. In the Sleep Deprivation group, 47.62% were men, and 52.38% were women. Similarly, in the Multinap group, 47.06% were men, and 52.94% were women. The chi-square analysis demonstrated that there were no significant sex differences between the two protocols ($\chi^2 = 1$, $p > 0.05$).

This comprehensive analysis of sleep lab participants, categorized by the sleep experimental protocols of Sleep Deprivation and Multinap, revealed no significant differences in the distribution of subgroups related to smoking habits, retirement status, or sex between the two experimental groups (Table 13).

	Sleep Deprivation *N (%)*	*Multinap* *N %)*	*Chi square* *P value*
Smoking			
Non-smoker	16 (76.19%)	10 (58.82%)	ns
Smoker	5 (23.81%)	7 (41.18%)	
Retirement Status			
Not retired	9 (42.86%)	4 (23.53%)	ns
Retired	12 (57.14%)	13 (76.47%)	
Sex			

Men	10 (47.62%)	8 (47.06%)	ns
Women	11 (52.38%)	9 (52.94%)	

Table 13. Comparison of sleep lab participants from the two experimental sleep conditions (i.e. protocol) along categorical demographic features.

In the sleep lab study, a comparison was conducted between participants categorized by the two experimental sleep protocols: Sleep Deprivation and Multinap. The aim was to assess differences along continuous variables related to demographics, well-being, sleep, and falls efficacy (Table 14). The Mann-Whitney U test was employed to evaluate the significance of these differences.

Age: Participants in the Sleep Deprivation group had a mean age of 65.14 years (SD = 10.24), while those in the Multinap group had a mean age of 63.18 years (SD = 7.71). No significant difference in age between the two protocols was observed ($p = 0.659$).

Sex: The sex composition within the two groups showed no significant difference. The Sleep Deprivation group had a sex composition of 0.52 (0.51), and the Multinap group had a composition of 0.53 (0.51) ($p = 0.986$).

BMI (Body Mass Index): The Sleep Deprivation group had an average BMI of 23.79 (SD = 3.14), and the Multinap group had an average BMI of 25.12 (SD = 3.96). No statistically significant difference in BMI was found between the two protocols ($p = 0.284$).

Alcohol Intake: The average alcohol intake was 4.36 units (SD = 4.52) for the Sleep Deprivation group and 6.53 units (SD = 5.19) for the Multinap group. However, this difference was not statistically significant ($p = 0.144$).

Physical Activity: Physical activity levels approached significance, with the Sleep Deprivation group averaging 4505.26 (SD = 3944.26) and the Multinap group averaging 2236.00 (SD = 2154.81) ($p = 0.056$).

Mental Well-being: No significant sex-based differences were observed in mental well-being assessed using the PHQ-9 and GAD-7 scales (PHQ-9: $p = 0.454$, GAD-7: $p = 0.532$).

Sleep Quality: There were no significant differences in sleep quality between the two groups based on PSQI scores ($p = 0.917$).

Chronotype: Participants' chronotype measured using the MEQ showed no significant difference between the Sleep Deprivation and Multinap groups ($p = 0.362$).

General Medical Assessment: The SF36 Physical Health (SF36 PH) and Mental Health (SF36 MH) components displayed no significant sex differences between the two groups (SF36 PH: p = 0.559, SF36 MH: p = 0.616).

GMQ Sleep Duration: The Sleep Duration scores were similar between the Sleep Deprivation (mean = 6.99, SD = 0.90) and Multinap (mean = 7.29, SD = 1.03) groups, with no significant difference (p = 0.177).

Falls Risk Assessment: No significant differences in falls risk were observed between the two protocols (p = 0.182).

This comparison between the Sleep Deprivation and Multinap protocols within the sleep lab study provides insights into potential variations in participant characteristics, with most variables showing no significant differences between the two experimental conditions (Table 14).

Variable	*Sleep Deprivation (21) Mean (SD)*	*Multinap (17) Mean (SD)*	*Mann-Whitney U p-value*
Age	65.14 (10.24)	63.18 (7.71)	0.659
Sex M0 F1	0.52 (0.51)	0.53 (0.51)	0.986
BMI	23.79 (3.14)	25.12 (3.96)	0.284
Alcohol Intake unit	4.36 (4.52)	6.53 (5.19)	0.144
Physical Activity	4505.26 (3944.26)	2236.00 (2154.81)	0.056
PHQ-9	0.86 (1.31)	0.47 (0.80)	0.454
GAD-7	0.67 (1.06)	0.47 (0.94)	0.532
ESS	3.95 (2.27)	4.18 (2.65)	0.988
ISI	3.38 (3.02)	2.82 (3.32)	0.341
PSQI	4.43 (2.66)	4.18 (1.88)	0.917
PSQI Sleep Latency mins	35.57 (95.68)	11.59 (7.85)	0.289
PSQI Usual Bedtime hrs	22.64 (0.76)	19.94 (7.52)	0.258
PSQI Wakeup Time hrs	7.12 (0.94)	7.44 (0.81)	0.275
PSQI Self-reported Actual hrs	6.40 (2.26)	7.82 (2.70)	0.331
PSQI Sleep Duration hrs	6.72 (1.76)	7.82 (2.70)	0.457
MEQ	61.29 (9.08)	59.29 (6.27)	0.362
Chronotype	1.38 (0.59)	1.41 (0.51)	0.727
SF36 PH	80.22 (3.81)	79.22 (3.91)	0.559
SF36 MH	72.10 (3.97)	71.18 (4.32)	0.616
GMQ SD	6.99 (0.90)	7.29 (1.03)	0.177
FES Total Score	1.94 (1.56)	1.25 (1.18)	0.182

Table 14. Demographic table for sleep lab participants comparing experimental sleep condition (i.e. protocol) for continuous variables.

Note: Patient health questionnaire PHQ-9, General anxiety disorder GAD-7, Epworth sleepiness scale ESS, Insomnia severity index ISI, Pittsburgh sleep quality index PSQI, Morningness eveningness questionnaire MEQ, Physical health short form survey SF36 PH, Mental health short form survey SF 36 MH, General medical questionnaire GMQ, Falls efficacy scale FES.

1.4.2.2 Validation of the Experimental Sleep Protocol

In a first step it was assessed whether the experimental condition successfully altered sleep pressure. In order to do that the main effects of experimental sleep protocol and time of the day on self-reported (KSS) and objectively measured (PVT) vigilance were examined. As described in the methods chapter the Karolinska Sleepiness Scale (KSS) provides a subjective sleepiness measure ranging from 0 (not at all) to 9 (very sleepy), while the psychomotor vigilance test (PVT) assesses reaction time variability associated with sustained attention. A two-way ANOVA was conducted to estimate the main effects and interactions between the experimental sleep protocol (comparing sleep deprivation and multinap sleep) and the test numbers, which represent the time of day at which the tests were taken. The P-values derived from the two-way ANOVA were used to determine the statistical significance of these effects.

Karolinska Sleepiness Scale (KSS) Analysis: For the KSS, the sleep protocol had a significant main effect ($F(1,36)=18$, $p=0.0002$), and the test number also showed a significant main effect ($F(1,36)=16$, $p<0.0001$) indicating an increase in sleepiness in the sleep deprivation group versus the multinap group as well as a time of the day modulation. Importantly, a significant interaction was found between the sleep protocol and the test number showing that the strongest detrimental effect of sleep restriction on sleepiness occurred during the circadian night ($p<0.0001$) (Figure 14).

Psychomotor Vigilance Task (PVT) Analysis: For the PVT mean RT with lapses measuring sustained attention the sleep protocol was not significant ($P=0.7$) but the test number showed a significant effect ($p<0.0001$) and there was a significant interaction between sleep protocol and test number was ($p=0.002$) suggesting that the increase in reaction time during the time spent in the protocol was more emphasized in the sleep deprivation group.

Similar results were found for the PVT slowest 10% RT with lapses. The sleep protocol did not show any significant effect ($F(1,36)=0.29$, $p=0.59$), but the test number did ($F(1,36)=2.4$, $p=0.01$). The interaction between sleep protocol and test number was also significant ($F(1,36)=3.5$, $p=0.0004$) indicating that vigilance was most compromised in the sleep deprivation group during the circadian night (Figure 14).

These findings suggest that the effect of the experimental sleep condition on self-reported (KSS) and objectively measured vigilance (PVT) emerged later within the experimental protocol as the effect of sleep pressure accumulated. It also showed that the time of the day representing the arousal signal of the intrinsic circadian clock modulated the vigilance and this modulation was not uniform in the two experimental conditions but was more emphasized when participants were more sleep deprived. These results are in line with the literature and validated that the experimental condition resulted in a different

level of homeostatic sleep pressure that also showed the well-known circadian modulation. This indicates that the effect of the sleep protocol on these measures is dependent on the time of day, which has important implications for the understanding of sleep and its impact on cognitive performance.

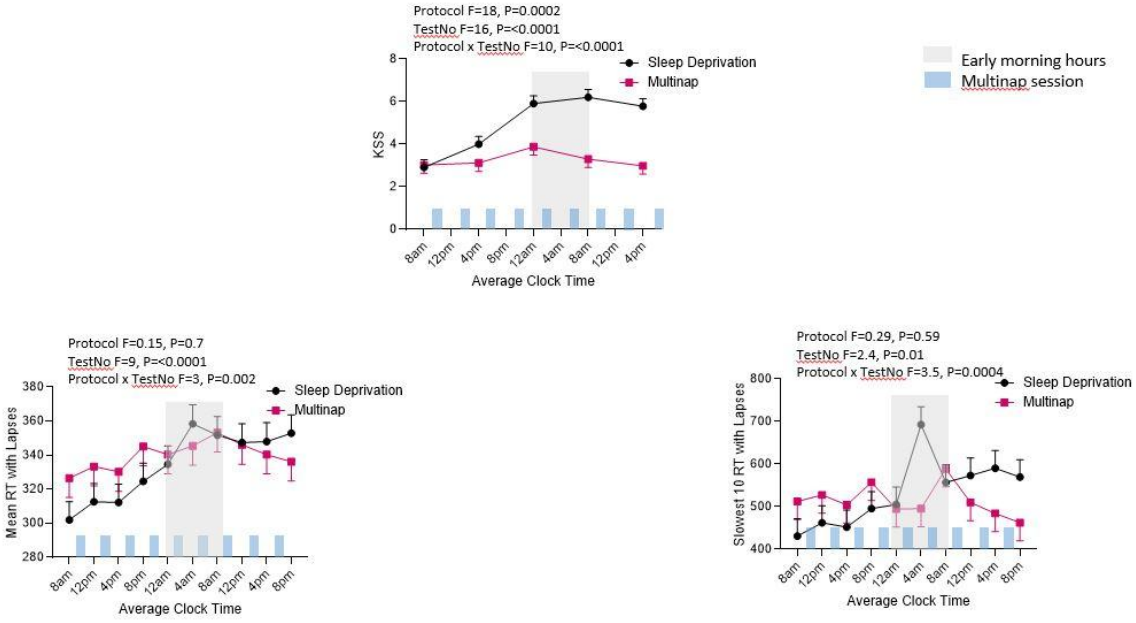


Figure 14. The effect of experimental sleep condition (i.e., Protocol) and time of the day (test number) on subjective and objective vigilance. Least square mean and SEM are indicated. Grey shaded area indicates the circadian night. Light blue horizontal bars indicate nap opportunities in the multinap condition. Detailed statistical results with degrees of freedom information are found in the main text.

Note: ANOVA results are reported as $F(df_1, df_2)$, p. For the experimental protocol (sleep deprivation vs. multi-nap), the between-subjects effect of protocol is F(1, 36).

1.4.2.3 Validation of the Postural Control Assessment Protocol

The study validated the postural control assessment by examining the effects of Vision (eyes open vs closed) and Touch (light touch vs no touch) on center-of-pressure (COP) outcome variables. The mixed models included the two within factors (i.e., Touch and Eyes conditions) and estimated their main

effects and the two-way interaction. The validation criteria were an expected positive effect of visual (i.e., eyes-open condition) and haptic (i.e., light-touch) feedback conditions on measures of PC.

Circumference showed a significant main effect of Vision ($F(1, 37) = 106$, $p < 0.0001$) and a significant main effect of Touch ($F(1, 37) = 670$, $p < 0.0001$). As expected, circumference was smaller in the eyes-open and light-touch conditions, confirming better stability under these conditions (Figure 15).

Path length showed a significant main effect of Vision ($F(1, 37) = 470$, $p < 0.0001$) and a significant main effect of Touch ($F(1, 37) = 456$, $p < 0.0001$). Path length also showed a significant Vision × Touch interaction ($F(1, 37) = 16.6$, $p < 0.0001$), indicating that the visual benefit was strongest when no tactile support was available. As expected, path length was shortest in the eyes-open and light-touch condition.

Ellipse area, sample entropy in the X and Y directions, and the Visual Analogue Scale (VAS) did not show significant main effects of Vision or Touch. These null findings suggest that not all COP outcome variables are equally sensitive to changes in visual or tactile input.

This interaction between the two sensorial feedback conditions indicates that the effect of the visual input (i.e. eyes condition) is more prominent when there is no other sensorial support such as light touch.

Importantly, Vision and Touch influenced the postural control measures differently. Their effects varied in degree and direction across the different sway variables. For example, Vision may have had a larger effect on path length compared to ellipse area.

In summary, study results suggest that the impact of sensorial feedback on postural control is variable-specific. Certain aspects of postural control, such as circumference and path length, appear to be significantly influenced by the state of visual feedback (eyes open or closed) or the presence or absence of tactile feedback (touch or no touch), respectively. However, other aspects like sample entropy in the X direction and ellipse area do not show significant main effects of these conditions (Figure 15).

Light touch can improve postural control by providing additional sensory information about the body's position in space. This information can be used to make more precise and timely adjustments to muscle activity, which can help to maintain balance and prevent falls.

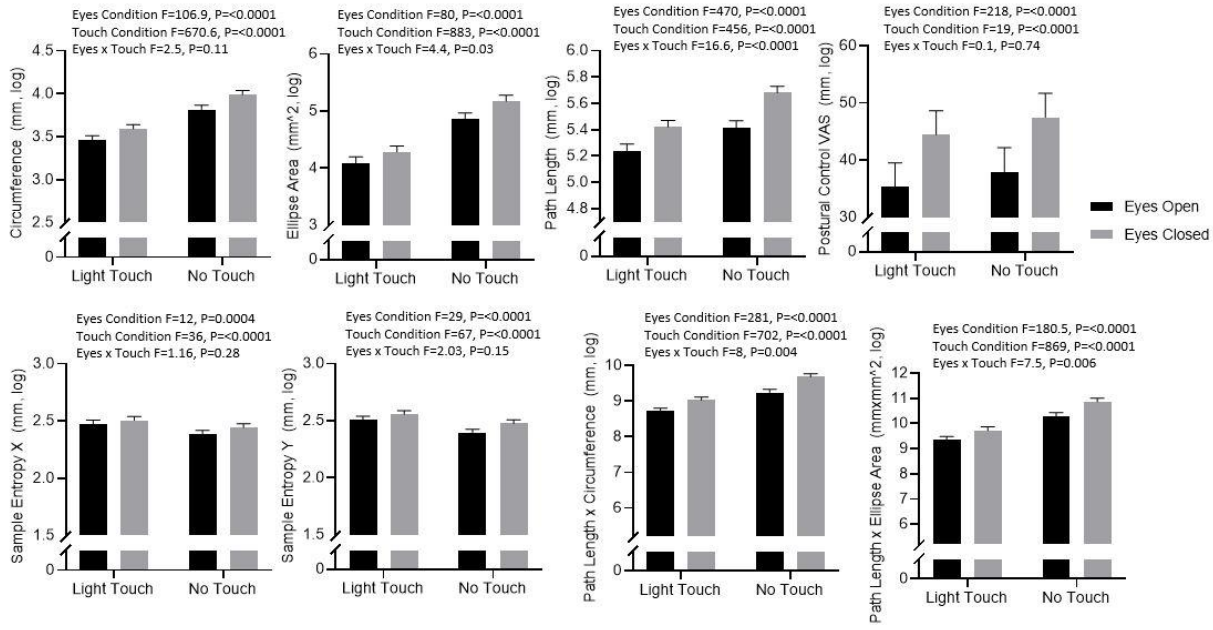


Figure 15. Main effects and two-way interaction between sensorial visual and haptic feedback on postural control outcome measures. Least square mean and 1± SEM are indicated.

1.4.2.4 The Effect of Experimental Sleep Condition on Outcome Measures of Postural Control

In the following step, a detailed analysis was used to explore the effect of the experimental sleep condition on the main PC outcomes (i.e., Circumference, Ellipse Area, Path Length, Sample Entropy X, Sample Entropy Y, and Postural Control VAS). This analysis revealed that there was no significant main effect of the sleep protocol on any of the postural control variables (Figure 16).

In summary, the analysis did not provide evidence to support the hypothesis that sleep restriction would have a negative effect on postural control variables measured in this study. This lack of a significant main effect of experimental sleep protocol suggests that the two sleep protocols may have similar impacts on postural control, at least with respect to the variables analyzed in the study.

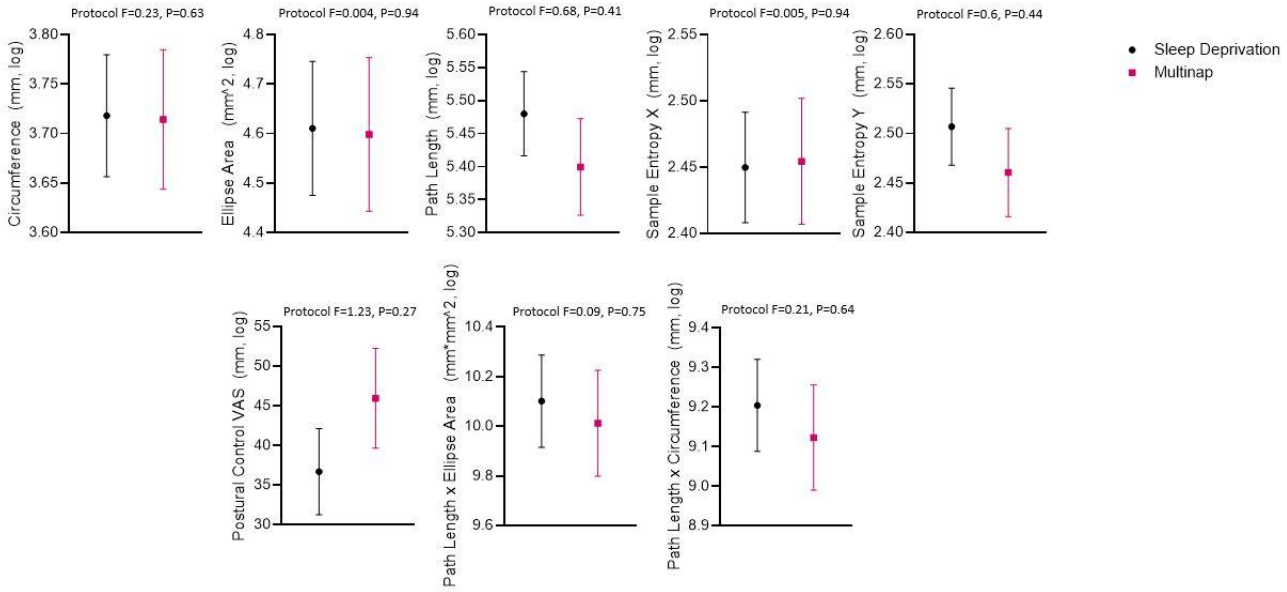


Figure 16. Main effect of experimental sleep condition (i.e., Protocol) on postural control outcome measures. Least square mean and 1± SEM are indicated.

1.4.2.5 Interaction Effects of Experimental Sleep Condition and Time of Day on Postural Control Measures

Given the hypothesized circadian effect on postural control, in the next step the interaction effects between experimental sleep protocol and time of day (represented by test numbers) on various postural control measures were analyzed. The multivariate model included the factors experimental sleep condition (sleep restriction and multinap) and test number (1 to 10).

The model did not return any significant main effect of experimental sleep condition while there was a significant main effect of the time of the day (i.e., test number) on the Path length, sample entropy Y and subjective effort to maintain PC (i.e., Postural control VAS) (Figure 17). The results suggested an indication for worse performance in the second part of the experimental protocol and/or during the circadian night. While the interaction terms between factors experimental sleep protocol and time of the day were not significant for any of the PC outcome measures the results indicated a relative impairment in PC during the circadian night mostly true for the sleep restriction protocol (e.g., Path length and the cumulative outcome measure between Path length and Circumference or path length and Ellipse area).

The majority of PC outcome measures such as Circumference, Ellipse Area, and the interaction variables Path Length x Circumference, and Path Length x Ellipse Area, demonstrated no significant main

effects of Protocol, whereas multiple parameters presented significant effect of time of day. For example, Path Length exhibited a significant main effect of time of the day ($F(9,324)=2.1$, $p=0.02$) and similarly, Postural Control VAS and Sample Entropy X also showed a highly significant main effect of time of the day ($F(9,324)=5.4$, $p<0.0001$ and $F(9,324)=5.2$, $p<0.0001$ respectively).

Interestingly the Postural Control VAS (subjectively perceived difficulty of maintaining balance) showed a gradual increase throughout the time spent in the study in both experimental protocols suggesting that there was an increasing self-perceived challenge in maintaining postural control over time whether due to sleep deprivation or potentially being affected by sleep inertia in the multinap protocol. Although there was no significant interaction between the two factors there was a clear trend for deterioration of postural control during the circadian night in the sleep deprivation protocol (e.g. circumference, ellipse area, etc.) (Figure 17).

These findings underscore the intricate interplay between sleep protocol, time of day, and postural control. The significant interaction effects observed for several measures suggest that the impact of sleep protocol on these aspects of postural control is not constant but changes over the course of the day.

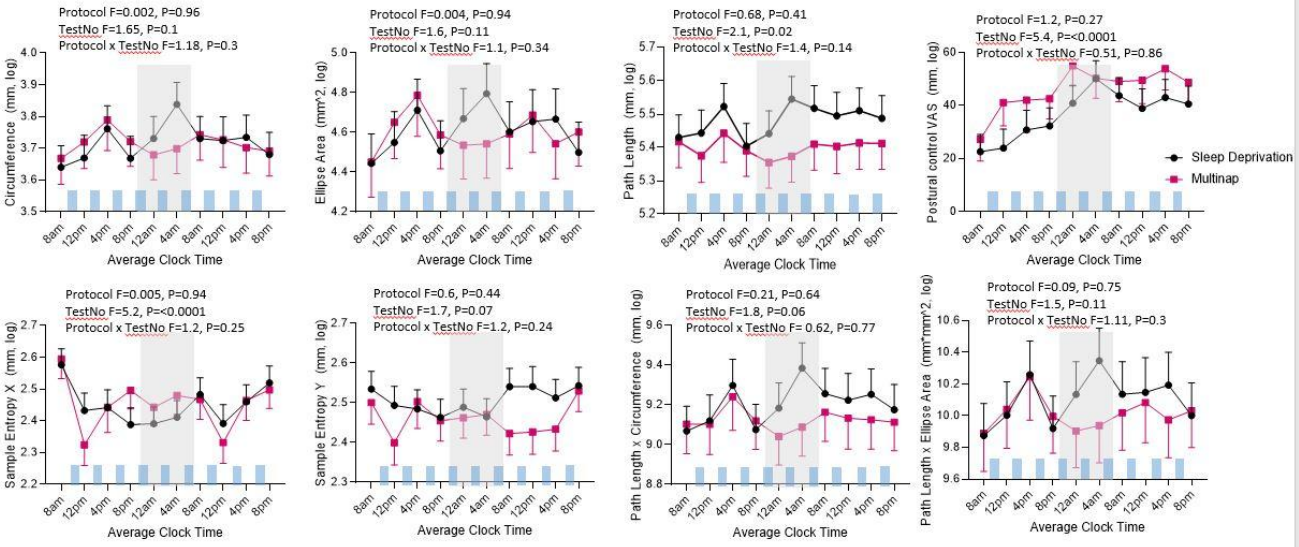


Figure 17. Main effects and interaction between experimental sleep condition (i.e., Protocol) and time of the day (i.e. TestNo) on postural control outcome measures. Given that the time of the day effect was expected to be modulated by the experimental sleep condition the main effect of time of the day is not visually represented. Grey shaded area indicates the circadian night. Light blue horizontal bars indicate nap opportunities in the multinap condition. Least square mean and 1± SEM are indicated.

1.4.2.6 Interaction Effects of Experimental Sleep Condition and Eye Conditions on Postural Control Measures

In the following step, an examination was made to test the interaction effects between sleep experimental condition and visual conditions (eyes open or closed) on various postural control measures including Circumference, Ellipse Area, Path Length, Postural Control VAS, Sample Entropy X, and Sample Entropy Y (Figure 18).

Self-perceived difficulty in maintaining postural control (**Postural Control VAS**) showed a significant interaction between Protocol and visual Conditions ($F(1,37)=5.5$, $p=0.018$) suggesting that the influence of visual conditions on postural control VAS was modulated by the experimental Protocol. Interestingly in open eyes condition those in the multinap group appeared to find it more difficult to maintain balance.

Conversely, for variables like **Circumference**, **Ellipse Area**, and **Path Length**, while visual Conditions manifested a highly significant effect ($p<0.0001$ across all), the interaction between Protocol and visual Conditions was not significant ($p=0.7$, $p=0.24$, $p=0.84$ respectively). This suggests that, despite the influence of visual Conditions on these variables, the interaction with Protocol does not significantly modulate this effect. The impact of Eye Conditions on these variables appears consistent across different levels of Protocol.

Similarly, in the exploration of **Sample Entropy X and Y**, and interaction variables (**Path Length x Circumference** and **Path Length x Ellipse Area**), the interaction between Protocol and visual Conditions did not demonstrate significant effects, indicating a stable influence of visual Conditions across different Protocols.

These findings highlight the complex interplay between sleep protocol, visual condition, and postural control. The significant interaction effects observed for several measures suggest that the impact of sleep protocol on these aspects of postural control is not constant but changes depending on whether the eyes are open or closed.

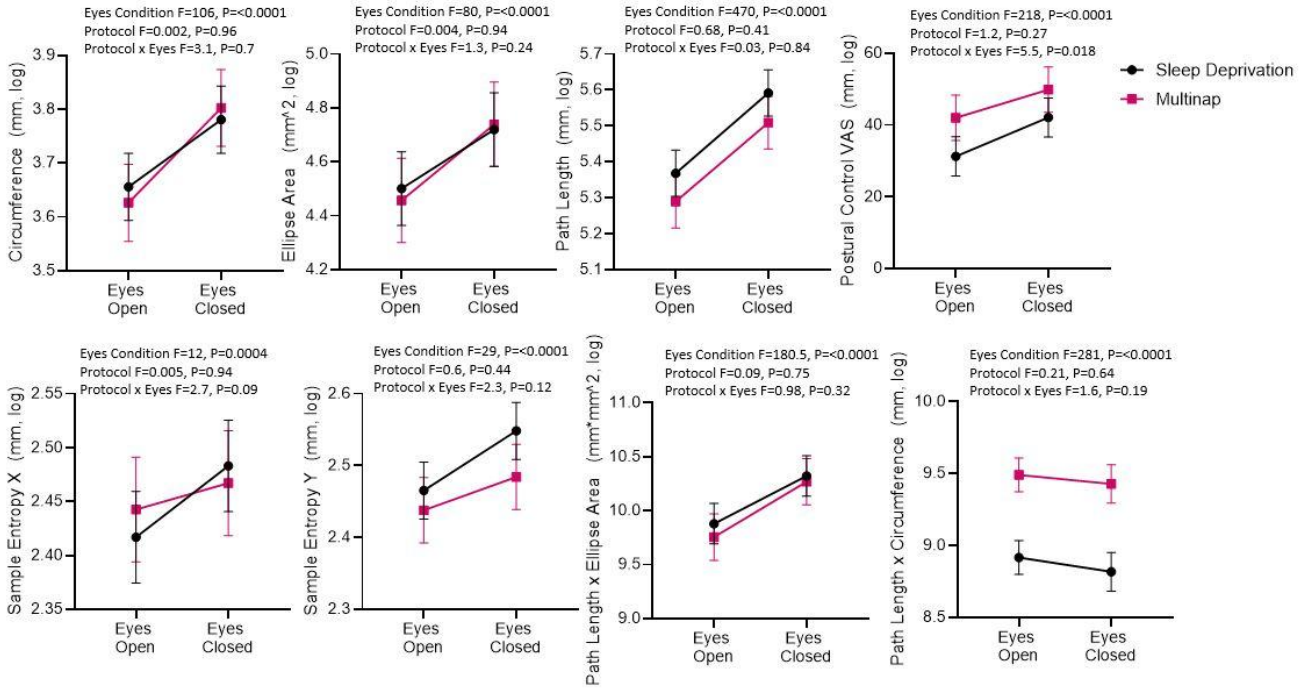


Figure 18. Main effects and two-way interaction of sleep experimental sleep condition (i.e., Protocol) and sensorial visual feedback on postural control outcome measures. Least square mean and 1± SEM are indicated.

1.4.2.7 Interaction Effects of Experimental Sleep Condition and Touch Conditions on Postural Control Measures

In the next step, the interaction effects between sleep protocol and haptic conditions (with light touch vs no touch) on various postural control measures was investigated, including Circumference, Ellipse Area, Path Length, Postural Control VAS, Sample Entropy X, and Sample Entropy Y (Figure 19).

In the analysis of **Circumference** and **Ellipse Area**, the haptic Condition demonstrated a highly significant main effect ($p<0.0001$ for both), indicating that different levels of haptic Condition have a substantial impact on these variables. However, the interaction effects between Protocol and haptic Condition were not significant ($p=0.89$ and $p=0.83$ respectively), signifying that the impact of haptic Condition on these variables is consistent across different Protocols.

The **Path Length** variable presents an intriguing narrative, where not only is the main effect of haptic Condition highly significant ($F(1,37)=456$, $p<0.0001$), but the interaction effect between Protocol and haptic Condition is also significant ($F(1,37)=4.1$, $p=0.04$). This suggests that the effect of haptic Condition on Path Length is modulated by the level of Protocol, revealing a complex interplay between

these two factors that warrants further exploration and analysis to interpret the specific conditions or levels at which this interaction is most pronounced.

In the examination of **Postural Control VAS**, while the haptic Condition elucidates a highly significant main effect ($F(1,37)=19$, $p<0.0001$), the interaction effect between Protocol and haptic Condition borders on the brink of significance ($F(1,37)=3.08$, $p=0.07$). This borderline significance suggests a potential trend or pattern that might be valuable to explore in future research.

Sample Entropy X unveils a significant interaction effect between Protocol and haptic Condition ($F(1,37)=5.2$, $p=0.02$), indicating that the influence of Touch Condition on Sample Entropy X is greater in the sleep restriction condition as compared to the multinap condition (Figure 19 left bottom panel). This interaction, combined with the highly significant main effect of Touch Condition ($F(1,37)=36$, $p<0.0001$), suggests a complex relationship between these factors in influencing Sample Entropy X.

Conversely, variables like **Sample Entropy Y**, **Path Length x Ellipse Area**, and **Path Length x Circumference** demonstrated highly significant main effects of Touch Condition ($p<0.0001$ for all), with no significant interaction effects, indicating a stable and consistent influence of haptic Condition across different Protocols.

These findings highlight the complex interplay between sleep protocol, haptic condition, and postural control. The significant interaction effects observed for several measures suggest that the impact of sleep experimental protocol on these aspects of postural control is not constant but changes depending on whether tactile feedback is present.

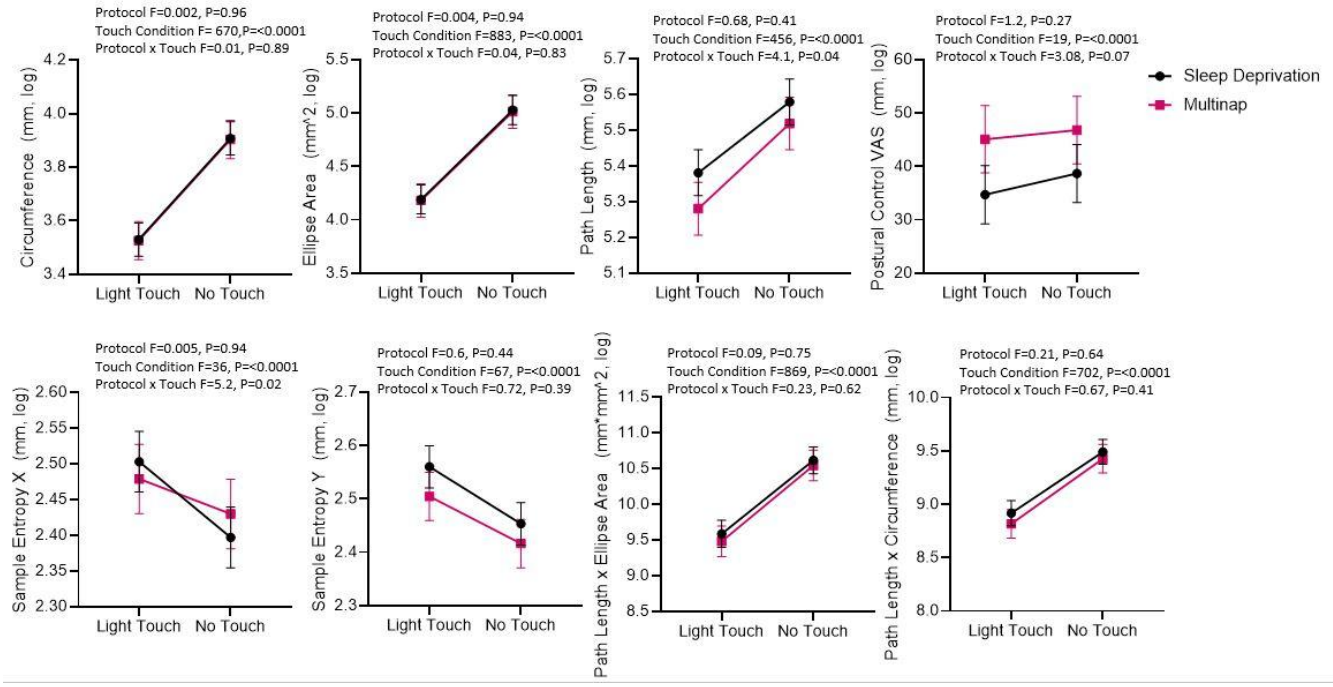


Figure 19. Main effects and interactions effects of experimental sleep condition (i.e., Protocol) and sensorial haptic feedback on postural control outcome measures. Least square mean and 1± SEM are indicated.

1.4.2.8 Interaction Effects of Experimental Sleep Condition and both Sensorial Feedback Conditions on Postural Control Outcome Measures

This study further explored the three-way interaction effects between sleep protocol, visual conditions (eyes open or closed), and haptic conditions (with light touch or no touch) on various postural control measures, including Circumference, Ellipse Area, Path Length, Sample Entropy X, and Sample Entropy Y (Figure 20).

The outcome measure **Circumference** showcased highly significant main effects for visual Condition ($F(1,37)=106$, $p<0.0001$) and haptic Condition ($F(1,37)=670.4$, $p<0.0001$), indicating that these sensorial feedback conditions independently exert a substantial influence on Circumference. However, the interaction effect between Protocol, visual Condition, and haptic Condition was not significant ($F(1,36)=0.34$, $p=0.55$), suggesting that the influence of visual and haptic Conditions on Circumference does not depend on the level of Protocol.

A similar narrative is observed in **Ellipse Area**, where visual Condition ($F(1,37)=80$, $p<0.0001$) and haptic Condition ($F(1,37)=883$, $p<0.0001$) manifest as highly significant main effects, yet the three-way interaction between sleep experimental protocol, visual condition, and haptic condition does not achieve significance ($F(1,36)=0.32$, $p=0.56$).

Path Length also revealed highly significant main effects for visual Condition ($F(1,37)=470$, $p<0.0001$) and haptic Condition ($F(1,37)=456$,$P<0.0001$), without a significant interaction effect ($F(1,36)=0.21$, $p=0.64$), denoting a consistent impact of visual and haptic Conditions across varying sleep experimental protocols.

The **Sample Entropy X** variable demonstrated significant main effects for visual Condition ($F(1,37)=12$, $p=0.0004$) and haptic Condition ($F(1,37)=36$, $p<0.0001$), but the interaction effect hovered on the brink of significance ($F(1,36)=2.7$, $p=0.09$). This borderline significance might suggest a potential trend or pattern.

Similarly, for **Sample Entropy Y**, despite the highly significant main effects of visual Condition ($F(1,37)=29$, $p<0.0001$) and haptic Condition ($F(1,37)=67$, $p<0.0001$), the interaction effect did not reach significance ($F(1,36)=0.94$, $p=0.33$), again indicating that the impact of visual and haptic conditions remains consistent across different sleep experimental protocols.

These findings underscore the complex interplay between sleep protocol, visual condition, haptic condition, and postural control. The significant three-way interaction effects observed for several

measures suggest that the impact of sleep protocol on these aspects of postural control is not constant but changes depending on both visual and haptic conditions.

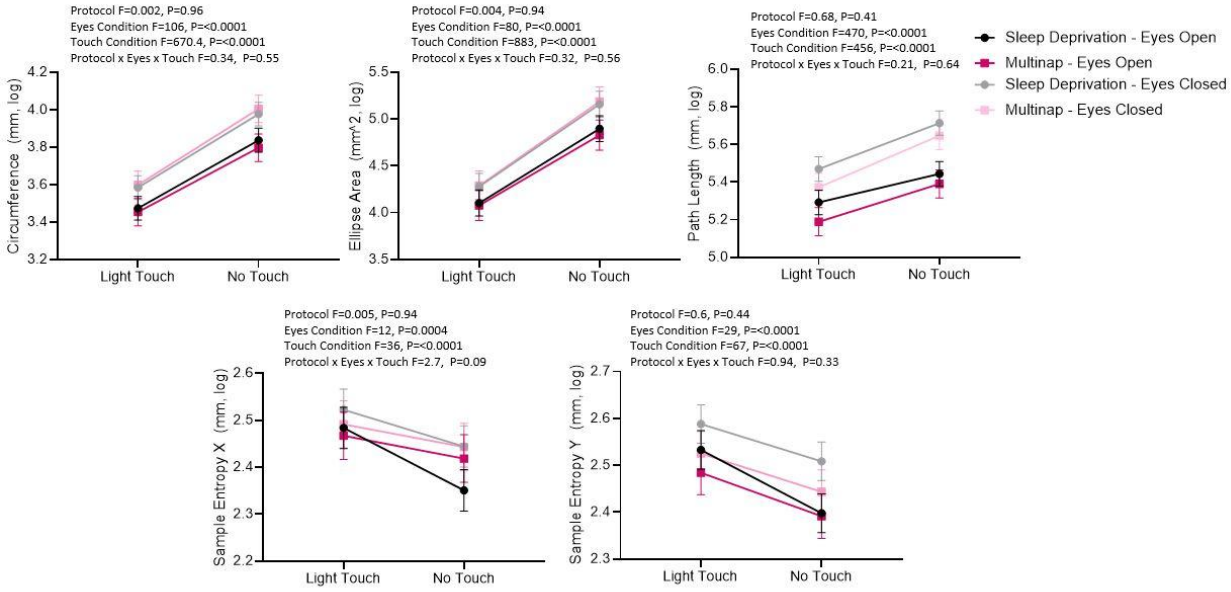


Figure 20. Main effects and three-way interaction of experimental sleep condition (i.e., Protocol), sensorial visual and haptic feedback on postural control outcome measures. Results for the two-way interactions are not displayed although they were included in the model. Least square mean and 1± SEM are indicated.

1.4.2.9 Interaction Effects of Experimental Sleep Condition, Time of Day, and Eye Conditions on Postural Control Measures

In the next step, an investigation was made to explore the three-way interaction effects between sleep protocol, time of day (represented by test numbers), and visual conditions (eyes open or closed) on various postural control measures. These measures included Circumference, Ellipse Area, Postural Control VAS (a subjective measure of postural control difficulty), and Sample Entropy Y (Figure 21).

Circumference and Ellipse Area both demonstrated highly significant main effects for visual Condition ($F(1,37)=106$, $p<0.0001$ and $F(1,37)=80.61$, $p<0.0001$ respectively), indicating a substantial influence of visual Condition on these variables. However, the interaction effects between visual Condition and time of the day were not significant for either variable, suggesting that the impact of visual Condition remains stable across various levels of time of the day.

In the analysis of Postural Control VAS, the main effects of eye condition and time of the day were both highly significant ($F(1,37)=218$, $p<0.0001$ and $F(1,37)=5.44$, $p<0.0001$ respectively), indicating a noteworthy influence of both these factors. The non-significant interaction effect indicates that these influences are independent of each other, with each factor exerting its effect regardless of the level of the other.

Similarly, Sample Entropy Y revealed a highly significant main effect for visual Condition ($F(1,37)=29.38$, $p<0.0001$) without a significant interaction effect, denoting a consistent influence of Eyes Condition across varying time of the day levels.

In the exploration of interaction variables, Path Length x Circumference and Path Length x Ellipse Area, Eyes Condition emerged as a highly significant main effect ($F(1,37)=281$, $p<0.0001$ and $F(1,37)=180$, $p<0.0001$ respectively), with non-significant interaction effects, underscoring the stable and pronounced influence of visual Condition on these variables across different time of the day levels.

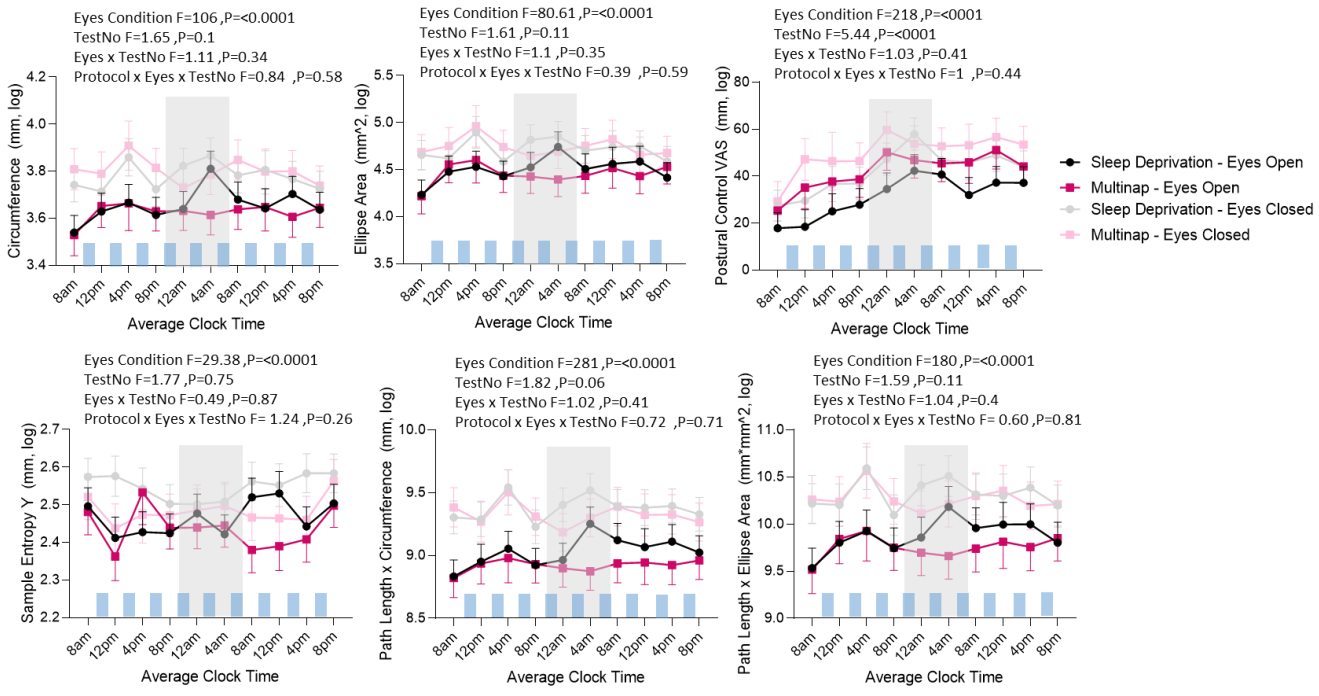


Figure 21. Main effects and interactions of experimental sleep condition (i.e., Protocol), time of the day (i.e., TestNo) and sensorial visual feedback on postural control outcome measures. Results for the two-way interactions are not displayed although they were included in the model. Grey shaded are indicates the circadian night. Light blue horizontal bars indicate nap opportunities in the multinap condition. Least square mean and 1± SEM are indicated.

1.4.2.10 Effects on Visuo-Motor Coordination with Implications for Sensorimotor Integration

1.4.2.10.1 Effect of Experimental Sleep Condition on Sensorimotor Integration Measured by a Visuo-motor Coordination Task

In the next step, the study examined whether the experimental sleep condition (i.e., protocol) influenced performance on another task that, similar to postural control, requires sensorimotor integration. This task, the pursuit tracking test, measures visuo-motor coordination and assesses an individual's ability to integrate visual information with motor control. As the participant had to chase a target moving along a circular trajectory with a constant speed on the screen (please see methods for details) the analysis focused on measures related to the time spent on target and deviation from the target measured in pixels for both dominant (1) and non-dominant (2) hands (Figure 22). In this analysis the lateralization (dominant vs non-dominant hand) was not included in the multivariate model but treated as separate dependent variable. Results indicated that, in line with expectations, performance with the dominant hand was superior to that with the non-dominant hand. Consequently, as expected, it was anticipated that the non-dominant hand would exhibit greater sensitivity to the effects of sleep loss compared with the dominant hand.

And indeed, the study found a significant main effect of experimental conditions on the visuo-motor coordination performance of the non-dominant hand. Both time on target ($F(1,36)=5.09$, $p=0.03$) and deviation from the target ($F(1,36)=5.62$, $p=0.02$), were significant indicating that pursuit tracking performance was compromised by sleep deprivation in the non-dominant hand.

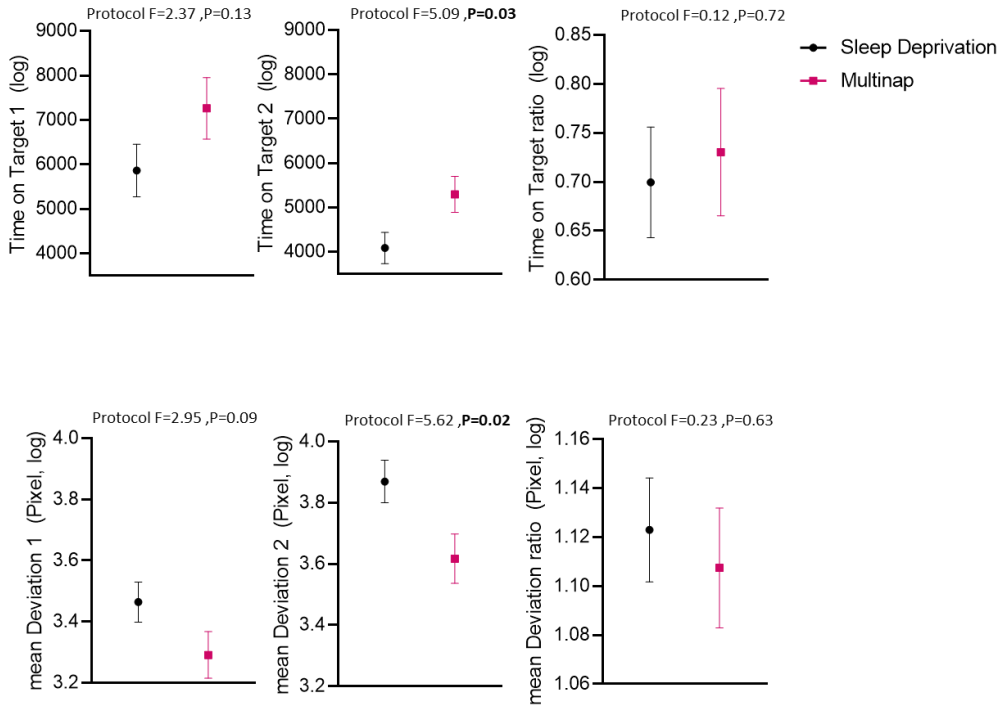


Figure 22. Main effect of experimental sleep condition on pursuit tracking performance. Performance was measured for both the dominant (1) and non-dominant hand (2). Least square mean and 1± SEM are indicated. Protocol refers to the experimental sleep condition.

1.4.2.10.2 Interaction Effects of Experimental Sleep Condition and Time of Day on Pursuit Tracking Test Measures

As presented above, the study further investigated the interaction effects between sleep protocol and time of day (represented by test numbers) on various pursuit-tracking test measures as well. These measures included Time on Target 1 and Cursor Deviation from Target 1 (representing trials with the dominant hand), and Time on Target 2 and Cursor Deviation from Target 2 (representing trials with the non-dominant hand) (Figure 23).

There were multiple measures indicating a main effect of the time of the day suggesting a gradual improvement in performance throughout the time spent on either protocol (e.g. mean deviation 1 and 2).

While the Target 1 showed a non-significant interaction effect between sleep protocol and time of day, for 'Time on Target 2,' there was a non-significant trend towards an interaction effect ($F(9,333)=1.8$, $p=0.06$) suggesting that pursuit tracking performance with the non-dominant hand gradually improved throughout the time spent in the laboratory in the multinap group but not in the sleep deprivation group. A similar but this time significant ($F(9,333)=2$, $p=0.03$) interaction was found for the mean deviation from

the target indicating that those in the multinap group improved their performance which was less true for those in the sleep deprivation group. This could be due to the effect of sleep (i.e., naps) on procedural memory consolidation).

These findings highlight the complex interplay between sleep protocol, time of day, and performance on the pursuit tracking test. The significant interaction effects observed for some measures suggest that the impact of sleep protocol on these aspects of performance is not constant but changes over the course of the day.

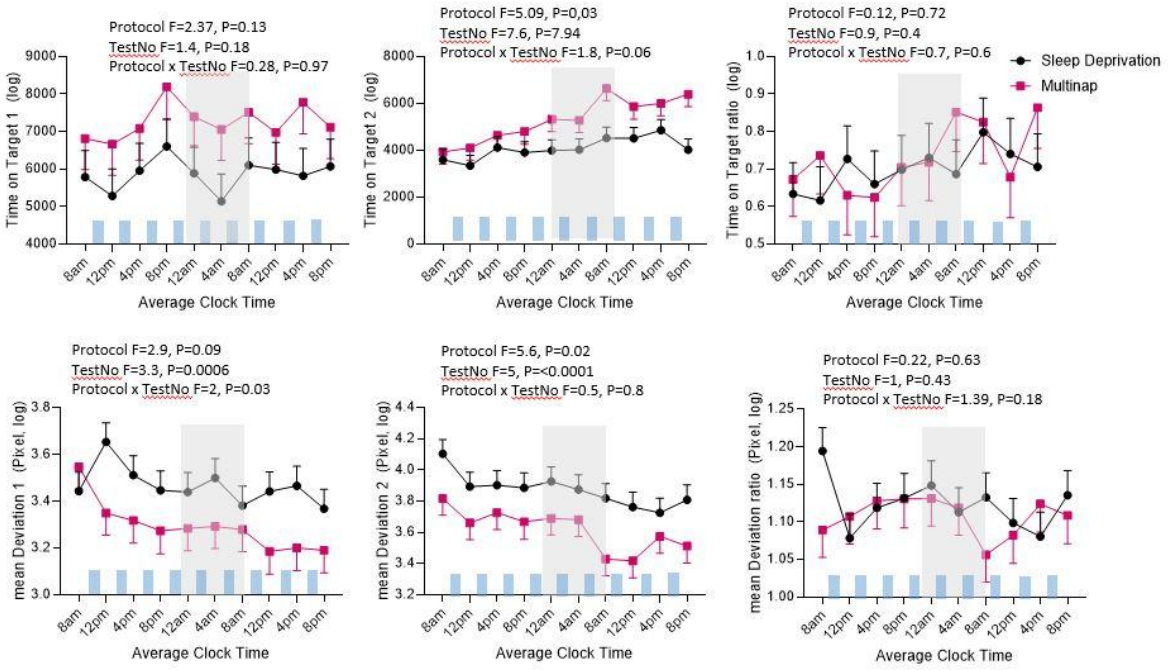


Figure 23. Main effects and interactions of sleep experimental condition (i.e., Protocol) and time of the day (i.e., TestNo) on pursuit tracking outcome measures. Grey shaded are indicates the circadian night. Light blue horizontal bars indicate nap opportunities in the multinap condition. Note: pursuit tracking variables time on target and mean deviation 1 = dominant hand, time on target and mean deviation 2 = non-dominant hand. Least square mean and 1± SEM are indicated.

1.4.2.11 Main Effect of Sex on Postural Control, Visuo-motor Coordination and Vigilance.

Given the cited differences in individual vulnerability to sleep loss, and the risk of falls (see chapter 1 section 1.1.1.6) between men and women in the next step it was investigated how sex modulates the studied outcome measures of sleepiness (KSS), vigilance (PVT), postural control (PC) and visuo-motor

coordination (i.e., pursuit tracking test) and the way they are influenced by experimental sleep, time of the day and sensorial conditions. This analysis uncovered several notable findings.

Interestingly, while neither subjective (KSS) nor objective vigilance (PVT) showed a significant sex main effect, PC as estimated by the circumference (F(1,36)=8.2, p=0.007), the ellipse area (F(1,36)=6.9, p=0.01) and the composite variables including both *path length*ellipse area* (F(1,36)=6.14, p=0.01) and *path length*circumference* (F(1,36)=5.8, p=0.02), all showed a significant sex differences with men presenting lower balance control performance compared to women (Figure 24).

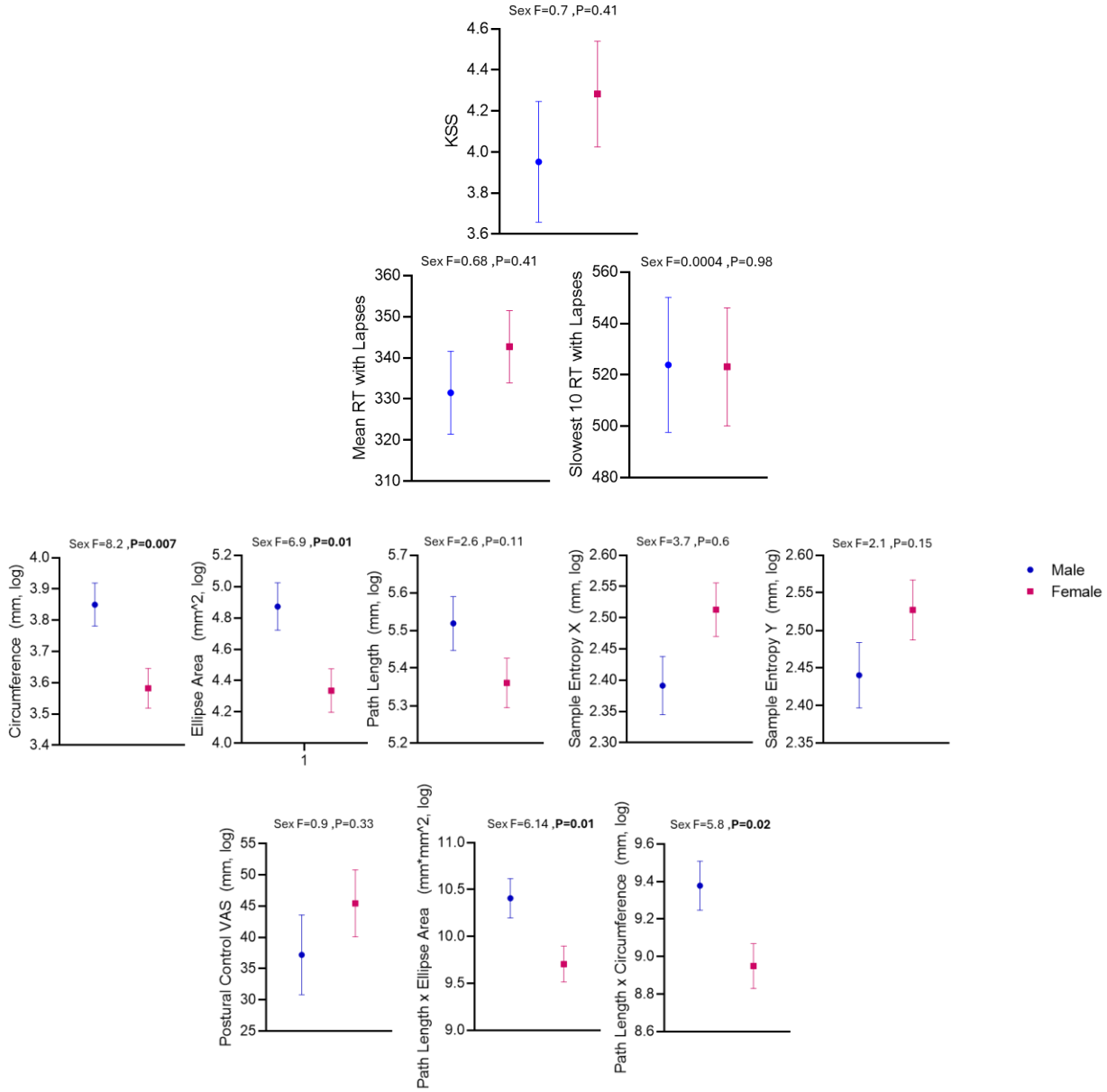


Figure 24. Main effect of sex on postural control, KSS and PVT outcome measures. Least square mean and 1±SEM are indicated.

In further exploration of sex effects on visuo-motor coordination the pursuit tracking cursor deviation from target 1 (dominant hand) exhibited a significant sex difference, with men demonstrating better performance (i.e. less deviation from the target) compared to women (F(1,36)=5.73, p=0.02). However, no sex difference was observed for the non-dominant hand or for either hand in the other outcome measure (i.e., Time on target) (Figure 25).

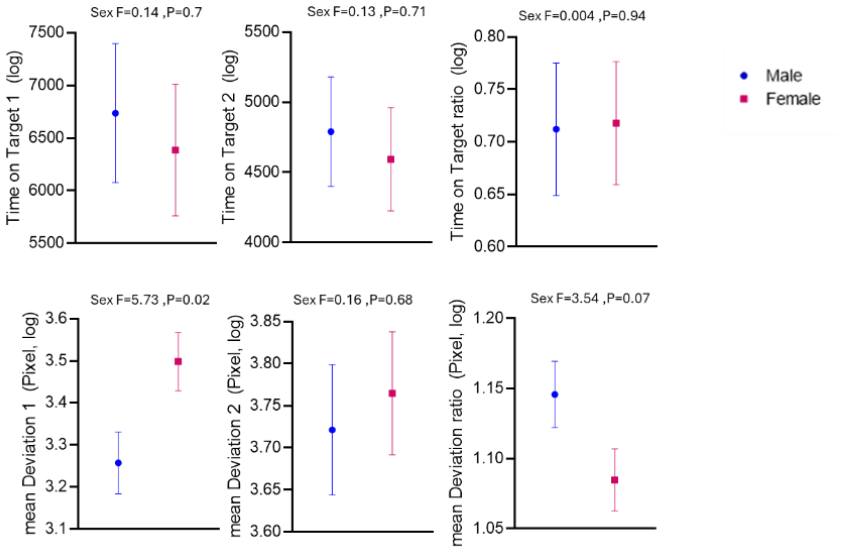


Figure 25. Main effect of sex on pursuit tracking outcome measures. Least square mean and 1±SEM are indicated.
Note: pursuit tracking variable time on target and mean deviation 1 = dominant hand, time on target and mean deviation 2 = non-dominant hand.

In conclusion, the analysis reveals significant sex differences in multiple postural control variables clearly indicating a better postural control performance in women as compared to men despite a marginal superiority of man in visuomotor coordination when using their dominant hand and no sex difference in either subjective or objective vigilance.

1.4.2.12 Interaction between Sex and Experimental Sleep Condition on Postural Control Measures

In a next step it was investigated whether sex modulated the effect of experimental sleep condition. For this a two-way ANOVA was used including factors *experimental sleep condition* and *sex*. While there was no significant main effect of experimental sleep condition nor a significant interaction between sex and experimental sleep condition there was a significant main effect of sex on multiple

outcome measures of PC. The results (Figure 26) indicated that man performed significantly worse compared to women independent of the experimental condition.

For circumference, a significant main effect was found for sex ($F(1,36)=8.2$, $p=0.007$), while the sleep protocol did not yield a significant effect ($F(1,36)=0.002$, $p=0.96$). Additionally, the interaction between sex and sleep protocol did not reach statistical significance ($F(1,36)=0.54$, $p=0.46$).

Similarly, the ellipse area displayed a significant main effect for sex ($F=6.9$, $p=0.01$) but not for the sleep protocol ($F(1,36)=0.004$, $p=0.94$). The interaction between these two factors was not significant ($F(1,36)=0.47$, $p=0.49$).

In terms of path length, neither sex ($F(1,36)=2.6$, $p=0.11$) nor the sleep protocol ($F(1,36)=0.68$, $p=0.41$) showed a significant main effect. Moreover, the interaction between sex and sleep protocol was not significant ($F(1,36)=0.01$, $p=0.89$).

Postural control VAS also did not display any significant main effects for either sex ($F(1,36)=0.9$, $P=0.33$) or the sleep protocol ($F(1,36)=1.2$, $p=0.27$). The interaction between sex and sleep protocol was not significant ($F(1,36)=1.6$, $p=0.2$).

For sample entropy x, the sleep protocol did not yield a significant main effect ($F(1,36)=0.005$, $p=0.94$), nor did the interaction between sex and sleep protocol reach significance ($F(1,36)=1.3$, $p=0.25$). The main effect for sex was borderline significant ($F(1,36)=3.7$, $p=0.06$).

Sample entropy y did not show significant main effects for either sex ($F(1,36)=2.1$, $p=0.15$) or the sleep protocol ($F(1,36)=0.6$, $p=0.44$). The interaction between sex and sleep protocol was not significant ($F(1,36)=0.28$, $p=0.59$).

For the interaction of path length with ellipse area, the study has found a significant main effect for sex ($F(1,36)=6.1$, $p=0.01$), but not for the sleep protocol ($F(1,36)=0.09$, $p=0.75$). The interaction between sex and sleep protocol was not significant ($F(1,36)=0.21$, $p=0.64$).

Finally, for path length's interaction with circumference, a significant main effect was observed for sex ($F(1,36)=5.8$, $p=0.02$), but not for the sleep protocol ($F(1,36)=0.21$, $p=0.64$). The interaction was not significant ($F(1,36)=0.11$, $p=0.73$).

In summary, sex exhibited significant effects on several postural control variables (specifically, circumference, ellipse area, and the interactions of path length with both ellipse area and circumference), with men demonstrating poorer postural control compared to women, independent of sleep deprivation

condition. However, the sleep protocol did not significantly impact any of the postural control variables. Moreover, the interaction between sex and sleep protocol did not significantly affect any postural control variables. These findings suggest that while sex plays a role in postural control while the sleep experimental protocol does not.

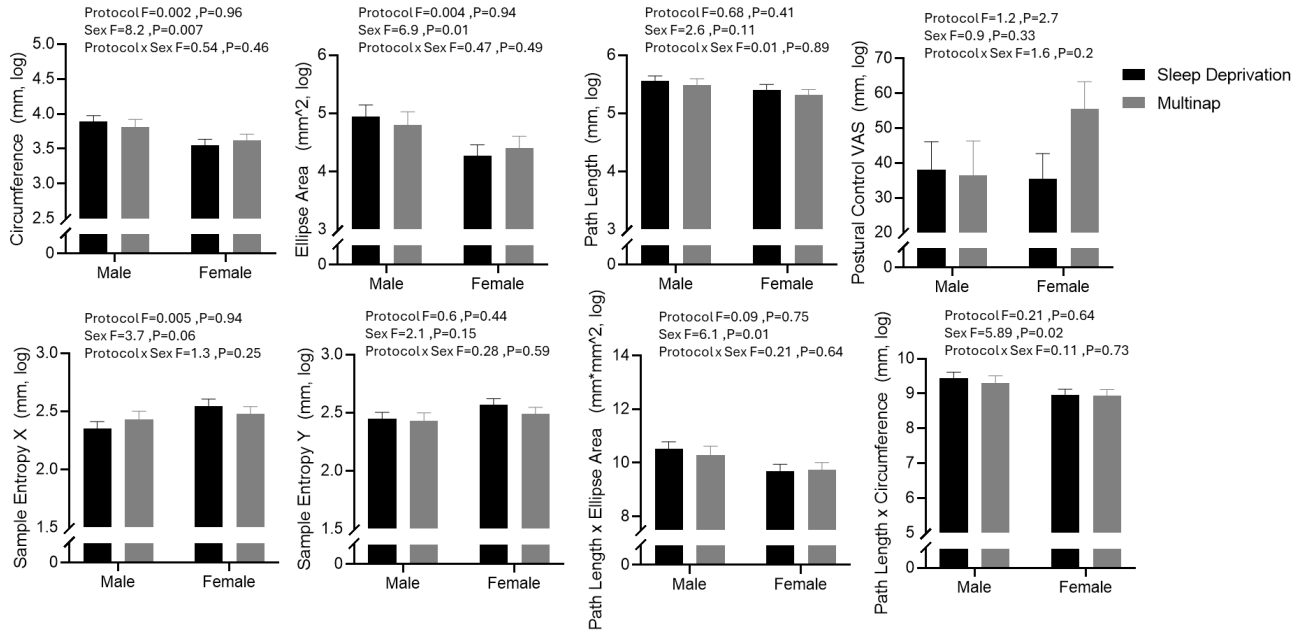


Figure 26. Main effects and two-way interaction of sex and experimental sleep condition on postural control outcome measures. Least square mean and 1± SEM are indicated. Protocol refers to the experimental sleep condition.

1.4.2.13 Interaction between Sex, Experimental Sleep Condition and Time of the Day

To test whether sex modulated the combined effects of sleep protocol and time of day, a three-way ANOVA was conducted with factors Protocol, Sex, and Test number. Overall, sex consistently showed significant main effects on multiple postural control outcomes, whereas sleep protocol did not. Evidence for interactions was limited, with the exception of sample entropy in the Y direction.

Circumference, sleep protocol had no effect, ($F(1, 36) = 0.002$, $p = 0.96$) Sex showed a significant effect ($F(1, 36) = 8.2$, $p = 0.007$), with men performing worse than women. Test number was not significant ($F(3, 111) = 1.6$, $p = 0.10$). The three-way interaction was not significant ($F(3, 111) = 0.57$, $p = 0.81$).

Ellipse area, no effect of protocol was found ($F(1, 36) = 0.004$, $p = 0.94$). Sex showed a significant effect ($F(1, 36) = 6.9$, $p = 0.01$). Test number was not significant ($F(3, 111) = 1.6$, $p = 0.11$), and the three-way interaction was not significant ($F(3, 111) = 0.65$, $p = 0.75$).

Postural Control VAS, no main effects of protocol ($F(1, 36) = 1.2$, $p = 0.27$), or sex ($F(1, 36) = 0.9$, $p = 0.33$), were found. A strong effect of test number was observed ($F(3, 111) = 5.4$, $p < 0.001$), with perceived difficulty increasing across the session. The three-way interaction was not significant ($F(3, 111) = 0.68$, $p = 0.72$).

Sample entropy Y, protocol was not significant, ($F(1, 36) = 0.6$, $p = 0.44$). Sex was not significant, ($F(1, 36) = 2.1$, $p = 0.15$). Test number approached significance ($F(3, 111) = 1.7$, $p = 0.07$). A significant three-way interaction was found ($F(3, 111) = 1.9$, $p = 0.04$), indicating that women exhibited greater entropy than men under the sleep deprivation condition, particularly during the first half of the laboratory session (Figure 27, bottom left panel).

Composite measures, for Path length × Circumference, protocol was not significant ($F(1, 36) = 0.09$, $p = 0.75$), nor was test number ($F(3, 111) = 1.5$, $p = 0.11$). Sex showed a significant effect ($F(1, 36) = 6.1$, $p = 0.01$). The three-way interaction was not significant ($F(3, 111) = 0.68$, $p = 0.71$). For Path length × Ellipse area, protocol was not significant ($F(1, 36) = 0.21$, $p = 0.64$). Sex showed a significant effect ($F(1, 36) = 5.8$, $p = 0.02$). Test number approached significance, ($F(3, 111) = 1.8$, $p = 0.06$). The three-way interaction was not significant ($F(3, 111) = 0.6$, $p = 0.70$).

In summary, the findings underscore that sex consistently influenced various postural control metrics mostly independent of the experimental condition and time of the day, while the sleep experimental protocol typically had minimal impact only. Notably, the time of testing (or test number) displayed significance in measures like Postural Control VAS with the perceived difficulty of maintaining postural control increasing during the time spent in the laboratory in either experimental condition. Interestingly the complexity signal (i.e., entropy) of CoP dynamics showed a three-way interaction with marked sex differences in the first part of the protocol and the SD experimental condition only. This suggests that during a normal day without naps the vulnerability of postural control is greater in men in the evening hours prior to habitual sleep.

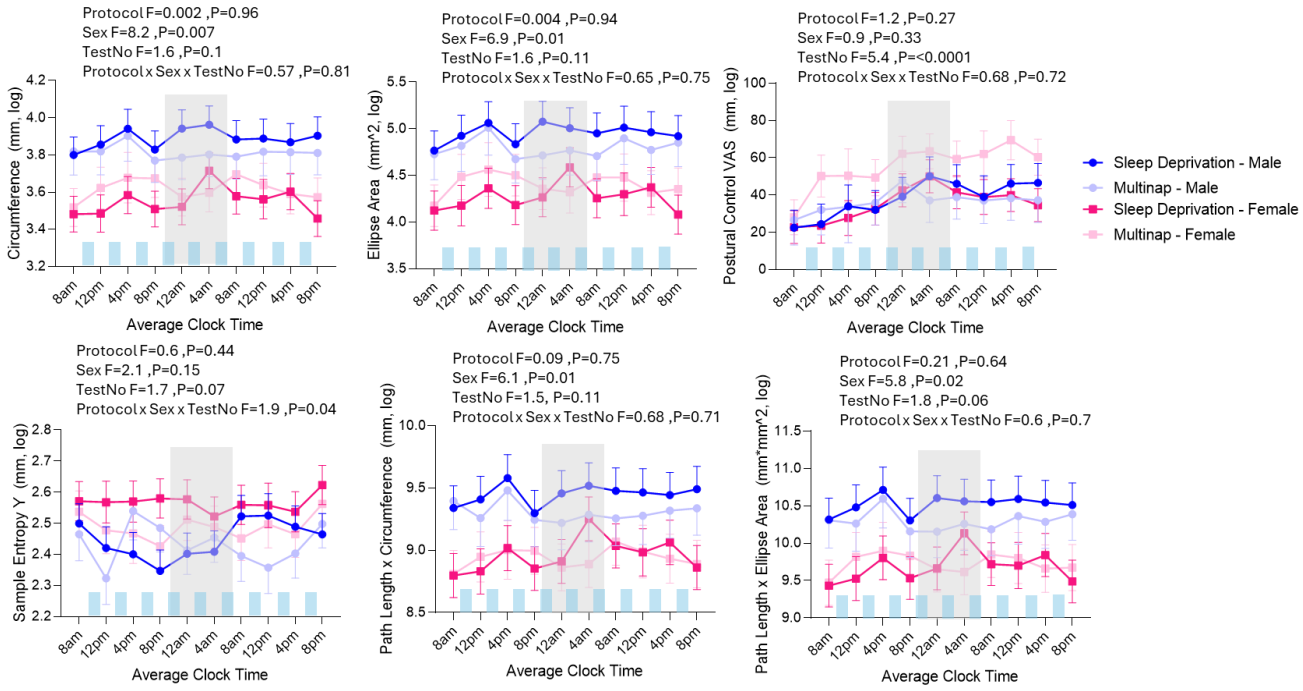


Figure 27. Main effects and interactions of sex, experimental sleep condition (i.e., Protocol) and time of the day (i.e., TestNo) on postural control outcome measures. Least square mean and 1± SEM are indicated. Results for the two-way interactions are not displayed although they were included in the model. Grey shaded are indicates the circadian night. Light blue horizontal bars indicate nap opportunities in the multinap condition.

1.4.2.14 Interaction between Sex, Experimental Sleep Condition and Eye Conditions

This study data suggests that participants in the multinap group exhibited better postural control than those in the sleep deprivation group across both eye and touch conditions. The sex difference in postural control was only observed in the eye-open condition, while no significant sex difference was detected in the eye-closed condition.

These findings indicate that sleep deprivation can negatively impact postural control, with the visual system playing a significant role. The effect of sleep deprivation appears less pronounced when eyes are closed, likely due to the compensatory role of other sensory systems, such as the vestibular system.

Interestingly, this study also suggested that sex may play a role in postural control. Under eye-open conditions, females exhibited poorer postural control than males. However, no significant sex difference was observed in the eye-closed condition. This hints at the possible greater reliance of females on the visual system for postural control.

Upon examining the three-way interactions between sex, sleep protocol, and visual conditions on postural control variables, the study observed significant findings across several variables:

In the context of **Circumference**, **Ellipse Area**, **Postural Control VAS**, **Path Length x Circumference**, and **Path Length x Ellipse Area**, the main effect of Eye Conditions consistently emerged as highly significant ($P<0.0001$ across all variables), indicating a pronounced influence on these postural control measures. However, the Protocol did not show significant main effects in these contexts, suggesting its impact on these variables is not substantial when considered independently.

The main effect of **Sex** revealed significance in influencing Ellipse Area ($F(1,36)=6.9$, $p=0.01$) and Path Length x Circumference ($F(1,36)=6.1$, $p=0.01$), suggesting that sex might exert a differential influence on these variables.

The three-way interaction effect between Protocol, Sex, and visual conditions displayed as significant across multiple variables: Circumference ($F(1,37)=5.3$, $p=0.02$), Ellipse Area ($F(1,37)=5.7$, $p=0.01$), Postural Control VAS ($F(1,37)=5.9$, $p=0.01$), and Path Length x Circumference ($F(1,37)=5.4$, $p=0.02$) and Path Length x Ellipse Area ($F=4.9$, $p=0.02$). This suggests a complex, interdependent relationship between these three factors in influencing these postural control measures, whereby the effect of one factor might depend on the level of the others.

However, in the context of **Sample Entropy Y**, while the main effect of visual condition was highly significant ($F(1,37)=29$, $p<0.0001$), the three-way interaction was not significant ($F(1,37)=1.8$, $p=0.18$), indicating that the influence of visual condition on Sample Entropy Y remains consistent across varying levels of sleep experimental protocol and sex.

The findings reveal significant effects of the three-way interaction between sleep protocol, sex, and visual condition on several postural control variables. This underscores a complex interplay between these factors, with significant main effects observed for eye condition and sex across multiple variables. In contrast, sleep protocol did not significantly affect any of the postural control variables (Figure 28).

Men perform much worse than women when they are sleep deprived particularly in the open eyes sensorial feedback condition. The differences disappear in the multinap group where men and women performed similarly but the effect of eye condition is still present. Therefore, the effect of sleep deprivation on healthy adults is modulated by both the sex and sensorial feedback with implications that men are at increased risk of falls when having sleep disturbances and particularly if they rely on visual input in a dim lit environment.

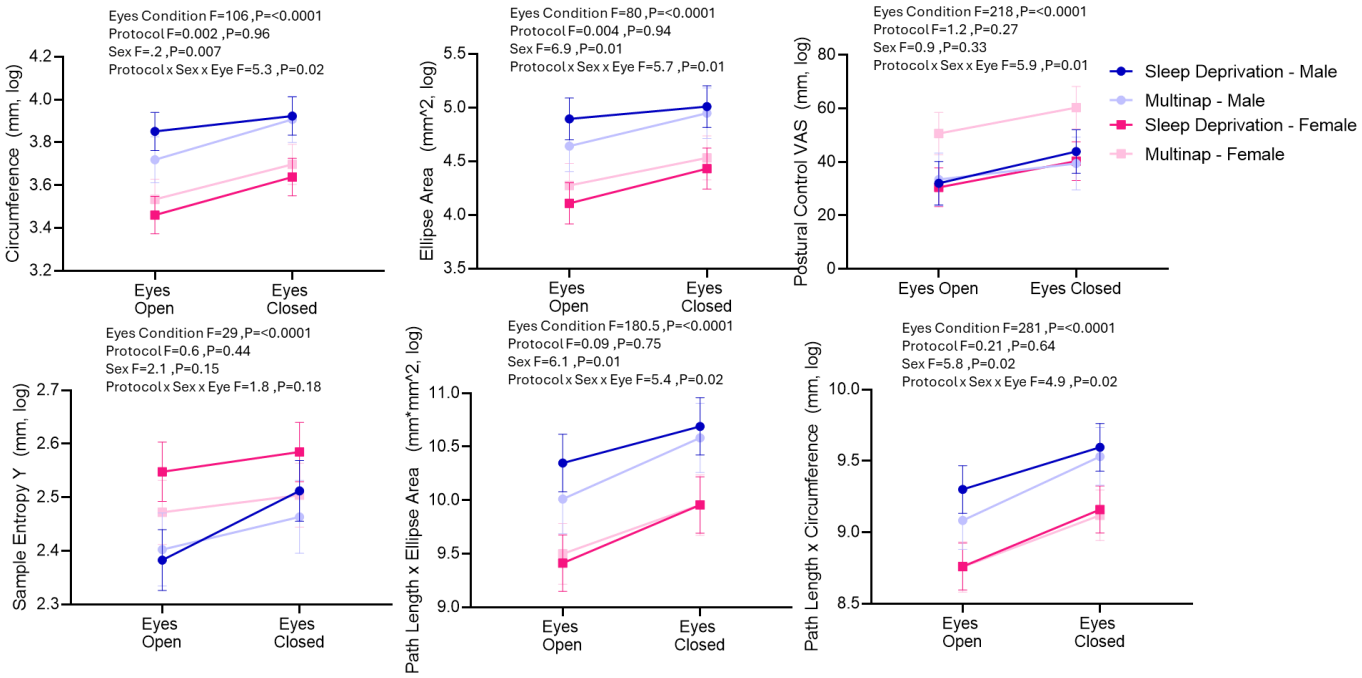


Figure 28. Main effects and interactions of sex, experimental sleep condition and sensorial visual feedback on postural control outcome measures. Least square mean and 1± SEM are indicated. Protocol refers to the experimental sleep condition.

1.4.2.15 Effect of Sex, Experimental Sleep Condition, and Sensorial Feedback

During the analysis, significant differences in postural control were observed based on the haptic condition to which participants were subjected. Specifically, there was a statistically significant main effect of the haptic condition across all postural control variables. Participants subjected to the light haptic condition showcased reduced circumference and ellipse area, decreased sample entropy *y*, and enhanced postural control VAS scores compared to those in the no haptic condition. This was further confirmed by the extremely high F-values and a consistent $p<0.0001$ across all postural control variables.

In contrast, the sleep protocol, which included both sleep deprivation and multinap conditions, did not appear to influence postural control in a statistically significant manner. All associated p-values for these conditions were above 0.05, suggesting that the type of sleep protocol did not directly impact postural control outcomes.

Furthermore, sex dynamics played a noticeable role in the postural control outcomes. Female participants consistently registered higher postural control VAS scores than their male counterparts. Additionally, a modest but statistically significant effect of sex was identified on the circumference, ellipse area, and pathlength measures, with the associated p-values for these metrics ranging between 0.01 and 0.02.

Exploring the complex interaction between haptic condition, sleep protocol, and sex, the results indicated a non-significant three-way interaction for the majority of the postural control variables. However, an exception was observed for the postural control VAS, which yielded a p=0.01. This suggests that the confluence of sex, touch condition, and sleep protocol potentially affected participants' subjective ratings of difficulty, even though it did not influence objective sway measures (Figure 29).

In conclusion, the results underscore the importance role of the light touch condition in influencing postural stability. While sex exhibited moderate effects on certain metrics, the sleep deprivation protocol remained inconsequential in shaping the outcomes.

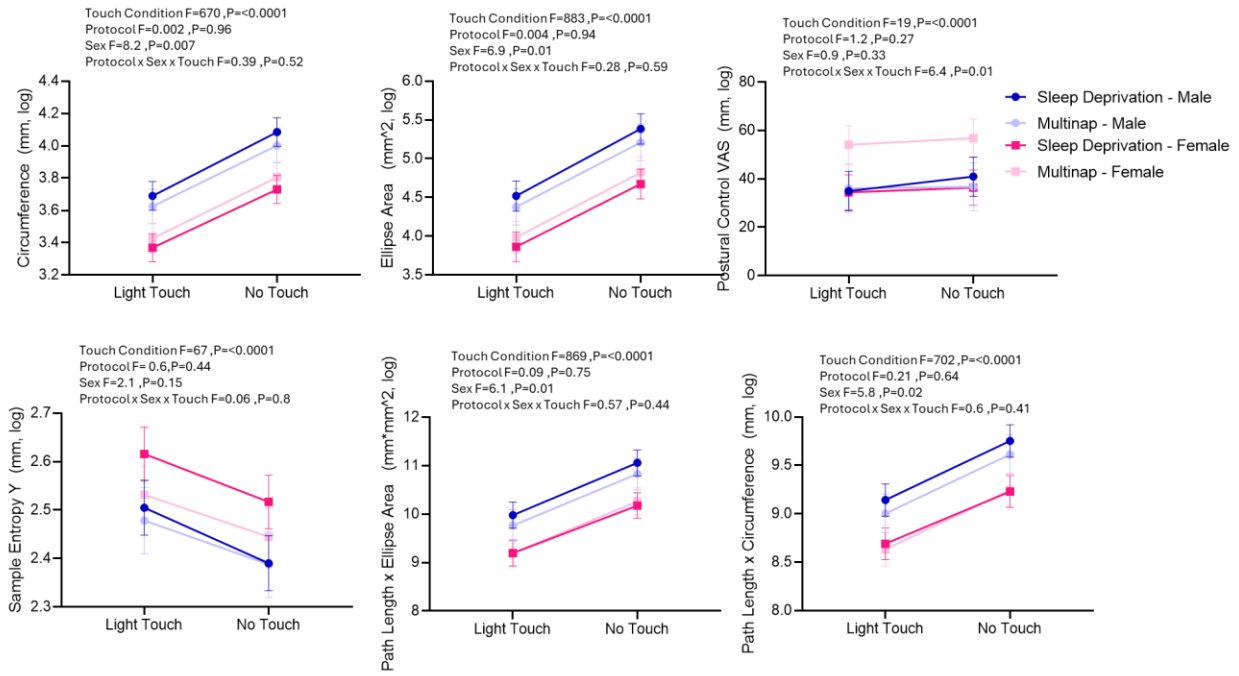


Figure 29. Main effects and interaction of sex, experimental sleep condition and sensorial haptic feedback on postural control outcome measures. Least square mean and 1± SEM are indicated. Protocol refers to the experimental sleep condition.

1.4.2.16 The Effect of Sex on Postural Control and its Interaction with the Sensorial Feedback Conditions

Given the reports on sex differences in the risk of falls in older adults, it was evaluated whether sex had an effect on postural control and whether this effect was independent or influenced by the sensorial feedback condition independent of sleep condition (i.e., protocol).

1.4.2.16.1 The Effect of Sex on Postural Condition and its Interaction with Visual Feedback

Based on a two-way ANOVA including factors sex and visual conditions (open or closed) multiple significant effects were observed on various postural control variables (Figure 30).

For the postural control variable of circumference, there was a significant main effect for both visual condition ($F(1,37)=106$, $p<0.0001$) and sex ($F(1,36)=8.2$, $p=0.007$) indicating that open eyes and female sex had a positive impact on postural control (PC). However, the interaction between visual condition and sex was not significant ($F(1,37)=2.09$, $p=0.14$).

The ellipse area similarly displayed a significant main effect for visual condition ($F(1,37)=80$, $p<0.0001$) and sex ($F(1,36)=6.9$, $p=0.01$), with no significant interaction between the two ($F(1,37)=2.3$, $p=0.12$).

In terms of path length, a significant main effect was noted for visual condition ($F(1,37)=470$, $p<0.0001$), while sex ($F(1,36)=2.6$, $p=0.11$) and the interaction between visual condition and sex ($F(1,37)=2.1$, $p=0.14$) were not significant.

For postural control VAS, a significant main effect for visual condition ($F(1,37)=218$, $p<0.0001$) was found, but there were no significant effects for sex ($F(1,36)=0.9$, $p=0.33$) or the interaction between visual condition and sex ($F(1,37)=0.43$, $p=0.51$).

Sample entropy x revealed significant main effects for visual condition ($F(1,37)=12$, $p=0.0004$) and a significant interaction between visual condition and sex ($F(1,36)=4.6$, $P=0.03$), but sex ($F(1,37)=3.7$, $p=0.06$) was not significant.

Sample entropy y demonstrated significant main effects for visual condition ($F(1,37)=29$, $p<0.0001$) and a significant interaction between visual condition and sex ($F(1,36)=6.7$, $p=0.009$), but not for sex ($F(1,37)=2.1$, $p=0.15$).

An additional composite measure of PC calculated as the product of Path length and Ellipse area indicated significant main effects for visual condition ($F=180.5$, $p<0.0001$) and sex ($F=6.1$, $p=0.01$), but the interaction between visual condition and sex was not significant ($F=0.38$, $p=0.53$).

Lastly, the product of Path Length and Circumference presented significant main effects for visual condition ($F(1,37)=281$, $p<0.0001$) and sex ($F(1,36)=5.8$, $p=0.02$), but the interaction was not significant ($F(1,37)=0.04$, $p=0.84$).

In summary, these findings show significant main effects of visual condition across all postural control variables indicating a net benefit of open eyes compared to closed eyes (Figure 30). Interestingly sex also demonstrated significant main effects on circumference, ellipse area, and the interaction of path length with both ellipse area etc. indicating that women had significantly better postural control than men. Significant interactions between eye condition and sex were seen in sample entropy along both axis (antero-posterior and medio-lateral) suggesting that the predictability of COP was lower in men and particularly in the opine eyes condition. However, the interaction did not significantly affect other postural control variables. This suggests that sex and sensorial feedback of visual conditions independently and

interactively influence postural control to varying degrees depending on the specific variable under consideration.

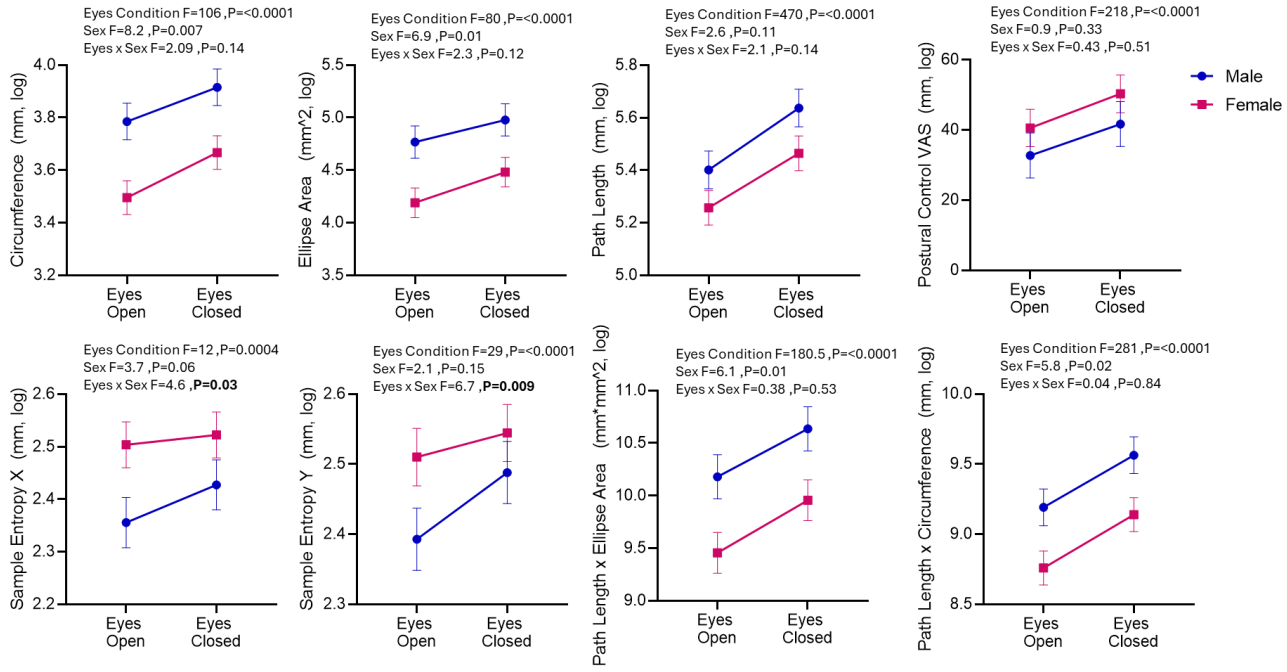


Figure 30. Main effects and interactions of sex and sensorial visual feedback on postural control measures. Least square mean and 1± SEM are indicated.

1.4.2.16.2 The Effect of Sex on Postural Condition and its Interaction with Tactile Feedback

In this examination of the two-way interactions between sex and sensorial feedback touch conditions (light touch or no touch), several salient findings emerged (Figure 31).

For circumference, a postural control variable, the study observed significant main effects for both sex ($F(1,36)=8.2$, $p=0.007$) and haptic condition ($F(1,37)=670$, $p<0.0001$) indicating the touch condition and being a female had a substantial positive impact on postural control. Yet, the interaction between sex and haptic condition was not significant ($F(1,37)=0.28$, $p=0.59$).

A similar pattern in the ellipse area was discovered. Both sex ($F(1,36)=6.9$, $p=0.01$) and haptic condition ($F(1,37)=883$, $p<0.0001$) showed significant main effects, but the interaction between these two factors was not significant ($F(1,37)=0.18$, $p=0.67$).

Regarding path length, the study found a significant main effect for the haptic condition ($F(1,37)=456$, $p<0.0001$), but sex ($F(1,36)=2.6$, $p=0.11$) and the interaction between the haptic condition and sex ($F(1,37)=0.81$, $p=0.36$) were not significant.

Postural control VAS revealed a significant main effect for haptic condition ($F(1,37)=19$, $p<0.0001$), but not for sex ($F(1,36)=0.9$, $p=0.33$) or the interaction between haptic condition and sex ($F(1,37)=0.67$, $p=0.41$).

For sample entropy x, the haptic condition showed a significant main effect ($F(1,37)=36$, $p<0.0001$). However, sex ($F(1,36)=3.7$, $p=0.06$) and the interaction between haptic condition and sex ($F(1,37)=1.7$, $p=0.18$) did not reach significance.

Sample entropy y demonstrated a significant main effect for haptic condition ($F(1,37)=67$, $p<0.0001$), but not for sex ($F(1,36)=2.1$, $p=0.15$) or the interaction between haptic condition and sex ($F(1,37)=0.16$, $p=0.68$).

Path length * ellipse area yielded significant main effects for sex ($F(1,36)=6.1$, $p=0.01$) and haptic condition ($F(1,37)=869$, $p<0.0001$), but the interaction between the two was not significant ($F(1,37)=0.44$, $p=0.5$).

Lastly, path length * circumference showed significant main effects for sex ($F(1,36)=5.8$, $p=0.02$) and haptic condition ($F(1,37)=702$, $p<0.0001$), but the interaction was not significant ($F(1,37)=0.65$, $p=0.41$).

In summary, haptic condition had a significant main effect across all postural control variables, while sex exhibited significant effects on circumference, ellipse area, and the interactions of path length with both ellipse area and circumference. The interaction between sex and haptic condition did not significantly affect any postural control variables. These findings suggest that sex and haptic condition both independently and interactively influence postural control, with the degree of influence varying depending on the specific variable considered (Figure 31).

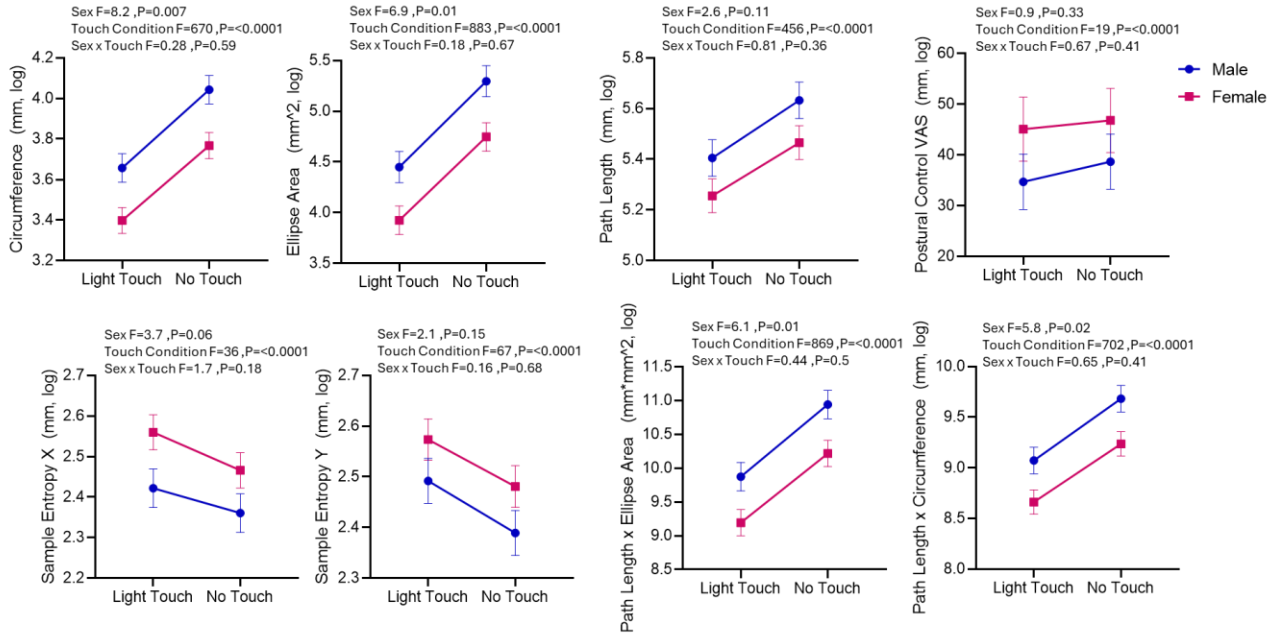


Figure 31. Main effects and interactions of sex and sensorial haptic feedback on postural control measures. Least square mean and 1± SEM are indicated.

Summary of Findings for Phase Two (Experimental Study)

The research examined the impacts of sleep restriction, time of the day (i.e., circadian rhythm), sensory feedback and sex on balance control and associated subjective effort and sensorimotor integration as measured by a visuo-motor coordination test in cognitively healthy older individuals. Thirty-eight volunteers (18 males, 20 females) experienced either a full night sleep deprivation or multiple short (i.e., 80 min) naps scheduled at 4-hourly intervals. The experimental protocol was successful in producing a differential effect on sleep pressure over time in the sleep restriction condition. This was supported by a significant increase in sleep pressure in the sleep restriction condition compared to the multinap condition and presented a modulation by the time of the day which by its profile suggested a circadian influence (e.g. higher sleepiness during the circadian night).

The sensorial feedback conditions had predictable effects on postural control in a way that stability was better in the light touch and the open eyes compared to the no-touch and closed eyes conditions. This was indicated by higher values on the conventional posturography metrics (e.g. ellipse area, circumferences etc.) and lower values on the sample entropy metrics inked to the dynamic of the center of pressure.

Sleep deprivation showed no significant main effect on any of the objective balance control or the subjective effort outcome measures; however, it modulated the effect of sex and sensorial feedback on balance control.

While the two sex groups did not differ in either subjective or objective vigilance there were marked differences across most studied outcome measures. Women showed better balance control across most objective postural control outcome measures compared to men but with no difference concerning subjective effort of balance control. Men appeared most affected in their balance control in the SD condition with visual feedback (i.e., open eyes) with no major sex differences in the multinap condition. Keeping eyes open and light touch conditions better postural stability in different ways; it decreases instability movements and makes maintaining equilibrium seem easier for participants. These effects remained consistent regardless of sleep state, with sensory inputs compensating for cognitive impairments irrespective of sleep conditions or time of day. Men relied more heavily on visual feedback to maintain balance, showing greater impairment when visual feedback was absent or during sleep deprivation.

The visuo-motor coordination performance, as measured by the pursuit tracking task, showed a significant main effect of the experimental condition with poorer performance on the non-dominant hand in the sleep deprivation condition. There were also interactions between sex and experimental sleep conditions. Men did better than women when using the dominant hand but with no marked differences seen in how long they could keep on target measures. Not getting enough sleep clearly had an adverse effect on performance with the non-dominant hand, which points to one-sided effects from lack of sleep on controlling movement.

The time of the day effects were not entirely conclusive as the predicted decline in performance during the circadian night was seen only in subjective measures like increased perceived instability and reduced alertness during sleep deprivation, while objective balance metrics (e.g., center-of-pressure measures) remained stable. Also, some of the outcome measures showed a gradual change over the time spent in the protocol, such as pursuit tracking performance with the non-dominant hand in the multinap group, which showed improvement over time, likely due to the effects of sleep on procedural memory consolidation. Moreover, results showed clear signs of circadian effects in the perceived difficulty levels and patterns of performance. Participants noted that they found it progressively harder to keep their balance as the study continued, especially those with sleep deprivation who experienced significant reductions in postural control due to circadian rhythm issues. However, using a method involving multiple naps seemed to slow down some of these declines, indicating its possible usefulness for maintaining thinking ability and physical strength.

The relationship between sensory feedback, sleep patterns, and sex showed more complexities. For example, men depended more on keeping their eyes open when deprived of sleep while women performed generally better. In tasks that needed tactile feedback, women kept better balance; however, in situations where the eyes had to be closed or there was no touch involved neither sex obviously did better than the other.

In conclusion, sleep deprivation did not markedly affect objective balance control but modulated the effect of sensorial feedback and highlighted several sex differences. It also impacted on visuo-motor coordination during the most challenging tracking task (i.e., when using the non-dominant hand). The research demonstrates important differences between men and women in controlling balance, with women typically outperforming men. Sensory feedback emerged as a key element in mitigating balance issues, underlining its value in interventions designed for individuals at risk of falls or sleep-related problems.

1.5 : Discussion

1.5.1 Main Findings

Chapter one included two studies on the intricate relationship between sleep, circadian rhythmicity, sex and postural control in cognitive healthy older adults. The first study investigated these association via an observational study design measuring and analyzing self-reported sleep, chronotype, health and lifestyle variables along subjectively perceived fall risk in both men and women. The second, experimental study examined how sleep quality, time of the day, biological sex, and sensory feedback mechanistically interact to influence balance control and in healthy older adults. It also investigated the effects of sleep loss, time of the day and sex on visuo-motor coordination as a cognitive function requiring sensorimotor integration, a neurophysiological function underlying postural control as well. The results both corroborate existing evidence and present some unexpected insights that call for further investigation. Taken together, these findings deepen the current theoretical and clinical perspectives on fall prevention strategies in aging populations.

As anticipated, women exhibited poorer self-reported sleep quality than men, consistent with well-documented trends in older adults that place women at a higher risk for insomnia and disrupted sleep (Krishnan & Collop, 2006; Mallampalli & Carter, 2014). This was evidenced by a significantly higher PSQI global score and shorter sleep duration compared to men. The same sex difference showed up in the smaller sample size recruited into the experimental study as well.

It was also expected that poor mental health indicators, such as elevated depression and anxiety, would correlate with reduced confidence in avoiding falls, aligning with existing research linking psychological well-being to fall risk perceptions (Onen & Onen, 2018). The observed increase in subjective sleep drive and difficulty during the circadian night, along with the restorative effects of short naps, were similarly in line with prior evidence demonstrating that sleep propensity fluctuates with circadian timing and that napping can mitigate sleep-related performance declines (Robillard et al., 2011; Tucker et al., 2017).

However, some findings deviated from initial expectations. While it was hypothesized that sleep deprivation would lead to more pronounced objective motor impairments, the objective balance metrics (e.g., center-of-pressure measures) remained relatively stable even under sleep deprivation. This contradicts the assumption that physiological sleep loss would manifest directly in measurable postural deficits. Instead, subjective impairments, such as increased perceived instability and reduced alertness, emerged without corresponding declines in static balance parameters. Another unanticipated result was

the diminished role of chronotype in predicting fall efficacy. Although circadian preferences are known to shift with age, the lack of a direct link to confidence in avoiding falls suggests that sleep timing may be less impactful on fall risk perception than initially presumed in this older cohort.

The interplay between sleep patterns, psychological health, and perceived fall risk emerged as a critical determinant of functional confidence. Women's poorer sleep quality, reflected in higher ISI and PSQI scores, not only confirmed well-established sex differences in sleep disturbance prevalence but also highlighted how these disturbances influence fall-related self-efficacy. Poor sleep quality appeared to amplify anxiety and depressive symptoms, thereby lowering confidence in avoiding falls. In men, later bedtimes, and possibly greater circadian misalignment—were associated with lower fall confidence, suggesting that sleep timing interventions could complement conventional fall prevention strategies. Although no direct association between chronotype and fall efficacy was found, these results reinforce that sleep schedules remain a modifiable factor with potential implications for reducing perceived fall risk in certain subgroups.

The strong association between falls efficacy and perceived physical and mental health (via SF-36) further corroborates the centrality of psychological and physical well-being in managing fall risk. Individuals who were more concerned about falling tended to report poorer mental health and signs of depression and anxiety (as indicated by PHQ-9 and GAD-7 scores). This emphasizes the importance of integrating mental health support and sleep interventions into comprehensive fall prevention programs.

Consistent with expectations, the circadian night presented a period of heightened sleep drive. Participants, especially those deprived of sleep, reported increasing difficulty maintaining stability. Yet, contrary to initial assumptions, objective measures of balance did not significantly deteriorate. This discrepancy suggests that subjective and cognitive factors, such as increased effort, reduced vigilance, or perceived instability, may precede measurable motor deficits. The PVT and KSS data confirmed that cognitive alertness was more sensitive to sleep loss than static postural control, aligning with research highlighting the complexity of translating physiological sleepiness into gross motor impairments.

This unexpected resilience of objective balance performance under sleep deprivation invites further inquiry. It is possible that the relatively stable, static tasks employed here did not fully capture subtle decrements in postural control. Future research should consider more dynamic or challenging balance tasks, which may be more sensitive to subtle sensorimotor impairments caused by sleep loss.

One of the study's expected findings was the pivotal role of sensory feedback, visual and tactile cues, in maintaining postural stability. Regardless of sleep state, participants who had visual or haptic input remained more stable, reinforcing prior evidence that sensory integration can compensate for cognitive or physiological deficits (Redfern et al., 2001; Peterka, 2002). That naps mitigated performance declines was anticipated based on existing literature (Tucker et al., 2017), offering a practical intervention for preserving both cognitive and physical functions in vulnerable individuals.

These results indicate that even when circadian misalignment or subjective fatigue is present, improving environmental conditions—such as enhancing lighting, providing stable reference points, or integrating tactile aids—can partially offset the detriments of poor sleep and support balance. This holds considerable promise for real-world applications in fall prevention programs, particularly in home or clinical settings.

While it was expected that men and women might differ in their sleep patterns and associated vulnerabilities, the exact nature of these differences was more complex than anticipated. Women's poorer sleep quality was expected, but their apparent resilience in maintaining balance under challenging conditions, even during sleep deprivation, was less predictable. Conversely, men demonstrated greater reliance on visual inputs and were more adversely affected without them, suggesting a potential need for sex-specific interventions that strengthen alternative sensory pathways, especially for men.

Additionally, the uneven effects of sleep deprivation on motor performance tasks, where men performed better with the dominant hand but struggled with the non-dominant one, were not fully anticipated. These nuanced, sex-related differences highlight that personalized rehabilitation and training programs should consider both sex and individual motor preferences. Such tailoring could help individuals maintain stability in real-world scenarios that challenge both their sensory and motor systems.

The findings extend current theoretical frameworks by demonstrating that balance control is influenced by a web of interrelated factors, biological rhythms, sensory cues, sex differences, and psychological states, rather than by motor function alone. Clinically, recognizing these interactions can inform targeted interventions. For instance, cognitive-behavioral therapy for insomnia, structured napping schedules, environmental modifications (enhanced lighting, tactile reference points), and psychological support for anxiety and depression could be integrated into a holistic fall prevention strategy. Similarly, acknowledging sex-specific vulnerabilities can guide the design of interventions that focus on improving physical health and reducing anxiety in women, while for men, diversifying sensory reliance and refining sleep timing may prove more beneficial.

On a theoretical level, the unexpected findings, such as stable objective balance metrics despite subjective impairments, point to the need for more sensitive assessment tools. Dynamic balance tasks, dual-task paradigms, and longitudinal studies that capture shifts in chronotype and their influence on motor function may offer richer insights. Understanding why certain populations remain resilient in the face of sleep disruption could inform strategies to strengthen balance in others.

By confirming expected results, revealing unexpected patterns, and integrating these outcomes within the current body of evidence, this study refines our understanding of how sleep quality, circadian rhythms, and sensory feedback interact to shape balance control and fall risk perceptions in older adults. This perspective lays the groundwork for future interventions that are both evidence-based and carefully tailored to individual vulnerabilities, ultimately supporting healthier aging and reduced fall risk in an increasingly older global population.

1.5.2 Strength and Limitations

This research project successfully investigated the role of sleep in self-reported and objectively measured falls efficacy and postural control among healthy adults. Its design involved multiple phases, including recruitment, screening, and controlled laboratory experiments, each meticulously planned to capture an array of data relevant to circadian rhythms, insomnia symptoms, and motor performance. One notable strength lies in the use of well-established and validated questionnaires, such as the Pittsburgh Sleep Quality Index, the Insomnia Severity Index, and the Falls Efficacy Scale, augmented by a thorough screening process. These rigorous inclusion and exclusion criteria ensured that the sample remained free of confounding medical, psychiatric, or substance-related factors, thereby enhancing the internal validity of the results.

A further advantage of the study was its integration of objective physiological and behavioral methods, including polysomnography, psychomotor vigilance tasks, and static posturography. These instruments, administered alongside subjective measures, allowed a convergent look at how sleep and circadian misalignment might affect both perceived and actual balance abilities. By adopting two distinct laboratory protocols, one involving 40 hours of sustained wakefulness and the other featuring repeated naps every four hours, the research effectively manipulated sleep pressure to examine cognition, brain activity, and emotional states. A repeated-measures design capturing tests at four-hour intervals amplified statistical power by mapping intra-individual variations in alertness and performance.

While this study made substantial progress in understanding how sleep, circadian rhythmicity, sex, senses, and balance are connected, some challenges came up that should be mentioned. Improving the research conditions and methods in future studies can build on the important foundation from this initial work.

One impediment encountered was suboptimal sound insulation in the laboratory facilities. Occasional auditory disruptions from adjacent rooms or hallway noise may have partially impacted sleep quality during daytime naps and postural control performance metrics given their reliance on attention and concentration. Upgrading lab soundproofing through improved door seals, sound-dampening panels, and protective isolation could enhance experimental reliability by minimizing external distractions.

Additionally, the postural control data acquisition software and force plate system experienced periodic technical glitches during testing sessions. Troubleshooting and debugging interrupted experimental continuity at times and may have distracted participants. Transitioning to a more refined and reliable postural assessment setup could improve consistency and precision of sway measurements. More seamless integration of control software, force plates, and data recording would further optimize lab protocols and efficiency.

Moreover, progression of the research was substantially delayed and disrupted by the COVID-19 pandemic. Public health restrictions necessitated pause in in-person testing during lockdowns. Participant recruitment and retention suffered due to heightened precautions and risks from in-lab visits. These virus containment measures severely impacted original timelines and milestones, necessitating restructuring of the research plan. Creative solutions to accommodate remote participation could mitigate these challenges in future studies.

In summary, while the multifaceted sleep and postural control experiments generated valuable data, enhancements in lab facilities, equipment reliability, and resilience to external disruptions could further optimize experimental conditions and productivity. Fine-tuning technical aspects of testing protocols and measurement apparatus may improve consistency and quality of data collection. Proactive contingency planning to surmount unforeseen obstacles like a global pandemic can aid in recovering schedules and milestones. Implementing these lessons learned can enable this research program to maximize scientific contributions moving forward.

1.5.3 Future Study Plans

By combining screening, experimental lab, and field components, this work generated pivotal foundational insights while also exposing critical gaps necessitating further scientific inquiry.

Several planned research endeavors will build upon sleep and circadian factors underpinning postural control study. Additional analyses warranted to fully harness the rich dataset regarding variable interactions and novel findings. Examining psychomotor vulnerability to sleep loss using neurobehavioral assays like the psychomotor vigilance task could reveal trait markers associated with balance impairment resilience versus susceptibility to sleep deprivation. Expanding the sample size can improve the power to detect such individual differences related to sleep loss vulnerability.

Incorporating dynamic posturography into experimental protocols, rather than relying solely on static stance conditions, will enable a comprehensive assessment of the effects of sleep and circadian disruption on compensatory balance reactions and fall risks. Introducing cognitive dual-task conditions while measuring postural control can clarify the consequences of divided attention, which is particularly relevant for cognitively demanding work environments. Analyzing objective sleep data recorded through polysomnography or actigraphy will provide direct insights into how sleep architecture, continuity, and depth influence motor functioning. Expanding sensory manipulations, such as vestibular inputs and eye-tracking, could further explore destabilizing scenarios (Cajochen, 2007; Guerraz & Bronstein, 2008). Long-term studies assessing the impact of interventions on fall risks in high-risk groups, such as shift workers, would enhance the practical applications of these findings.

Additional sensory manipulations can build upon the visual and proprioceptive conditions examined. For instance, manipulating projected environments and tracking eye movements could simulate destabilizing scenarios like dizziness to probe associated postural disruption. Assessing eye movements and vestibular function will clarify relationships between gaze, oculomotor control, visual dependence, and balance.

In summary, this study has sparked an extensive and cross-disciplinary research endeavor that sheds light on how sleep patterns, circadian rhythms, sensory inputs, biological sex, cognitive abilities, and individual differences influence balance control. This comprehensive undertaking holds remarkable potential to revolutionize the way the study diagnose, predict, prevent, and treat balance disorders and falls risk across diverse populations. The empirical evidence and conceptual framework established by this research pave the way for groundbreaking discoveries that will benefit fields such as occupational health, aging research, neuroscience, and personalized medicine. The multitude of avenues for further exploration catalyzed by these findings carries profound implications for improving health and well-being on a global scale.

Chapter 2
Sleep, Circadian Rhythms, and Performance in Mariners: Fall Risk and Self-Reported Sleep-Related Issues

The working environment that the sea presents has its own one of a kind sort of challenges which affect the health and the performance of the mariners very severely. As there are the individuals who work in very challenging and sometimes even quite impractical situations, mariners face a set of occupational stress which can ruin their sleeping and daily habits. Such elements as the absence of strict schedules for the watch, the tight space the sailors have to live in, as well as the scarcity of natural light, make it possible for people there to get their sleeps disrupted and this, in turn, is a reason for them to experience the impairments in both the physical and cognitive performance of theirs.

The lack of knowledge on the issue of sleep and circadian dysregulation brings out the fact that steadiness on the boat is mandatory while the person should keep balance on a moving vessel. The efficiency that their roles require is not only just balance and coordination but also the ability to be reactive fast to the ever-changing conditions. The inability to sleep may cause them to be unable to do these tasks, thus the risks of accidents and injuries might go up, something that is not necessarily needed in the given environment. Besides falls, slippage control at a greater rate can result in severe injuries which will affect not only the mariner but also the crew and the ship's safety and effectiveness as well.

This section is to demonstrate the existence of specific problems that sailors meet regarding the time they must sleep and the performance of the work due to their work rhythm set by the rotation of circadian rhythms. Through an in-depth investigation into the conditions, we are enabled to get a broad insight into the disorder and its issue of significance among particular professions. Moreover, this research serves to put a spotlight on the necessity for the application of some constancy plan or activities in problem areas and the complete eradication of sleep disorders thus getting a favorable effect on security, as well as the efficiency of the marine operations.

Through a comprehensive understanding of these dynamics, it is possible to contribute to the development of effective solutions that support the well-being of mariners, reduce the risk of falls, and promote optimal functioning in their demanding roles. Addressing these issues is not only vital for the health of individual mariners but also essential for ensuring the overall safety and effectiveness of maritime operations.

2.1 Background

2.1.1 Sleep, Circadian Rhythms, and Performance in Mariners

The maritime work environment presents a unique occupational setting that poses several challenges to workers' health, safety, and performance. Mariners work in environments that are distinct from most land-based occupations due to factors such as disrupted sleep patterns, circadian dysregulation, and physically demanding tasks, which are exacerbated by the challenging and unpredictable conditions on the open sea. This chapter explores how the distinct features of the maritime environment, particularly in relation to sleep and circadian rhythms, influence postural control and performance in mariners. By examining the interplay of these factors, we gain insights into the broader implications for safety, well-being, and generalizability to other extreme occupational environments.

The first and perhaps most critical factor is the unique occupational environment in which mariners operate. Mariners are required to maintain rigorous schedules that often include night watches, irregular sleep periods, and long shifts, all of which contribute to chronic sleep disruption. In addition, the environment aboard a ship deprives individuals of regular natural light cues, which are vital for maintaining proper circadian alignment. This circadian dysregulation can lead to misalignment between the mariners' internal biological clocks and their external schedules, exacerbating fatigue and impairing performance. Sensory deprivation, combined with confined living quarters, further adds to the complexity of maintaining alertness and physical coordination. Studying postural control in this population provides valuable insights into how extreme environments influence the body's balance and motor functions, especially in relation to increased fall risk due to disrupted sleep and circadian rhythms.

Physically demanding work is another hallmark of the mariner's occupation. The work on a constantly moving vessel requires a high level of postural control, as the unstable surface underfoot challenges balance and proprioception in ways that few land-based environments do. Mariners must also maneuver through confined spaces, climb ladders, and carry heavy equipment, all of which add to the physical strain. Poor postural control in such a setting has severe safety implications. Given the physical demands placed on mariners, even slight impairments in balance can increase the risk of falls or other injuries, potentially endangering both the individual and their crew.

Another key aspect of this study is its generalizability to other environments. While mariners represent an extreme occupational group, the factors that impact their postural control—sleep disruption, circadian misalignment, sensory distortion, and confinement—are not unique to the maritime industry. Other high-risk professions, such as shift workers, military personnel, miners, and offshore oil

rig workers, experience similar challenges. Furthermore, environments such as aerospace, Antarctic research stations, and space exploration also feature sensory deprivation and physical confinement. The findings from the mariners study could therefore have broader implications for understanding how postural control is affected in various extreme or isolated settings, offering insights into occupational health and safety practices that could be applied across different industries.

Finally, the novel contribution of this research lies in its focus on a relatively understudied population—mariners. Although much research has been conducted on postural control and fall risks in various occupational settings, the specific challenges faced by mariners have not received sufficient attention. The inclusion of mariners in this study fills a significant gap in the literature, particularly in the context of how extreme environments impact postural control and sensorimotor integration. By investigating how sleep and circadian disruption affect mariners' ability to maintain balance and physical coordination, this study adds a new dimension to our understanding of occupational safety and performance in extreme conditions.

In conclusion, the study of mariners provides a unique perspective on how extreme environments—marked by disrupted sleep, circadian dysregulation, sensory deprivation, and physical confinement—impact postural control. This research not only highlights the safety risks faced by mariners due to impaired postural control but also has the potential to inform safety practices in other professions that involve similar environmental challenges. By addressing the complex interplay between sleep, circadian rhythms, and physical demands, this study makes a novel contribution to the broader field of occupational health and safety, particularly in high-risk and extreme environments.

2.1.1.1 The Maritime Industry

Maritime transportation, or more generally known as waterborne transport, is the transfer of people or goods, also referred to as cargo, via waterways. Freight transport by sea has been widely used throughout history. The advent of aviation has diminished the importance of sea travel for passengers, though it is still popular for short trips and pleasure cruises. Transporting by water is cheaper than transporting by air despite the fluctuating exchange rates and fees placed on top of freighting charges for carrier companies. Water transportation is cost-effective because it is suitable for a wide range of products and large volume shipping, environmentally friendly within all modes of transport, has extensive worldwide coverage and also provides multiple carrier options (Martin, 2009).

Maritime transportation is known to be the transport between any two regional points worldwide by boat, ship, sailboat, or barge, over oceans and lakes, through canals, or along rivers. Shipping may be for commerce, recreation, or military purposes. While extensive inland shipping is less prominent today, the major waterways of the world including many canals are still very important and are integral parts of worldwide trade and economies. Any kind of material can be moved by water; however, water transportation becomes impractical when material delivery is time-dependent. One such example includes the delivery of perishable products. Still, water transportation is highly cost-effective with regular schedulable cargoes, such as trans-oceanic shipping of consumer products – and especially for heavy loads or bulk cargos, such as coal, coke, ores, or grains. Arguably, the Industrial Revolution took place best where cheap water transport by canal, navigations, or shipping by all types of watercraft on natural waterways supported cost-effective bulk transport (Heaver, 1993; Martin, 2009).

According to the International Maritime Industry Report (2014), the maritime sector consists of the following sectors:

1. Shipping industry
2. International transport of passengers for travel and leisure
3. International transport of freight
4. Shipbuilding and boatbuilding (marine leisure vessels)
5. Military sector

Everybody in the world benefits from the shipping of food, technology, medicines, and manufacturing materials. As the world's population continues to grow, particularly in developing countries, low-cost and efficient maritime transportation has an essential role to play in growth and sustainable development. Shipping helps ensure that the benefits of trade and commerce are more evenly spread. No country is entirely self-sufficient, moreover, every country relies on maritime trade to sell what it has and buy what it needs. Much of what is used and consumed in everyday life either has been or will be transported by sea, in the form of raw materials, components, or finished articles.

According to the International Maritime Organization report (IMO, 2019), maritime transportation is the backbone of global trade and the global economy. It is essential to the world's economy as over 90% of the world's trade is carried by sea, and it is, by far, the most cost-effective way to move bulk amounts of goods and raw materials around the world. Maritime activity has a key role to

play in the alleviation of extreme poverty and hunger as it already provides an important source of income and employment for many developing countries, such as the supply of seagoing personnel and ship recycling, ship owning and operating, shipbuilding and repair, and port services, among others.

2.1.1.2 Fatalities and Occupational Hazards in the Maritime Industry

The maritime industry is considered one of the most hazardous occupations (Jaremin, 2005). However, fatal accident rates have been reduced over the 20th century among employed seafarers by British shipping companies (Roberts, 2008). The reason behind this was factors of improvement in the shipping industry from safety equipment to ship design and the services provided for rescuing. Thus, it is not obvious even with the expansion of cargo shipping in recent years if the fatal rate has changed (Roberts et al., 2014).

Records of a study show a higher rate of fatality among British seamen, 21 times more than the general workforce of the period between 2003 to 2012 (Roberts et al., 2014). Meanwhile, a previous study showed a decrease in the rate of fatality for the period between 1919 to 2005 (Roberts, 2008). Ships are registered with a flag of convenience, which allows them more freedom than stringent British registry criteria. Therefore, hazardous cargo on these ships contributes to a higher rate of fatality and casualty related to occupational accidents, including falls overboard, on board, and into docks, off-duty and on-duty among crew working on these vessels (IHS Fairplay "world fleet statistics 1999-2011; world casualty statistics 1999-2010," 2012). Deck crews are more at risk in terms of the highest risk of fatality due to the type of heavy on-duties carried out (Roberts, 2006; Roberts and Marlow, 2005; Nielsen and Panayides, 2005; Nielsen, 1999; Hansen, 1996).

Although the importance of world trade of goods and people in the maritime industry means it cannot be understated, seafaring is considered one of the most “physically demanding professions in one of the most dangerous work environments” (International Marine Health Association, 2012). Great concerns and emphasis have been placed and researched on the effect of the physical demands and working hours on the working population within the marine sector (Beurskens et al., 2007; Harrisson et al., 1982; Raslear, 2013; Janssen et al., 2003; van Amelsvoort, 2002). Nonetheless, it has also been suggested that the effect of the demand of the marine industry on the health and well-being of the workers has been an under-investigated issue in the maritime domain (Allen, 2008), especially when compared to the large amount of accomplished research related to road- and air-transport industries where research has shown that driver fatigue may account for up to 20% of road accidents and around

20–30% of all fatal road crashes, and air crash investigations have highlighted the role of sleepiness and fatigue in fatal incidents associated with pilots and air traffic controller errors (The Royal Society for the Prevention of Accidents, 2017).

Brown (1989) published a review exploring the relationship between hours of work, fatigue, and safety at sea, with evidence of increasing interest in the human element. Finding few accident cases citing fatigue due to sleep deprivation as a risk factor, Brown (1989) identified inadequate reporting systems as central to understanding how legislative channels are overlooking this problem. Eleven years later, a review focused on the British offshore oil support industry found a similar picture to Brown, concluding that sleep deprivation and fatigue have been noticeably under-investigated in the maritime domain (Collins, 2000).

2.1.1.3 Sleep and Circadian Disruptions linked to the Maritime Work Environment

Mariners often face difficulties in getting quality sleep due to factors such as noise, vibration, and work-related stress. The uniqueness of the onboard environment is characterized by the influence of noise and motion. Studies by Tamura et al (1997, 2002), Rapisarda et al (2004), and Ellis, Allen, and Burke (2003) underline the impact these factors have on sleep and performance. Shift work and long work hours contribute to sleep deprivation among mariners, impacting their performance and well-being. While the focus often leans towards the duration of sleep, the quality of sleep is equally important. Fragmented sleep and frequent awakenings are common issues among mariners.

Shift work interferes with the internal body clock, leading to circadian and sleep disturbances, and reduced cognitive performance. The maritime environment, often devoid of natural time cues like sunlight, exacerbates circadian disruptions. The misalignment between the body's internal clock and the work schedule can result in a phenomenon similar to jetlag, affecting a mariner's cognitive and physical abilities.

Chronic partial sleep deprivation, as discussed by Vyazovskiy and Harris (2013), Lo et al (2012), and Foo et al (1994), ties directly into the demands placed on mariners. The consequences of chronic sleep deprivation, including reduced performance and cognitive impairment, provide critical insights into the specific challenges that maritime workers face.

2.1.1.3.1 Fatigue as a mediator of sleep and circadian disturbances on occupational hazards in the maritime industry

Defining sleep deprivation among working people in the marine sector is essential to construct theoretically rooted measurement tools of the amount of sleep loss and its impact on physical and mental performance. A useful starting point to understand sleep deprivation is fatigue, which according to the International Maritime Organizations (IMO) guidelines (International Maritime Organization, 2004) is defined as follows: "A reduction in physical and/or mental capability as the result of physical, mental or emotional exertion which may impair nearly all physical abilities including; strength, speed, reaction time, coordination, decision making or balance." Based on this definition, sleep deprivation can be understood as a direct cause of fatigue related to shift work and extended work hours, an argument also documented by Lauber and Kayten (1988). Studies of traditional shift workers on marine vessels demonstrate that the timing of the shift influences the amount of sleep obtained (Akerstedt et al., 1982; Tepas and Carvalhais, 1990). This is well explained by the numerous empirical studies demonstrating a strong circadian modulation of sleep duration and quality as well as associated brain activity (Lazar et al., 2015).

Despite the large amount of data indicating that sleep is essential for normal waking performance, long-term health, and well-being, sleep deprivation is only likely to be tackled as a serious issue in the maritime industry once a reliable picture concerning its prevalence and negative impact on workers' health and safety, and associated economic measures are established. Unfortunately, a reliable picture concerning prevalence and impact can only be built up once sleep deprivation is taken seriously enough to warrant accurate and reliable reporting systems. This obviously may be hindered by conflicting interests between marine workers and stakeholders. Such a state of affairs has meant that research into sleep deprivation prevalence is quite limited and has often been localized and vessel-specific.

Grech, Horberry, and Humphreys (2003) studied the Royal Australian Navy and reported fatigue due to sleep deprivation as a major problem. With a sample of 79 crew from 6 patrol boats, questionnaire data were collected showing approximately 44% of participants worked more than 80 hours a week, and 62% reported not getting enough sleep. Gander (2005) investigated fatigue due to sleep deprivation alongside drug and alcohol use in the New Zealand shipping industry with a sample including representatives from the leisure, fishing, and commercial industries. Whilst Gander (2005) points out that methodological shortcomings prohibit generalization from the study, the fact that 16% of vessel owners/operators in the Taylor Nelson Sofres TNS sample rated the risk of a seafarer being injured due to a sleep deprivation-related accident as 'high' or 'very high' certainly supports concerns raised in the author's own work. Moreover, Le Quesne (2001) and Gander (2005) conducted a study looking at masters

and mates working on New Zealand inter-island ferries and found that 61% of officers felt they were often or always affected by sleep deprivation when on duty. It was also found that 26% of the ferry sample could recall being involved in fatigue due to sleep deprivation-related incidents or accidents in the last 6 months.

Using a questionnaire incorporating standardized measures of health and fatigue due to sleep deprivation, Smith, Lane, and Bloor (2001) studied seafarers in the British offshore oil support industry and compared them with installation workers and an onshore sample. Evading any over-simplistic sleep deprivation and fatigue categorization, it was found that the different groups of employees had a different sleep deprivation profile according to the symptoms used for comparison. Whilst the onshore workers were found to have a higher proportion of respondents reporting symptoms of depression and confusion, the seafaring and installation employees conversely reported higher levels of lethargy and poor-quality sleep.

Beyond and understandable variation in levels of sleep deprivation between seafarers and other working populations, Smith et al. (2003) also showed evidence of internal diversity within the maritime community. Surveying the short sea trip sector within the territorial seawater, the authors found this sample of marine workers to have a higher profile of sleep deprivation compared with the offshore oil support staff studied in the first phase. Where such diversity is evident even at a British level, it must be acknowledged that the issue of prevalence can become redundant unless tied to meaningful group classifications. Considering seafarers as a homogenous population is clearly inappropriate where working patterns and way of life can vary enormously according to several factors including cargo, type of trade, crew nationality, and flag of registration. In the remaining sections of this chapter, the focus is placed on exploring the factors associated with fatigue due to sleep deprivation and lack of sleep itself.

Tirilly (2004) conducted research onboard two vessels, one fishing and one oceanographic, to study the impact of fragmented work schedules on alertness over 24 hours. The author found that although sleep was fragmented into two or three episodes on the oceanographic vessel and five to six episodes on the fishing vessel, the 24-hour circadian alertness rhythm was maintained in both instances. Interestingly, Tirilly (2004) points out that such sleep fragmentation should be seen as more than an occupational phenomenon with social factors such as mealtimes likely to play a part. The seafarers studied showed a circadian-predicted dip in alertness during the night and a pronounced afternoon dip, which raises concern in terms of accident risk.

Similarly, studying the crew onboard a naval vessel, Goh (2000) also investigated how circadian rhythms interact with shift duty scheduling. A group of 20-day workers was compared with 49 workers

onboard a naval vessel, with salivary melatonin and cortisol used to indicate circadian variation. Whilst at a general level, it was shown that shift work has a detrimental impact on circadian rhythms, it is important to note a high level of inter-individual variation was observed, which should not be underplayed. Strategies addressing fatigue may need to account for the fact that different individuals may be more suited to different shifts, a subtle variation on the person-environment fit model (Caplan, 1987).

Aside from the commonly recognized factors, other aspects such as age, perceived voyage difficulty, and experience also play a role in predicting fatigue levels, as shown by Leung et al (2006) and Wadsworth et al (2006). These individual and organizational risk factors add another layer to the complex interplay of factors affecting sleep and fatigue in maritime workers.

2.1.1.3.2 Effects of Sleep and Circadian Rhythms on Postural Control and Sensorimotor Integration in Mariners

Lack of quality sleep and circadian misalignment can lead to issues with postural control, a crucial factor when working on a moving vessel. Sub-optimal sleep conditions can negatively affect the sensorimotor system, complicating tasks that require fine motor control and balance, such as navigating through narrow spaces or managing equipment.

Evidence in animals shows a link between the vestibular system and biological rhythms. Studies by Horowitz et al (2005), Cavdar et al (2001), and others have explored how the vestibular system interacts with circadian rhythmicity, influencing body temperature and locomotor activity. Martin et al (2015, 2016) demonstrated these effects in both animals and humans. These findings set the stage for understanding how complex biological systems can be influenced by environmental factors and how this can translate into human conditions, such as those faced by mariners.

Summary: **Sleep, Circadian Rhythms, and Performance in Mariners**

Maritime work conditions place substantial stress on sleep quality and circadian rhythm alignment, which in turn significantly impact a mariner's job performance, particularly in tasks requiring postural control and sensorimotor integration. Addressing these issues require targeted interventions that consider the unique challenges of the maritime work environment, aimed at improving both sleep and circadian alignment. By doing so, we can hope to enhance not just the well-being of mariners but also the overall safety and effectiveness of maritime operations.

Research gap: Sleep, circadian rhythmicity and Postural Control in Mariners

Despite the increased prevalence and significance of sleep deprivation in our society and particularly in the maritime industry where workers are exposed to various risk factors impacting cognitive function and postural control, there are no studies to my knowledge that tried to assess sleep, and circadian rhythmicity/chronotype and their potential association with the risk of falls. It is admittable that studying sleep in mariners is challenging given their continuous work schedule with extensive work hours on a daily basis. Therefore, this study aimed to address this research gap but piloting the possibility of surveying sleep, health, and fall risks in mariners on duty using online methods.

2.2 Aims and Objectives

2.2.1 Aim:

- To investigate the feasibility of assessing sleep, chronotype, risk of falls and associated health, lifestyle and work-related characteristics in mariners and also to explore their interrelationship.

2.2.2 Research Questions and Hypotheses:

- Is it feasible to study habitual sleep, chronotype, physical and mental health, lifestyle and work-related wellbeing as well as the risk of falls in mariners using online methods?

- Is self-reported risk of falls associated with self-reported sleep, chronotype, physical and mental health, lifestyle and work-related wellbeing in mariners?

    - *Hypothesis: Given the exploratory pilot nature of this study, the research had no strong a priori hypothesis except that it was assumed that the online survey methods would be feasible allowing to collect with some considerable meaningful data.*

    - *Hypothesis: Shorter and worse sleep quality will be associated with higher self-reported risk of falls in mariners.*

2.3 METHODS

This was a pilot/feasibility study investigating self-reported falls risk and sleep in mariners working on board ships using a cross-sectional survey study design.

2.3.1 Sleep and Postural Control in Mariners

Funding Statement

The study was funded by the Saudi Arabian Mission in the United Kingdom.

Ethics Statement

A study into sleep and its contribution to postural control; Investigating sleep durations with relation to risk of falls amongst workers of the maritime industry was conducted in strict adherence to ethical standards. The study received ethical approval from the University of East Anglia's Faculty of Medicine and Health Sciences Research Ethics Committee (Reference: 2020/21-147), was conducted in strict adherence to ethical standards, and complied with the General Data Protection Regulation (GDPR) and the Data Protection Act 2018.

Procedures

The study involved two main stages: recruitment of participants and administration of an online questionnaire.

Recruitment was conducted by contacting relevant maritime organizations in the Red Sea, Arabian Gulf, and Mediterranean Sea regions. Representations from bodies such as maritime networking institutes were approached via phone calls and emails to request assistance with circulating study information and recruitment materials among their employees and members. Additionally, the research team submitted a proposal to the Maritime Studies College in order to connect with appropriate groups that could aid recruitment in the maritime community.

Once relevant contacts were established, these organizations were asked to distribute links to the online survey among their workforces. The survey was hosted securely using the Microsoft Forms platform. Employees who expressed an interest in taking part were first presented with the detailed participant information and were invited to sign the consent form. Only after providing written consent did participants gain access to the full research questionnaire.

The online questionnaire incorporated validated measures on demographics, health status, lifestyle factors, sleep quality and duration, chronotype, fall risk, and maritime work environment. Participants could expect the survey to take around 40 minutes to complete. To avoid undue eyestrain or fatigue, participants were prompted at regular intervals to take breaks as needed before continuing the questionnaire. Upon fully completing the survey, participants had the option to provide their payment details to receive £20 reimbursement for their time and contribution.

Participant inclusion/exclusion criteria:

Inclusion criteria:

- Age >18
- Maritime industry worker
- Conversational English and capacity to consent
- Availability to take part in the study

Exclusion criteria:

- No specific exclusion criteria were mentioned aside from the inclusion criteria above.

Data Collection:

The primary data collection tool was an electronic questionnaire, disseminated via Microsoft Forms. This approach ensured a wide reach and facilitated ease of response for participants regardless of their location.

Questionnaire Components:

1. **Self-Reported Sleep**: Participants were prompted to detail their typical sleep patterns, including duration, quality, timing and any disturbances they might experience. This information provided insights into the general sleep health of mariners and its potential implications on their daily

activities (see appendix 1). The questions were selected from multiple questionnaires including PSQI, Epworth Sleepiness Scale and Munich Chronotype Questionnaire

2. **Falls Reports**: Mariners were asked to recount any recent incidents of falls or near-falls they had experienced, respond to questions from the occupational slip, trip and fall (STF) risk assessment test developed by the Japan Industrial Safety and Health Association (JISHA). They also had to fill out the Falls Efficacy Scale (FES) (see appendix 1).

3. **Daily Activity**: Understanding the daily routines of mariners, including work shifts, physical exertions, and rest periods, was essential. This section aimed to capture how their daily activities and shift work patterns might interact with their sleep patterns and potentially influence their balance and coordination (see appendix 1).

4. **Exposure to Light**: Given the critical role of light in regulating circadian rhythms, participants were asked about their typical exposure to natural and artificial light. This section aimed to explore how varying light conditions at sea might impact circadian rhythmicity and, in turn, postural control (see appendix 1).

Statistical Analysis Plan

In the Mariners study, a feasibility and exploratory pilot investigation, two types of statistical approaches were employed. First, given the feasibility aim, descriptive statistics were used to provide a summary of the amount of collected quantitative data expressed as count and percentage of completed items relative to the number of returned surveys. Similarly, descriptive statistical approach was used to characterize the centrality and dispersion —including means, standard deviations (SD), mode and medians—for continuous data. Categorical variables were summarized using frequency data presented as counts (N) and percentages. The number of returned questionnaires and completed items as well as the meaningful interpretability of the collected data represented the primary outcome of the analysis. Second, exploratory correlational analyses were conducted to examine the association between falls risk and various measures related to sleep, chronotype, lifestyle, and physiological wellbeing s. All analyses were performed using SAS 9.4 (SAS Institute Inc.) and SPSS 29 (IBM).

Given that multiple variables exhibited non-normal distributions, Spearman rank-order correlation coefficients were calculated. This non-parametric method is suitable for assessing relationships between variables that are not normally distributed or are measured on an ordinal scale. The strength and direction of these correlations were interpreted based on the correlation coefficient values, with statistical significance threshold set at 5%.

Group comparisons were not applicable in this study design. Since the sample consisted almost exclusively of male participants and there were no different protocols or intervention groups, analyses comparing groups based on sex or other factors were not included. Additionally, given that exploratory nature of the association analysis, no control variables were included in the form of multivariate regressions or partial correlations but only the bivariate correlations are reported.

Throughout the analysis process, the limitations inherent to the study's homogeneous sample and exploratory design were acknowledged. Recognizing that the findings would be preliminary, the results were approached with caution. The study was designed to generate hypotheses and provide valuable preliminary insights rather than to draw definitive conclusions.

The study aimed to contribute to the understanding of fall risk factors and to inform future research directions in this important area of investigation.

2.4 Results

2.4.1 Feasibility and Efficacy of Investigating Risk of Falls: A Remote Assessment of Sleep and Health

The *Mariner* study set out with an intention to gauge the feasibility and pilot efficacy of assessing the association between self-reported sleep and postural control remotely, utilizing online questionnaires. Additionally, a focal point of the exploration was to delve into the relative prominence of certain work-related, health-related, and sleep-related factors in relation to the risk of falls among mariners.

This study endeavor has proven feasible, evidenced by the acquisition of data from a commendable total of 105 individuals who returned the questionnaire. Notwithstanding, full completion was achieved by 77 participants, indicating a completion rate of 73.33%. This signifies that almost three-quarters of individuals who initiated the questionnaire proceeded to complete it in its entirety. This noteworthy completion rate demonstrates a feasible engagement with the study's remote assessment, illustrating that participants were amenable to and capable of comprehensively engaging with the online questionnaire format. Although sex was not an exclusion criterion no female mariners returned the questionnaire. Furthermore, data collection for the mariners' study was involved between September 2021 and early 2022.

The sample comprised participants predominantly in their early thirties (M=31.49, SD=7.51) with a median age of 30, and a notable they were all males, constituting 96.19% of the sample for which sex data was available.

Education was reasonably well-distributed, with 41.9% possessing a postgraduate degree, and a mean education period of 16.87 years (SD = 5.25). The participants primarily fell within the 'Very High' yearly income category (46.67%).

The physical characteristics reflected a mean height of 172.24 cm (SD = 7.38) and a mean weight of 74.32 kg (SD = 12.69) that would correspond to an estimated average BMI (25.1 kg/m^2) within the normal range. The **Chronotype** variable had a mean score of 2.92 (SD = 1.37), with a mode of 4 and a median of 3 what correspond to normal and slightly early type chronotypes, respectively.

Alcohol and **Smoking** habits of the participants were predominantly on the lower side, with 99.05% reporting 'No' to alcohol abuse, and %77.14% not engaging in smoking or vaping.

In terms of **Sleep** variables, a diverse range of metrics was observed, such as a mean of 69.8 minutes (SD = 141.70) for time taken to fall asleep (i.e. sleep latency) in the past month, and a mean of 8.54 hours (SD = 19.10) for sleep duration in the past month.

The **Health** variable illustrated that 52.38% reported suffering from roster symptoms, with a mean score of 1.75 (SD = 0.73).

Falls Efficacy Scale (FES) exhibited a mean total score of 25.72 (SD = 12.99), indicating a moderate perception of stability and confidence in avoiding falls during activities of daily living among participants.

Postural Control variables such as 'One Leg Stand Eyes Closed' and 'Train Stand' presented means of 8.74 mins (SD = 27.93) and 12.31 mins (SD = 21.90), respectively, illustrating the participants' ability to maintain stability in different stances.

It can be concluded that the *Mariner* study, through its exploration of self-reported sleep and postural control measures, and examination of work, health, and sleep-related factors in relation to fall risks among mariners, has demonstrated that remote assessment via online questionnaires is a feasible approach. The findings derived from the variables explored offer a foundational understanding of the demographic, health, sleep and lifestyle characteristics of the participating mariners, providing a baseline upon which future research might build. further explore and validate these relationships and findings in broader contexts and applications. The insights garnered, especially those pertaining to the significant associations and interaction effects observed, provide a valuable starting point for future investigations into developing targeted interventions or strategies to mitigate fall risks among mariners, considering the influences of various factors as illuminated by the current study.

Variable	Count	Percentage (%)	Mean (std)	Mode	Median
Age	98	93.33	31.49 (7.51)	24	30
Sex	101	96.19	Males		
Education period (years)	91	86.67	16.87 (5.25)	22	17
Degree level					
Highschool or equivalent	9	8.57			
Undergraduate degree	36	34.29			
Postgraduate degree	44	41.9			
Yearly income					
Very low	5	4.76			
Low	7	6.67			
Average	11	10.48			
Above average	3	2.86			
High	16	15.24			
Very high	49	46.67			
BMI					
Height (cm)	102	97.14	172.24 (7.38)	175	174
Weight (kilograms)	101	96.19	74.32 (12.69)	79	76
Chronotype (MCTQ single item)	96	91.43	2.92 (1.37)	4	3
Alcohol abuse					
Yes	1	0.95			
No	104	99.05			
14 units alcohol weekly					
Yes	3	2.86			
No	101	96.19			
Alcohol intake (units)	74	70.48	0.27 (0.63)	0	0
Smoke or vape					
Yes	24	22.86			
No	81	77.14			
Smoke/vape daily amount	24	22.86	8.50 (9.42)	5	5
Average caffeine intake daily	79	75.24	2.96 (2.22)	1	2
Sleep - PSQI					
Past month time to sleep (mins)	104	99.05	69.83 (141.70)	5	10
Time in bed (hours)	101	96.19048	6.89 (2.10)	6	6.5
Sleep quality	102	97.14286	2.01 (0.78)	2	2
Daytime sleep habits					
Past month sleep (hours)	103	98.1	8.54 (19.10)	6	6.5
Time to wake up (mins)	101	96.19	10.29 (8.03)	5	5
Time to fall asleep (mins)	101	96.19	19.51 (21.34)	5	10
Nap duration (mins)	50	47.62	58.86 (99.08)	30	30
Dream to sleep until (hours)	99	94.29	9.55 (3.10)	12	10
Additional sleep need (mins)	67	63.81	45.00 (58.74)	5	20
Mins to wake up	99	94.29	10.74 (9.12)	5	7
Night before free days fall asleep time (mins)	96	91.43	17.46 (22.36)	5	10
Nap (mins)	39	37.14	35.13 (35.85)	30	30

Read time (mins)	93	88.57	10.76 (16.32)	0	5
Read time fall asleep (mins)	86	81.9	20.79 (29.37)	5	10
Health impact from roster symptoms	55	52.38	1.75 (0.73)	2	2
Falls efficacy scale (FES) total score	79	75.24	25.72 (12.99)	18	19
One leg stand eyes closed (mins)	76	72.38	8.74 (27.93)	1	3
Train stand (mins)	74	70.48	12.31 (21.90)	5	5
One leg stand eyes open (mins)	76	72.38	12.75 (30.91)	5	5
Staying awake while driving	101	96.19048	1.30 (0.66)	1	1

Table 15. Summary table of the number of responses per questionnaire item expressed as total count (n) and % as well as the descriptive results [mean(SD)] for the respective items. This included demographic, sleep, postural control and health-related characteristics of mariners participating in the study.

2.4.2 Demographic and Variable Correlations with Fall Efficacy

To illustrate the demographic characteristics and potential predictors of fall efficacy, a detailed analysis was performed. The sample predominantly consisted of males, with an average age of 31.49 years (SD = 7.51).

A pivotal aspect of the results centers around the correlations between various demographic and health-related variables and the Falls Efficacy Scale (FES) Total Score, serving as a substitute metric for perceived stability and fall risk. A diversity of correlations was observed, some of which were notably significant and offered insightful revelations into the multifaceted nature of fall risk among mariners.

Notably, a moderate, significant negative correlation was uncovered between **Education Period** and FES Total Score (r=−0.33, p=0.006), suggesting that a longer period of education was associated with reduced concerns related to falling. Contrastingly, **Past Month Time to Sleep** was positively correlated with the FES Total Score (r=0.48, p<0.00001), indicating that participants who took longer to fall asleep also expressed heightened concerns about falling.

Moreover, **Bedtime** demonstrated a mild, but significant positive correlation with FES Total Score (r=0.28, p=0.012), hinting at a potential relationship between later bedtimes and increased fall concerns. Variables like **Read Time** and **Read Time Fall Asleep** also demonstrated significant correlations (r=0.37, p=0.001 and r=0.54, p<0.0001 respectively), elucidating potential links between reading habits, sleep latency post-reading, and fall efficacy concerns.

Variables	*Spearman Rs*	*P values*
Age	0.07	0.553
Education Period (Years)	-0.33	**0.006**
Height (cm)	-0.19	0.094
Weight (kg)	0.04	0.720
Chronotype (7)	-0.18	0.123
Alcohol Intake (Units)	-0.06	0.672
Smoke/Vape (daily amount)	0.05	0.850
AVG Caffeine Intake (daily)	-0.15	0.249
Bedtime	0.28	0.012
Get Up Time	-0.17	0.130
TIB WD	0.15	0.207
Past Month time to sleep (mins)	0.48	**<0.00001**
Past Month Morning Wake Time	-0.10	0.372
Past Month Sleep Hours	0.03	0.770
Fully Awake time	-0.12	0.273
Read Time	0.37	**0.001**
Read Time Fall Asleep (mins)	0.54	**<0.0001**
One Leg Stand Eyes Closed (mins)	0.20	0.079
Train Stand (mins)	0.18	0.117
One Leg Stand Eyes Open (mins)	0.21	0.072
Sleep Quality (4)	-0.21	0.066
Staying Awake while Driving (4)	0.38	**0.001**

Table 16. Correlations between Falls Efficacy Scale (FES) Total Score and various demographic, health, sleep, and lifestyle variables in Mariners.

These findings underscore the multifaceted nature of factors influencing fall efficacy among mariners, intertwining physical and psychological realms. The observed correlations highlight not only the tangible, physical aspects traditionally associated with fall risks, such as stability during the one-leg stand test but also the psychological and lifestyle-oriented facets, such as sleep habits and reading time.

In the context of the Mariner study, the successful gathering of data from a sizable participant pool through remote methodologies establishes a promising precedent for future research endeavors in this domain. Furthermore, the correlations between various lifestyles, health, and demographic variables, and perceived fall risk provide a foundational platform upon which subsequent research might build.

Summary of Findings for the Mariners' Study

The Mariner study successfully demonstrated the feasibility of using online questionnaires to assess self-reported sleep and postural control, with a completion rate of 73.33% from the 105 participants who returned the questionnaire. This high level of engagement suggests that remote assessment methods are both practical and effective for this population. The study primarily involved male participants (96.19%) with an average age of 31.49 years, highlighting the demographic skew of the sample. Educational attainment was diverse, with 41.9% of participants holding postgraduate degrees and a mean education period of 16.87 years. Additionally, most participants reported very high yearly incomes, further contextualizing the study population.

Health and lifestyle metrics revealed that participants had a mean BMI based on an average height of 172.24 cm and weight of 74.32 kg. Alcohol and smoking habits were notably low, with 99.05% abstaining from alcohol abuse and 77.14% not engaging in smoking or vaping. Sleep-related findings indicated a mean time to sleep of 69.83 minutes in the past month and a mean sleep duration of 8.54 hours. Despite this, 52.38% of participants reported experiencing roster symptoms, reflecting underlying health-related challenges that could impact their stability and confidence.

In terms of postural control and fall risk, the Falls Efficacy Scale (FES) results indicated a moderate perception of stability, with a mean score of 25.72. Postural control tests showed participants' ability to maintain balance, with averages of 8.74 minutes for the one-leg stand with eyes closed and 12.31 minutes for the train stand test. These results provide a valuable baseline for understanding participants' physical stability.

The study identified significant correlations between various demographic, health, and lifestyle variables and fall efficacy. Longer education periods were associated with reduced concerns about falling, as indicated by a significant negative correlation with FES scores. Conversely, participants who took longer to fall asleep reported heightened concerns about falling, with a strong positive correlation between time to sleep and FES scores. Similarly, later bedtimes were mildly associated with increased fall concerns. Reading habits also emerged as significant factors, with time spent reading and the time taken to fall asleep after reading positively correlated with fall efficacy scores. These findings suggest that both behavioral and psychological factors play a critical role in influencing fall risk.

2.5 Discussion: Mariners Study

This study explored relationships between sleep patterns, circadian rhythms, and perceived fall risk factors among maritime workers—a younger, predominantly male occupational group frequently overlooked in fall prevention research. By relying solely on self-reported measures collected remotely, the Mariners study highlights unique aspects of fall risk that differ from those commonly observed in older populations and underscores the potential for innovative data collection methodologies. The findings reveal significant insights into the feasibility of remote assessment and the factors contributing to fall risks in this occupational group, with implications for safety and performance in demanding conditions.

2.5.1 Feasibility and Methodological Innovation

The successful remote administration of questionnaires (with a completion rate exceeding 70%) represents a significant methodological achievement. This outcome was somewhat anticipated, given emerging evidence that digital platforms can effectively engage diverse occupational groups (Pratap et al., 2020). Yet, it remains notable that such challenging population—mariners who often work under demanding and variable conditions—was receptive to this approach. Establishing feasibility sets the stage for larger-scale research and more extensive interventions that leverage remote monitoring tools in similarly hard-to-reach or mobile workforces.

2.5.2 Main Findings of Mariners Study

Key findings highlighted significant correlations between sleep parameters and fall efficacy. Longer sleep onset latency was associated with heightened fall concerns, reflecting the potential impact of hyperarousal on balance and confidence. Similarly, later bedtimes correlated with increased fall apprehension, emphasizing the role of sleep regular routines. Pre-sleep activities, such as extended reading durations, were also linked to greater fall concerns, suggesting that these behaviors might disrupt sleep quality and exacerbate fall risks. These results align with prior literature showing the importance of sleep patterns on cognitive and physical performance (Liu-Ambrose & Flack, 2019).

The study found that the majority of participants reported low engagement in alcohol and smoking habits, with nearly all abstaining from alcohol abuse and a significant proportion refraining from smoking or

vaping. This pattern may reflect the occupational context in which data was collected, as participants were predominantly on duty at the time of questionnaire completion. Being on duty likely discouraged engagement in such behaviors due to professional and operational responsibilities, adherence to maritime regulations, and the potential risks associated with impaired performance in a high-stakes environment. Previous research highlights that occupational settings with stringent safety requirements often see reduced substance use among workers during active duty periods (Gander, 2005; Smith, Lane, & Bloor, 2001).

Maritime workers, in particular, operate under demanding conditions requiring acute alertness and physical coordination. Substance use, such as alcohol or smoking, could exacerbate fatigue, disrupt sleep, and impair cognitive and physical performance, further increasing the risk of falls or accidents (Grech, Horberry, & Humphreys, 2003). The maritime industry's emphasis on safety and the potential legal or professional consequences of substance abuse further explain the observed low prevalence rates (International Maritime Organization, 2004). Additionally, cultural and organizational norms within the maritime industry might discourage substance use during active service periods, aligning with broader regulatory frameworks aimed at minimizing occupational hazards.

Moreover, the low rates of substance use align with findings from other high-risk occupational groups where safety-critical roles necessitate abstention from behaviors that could impair performance (Collins, 2000). However, it remains unclear whether these habits persist during off-duty periods, an area that warrants further exploration in future studies. Investigating the interplay between duty cycles, substance use patterns, and occupational performance could offer valuable insights into the holistic health and well-being of maritime workers.

Another anticipated outcome was the association between higher education levels and lower fall concerns. Cognitive reserve theory suggests that individuals with greater intellectual resources may better compensate for various health challenges, potentially including fall risks (Stern, 2012). Identifying a protective effect of education in this younger, occupationally active group reinforces the idea that cognitive resilience can confer benefits beyond traditional markers of health and function.

Despite these alignments with existing theories, the Mariners' study also produced findings that challenged initial assumptions. Age and sleep duration—factors that are often pivotal in older cohorts—

showed minimal influence on fall perceptions in this younger sample. While it might have been expected that younger mariners with shorter sleep durations or certain age-related characteristics would mirror trends seen in older adults, the relative insignificance of these factors suggests that the mechanisms underlying fall risk perception may differ substantially by age and occupational context.

Additionally, the relationship between certain functional perceptions (e.g., concerns about driving ability) and fall concerns was stronger than anticipated. This cross-domain correlation implies that perceived deficiencies in one skill may generalize to other domains, fueling broader anxiety about physical competency. Such findings underscore that fall risk perceptions are not merely about balance or mobility in isolation but can reflect wider confidence—or lack thereof—across different functional tasks.

Moreover, the study's contribution to understanding fall risks in mariners enriches the existing literature on sleep and occupational health. It provides a foundation for developing comprehensive prevention strategies that address the unique challenges of the maritime industry, such as disrupted circadian rhythms and the physical demands of working on moving vessels.

2.5.3 Clinical Implications

The Mariners study extends theoretical frameworks that link sleep quality, psychological state, and cognitive reserve to functional health outcomes. While much of the fall prevention literature focuses on older adults and established high-risk groups, these findings highlight the relevance of sleep education, and daily routines for a younger population in a demanding work environment. If workers' sleep patterns and bedtime practices have meaningful impacts on their sense of stability and safety, addressing these factors early in their careers may preempt more pronounced fall risks later in life.

Clinically and practically, these insights pave the way for tailored interventions in occupational health programs. For maritime workers, providing education about sleep, promoting consistent bedtimes, and advising against prolonged pre-sleep activities that might delay onset latency could enhance both perceived and actual safety. Cognitive training programs or initiatives that foster continuous learning and problem-solving skills may further bolster resilience against fall-related anxiety.

Moreover, as the maritime environment typically disrupts conventional circadian patterns due to irregular shift work, noise, and vessel movement, interventions could include strategies to stabilize sleep-wake cycles. For example, controlled lighting, scheduled rest periods, and guidance on managing pre-sleep behaviors might reduce hyperarousal, thus improving sleep quality and reducing fall-related apprehensions.

2.5.4 Strengths and Limitations of the Mariners Pilot Study

One of the most notable strengths of this pilot investigation lies in its demonstration of *feasibility* for remote data collection among maritime workers. By distributing an online survey via Microsoft Forms and collaborating with maritime organizations, the study successfully reached a widely dispersed population, a process that can be challenging in a profession marked by irregular schedules and offshore assignments. This method not only expanded participant accessibility but also underscored the potential for digital tools to capture health-related data in challenging occupational settings. Additionally, the study's *ethical rigor*, underscored by approvals from the University of East Anglia's Faculty of Medicine and Health Sciences Research Committee, reinforced participant trust and compliance with data protection standards. Another strong point is the *use of validated, multifaceted questionnaires* that looked into sleep, circadian rhythms, and self-reported fall risk. This comprehensive approach enabled the study to account for a variety of behavioral and environmental factors relevant to maritime work. Moreover, as a *pilot* project, it effectively identified potential areas for deeper investigation, thereby laying the groundwork for larger-scale, more definitive studies.

Despite these advantages, the Mariners' study also presented certain *limitations* that temper the generalizability of its findings. The reliance on a *predominantly male* sample constrains the applicability of the results to women in the maritime industry, who might experience different sleep disruptions or physical demands. Furthermore, *self-report measures* can introduce biases, including recall errors and social desirability effects, potentially diminishing the accuracy of the reported sleep habits and fall incidents. Without an objective measure, such as actigraphy or onboard observational assessments, there is less certainty about the real-world implications of the noted correlations. Finally, the *pilot nature* of the research meant a modest sample size and an exploratory approach focused on hypothesis generation rather than definitive causal inferences. Consequently, these results, while valuable for directing future inquiries, should be interpreted cautiously until replicated and expanded upon in more robust, controlled investigations.

2.5.5 Future Directions

This study's unexpected findings and methodological successes invite further investigation. Longitudinal research could determine whether early interventions aimed at improving sleep quality or enhancing cognitive resilience have lasting protective effects on perceived or actual fall risk. Comparing maritime workers to other occupational groups characterized by unusual schedules or challenging environments (e.g., shift workers in healthcare or aviation) may uncover common threads or unique vulnerabilities.

In addition, future studies might expand beyond self-report measures to include objective assessments of sleep and cognitive function, thus validating and refining the relationships identified here. While the feasibility of remote data collection is established, integrating wearable devices or mobile cognitive testing platforms could provide richer, real-time insights into how sleep disruptions affect functional confidence. A multifaceted approach that combines subjective reports with objective metrics could yield a more nuanced understanding, ultimately guiding more precise and effective interventions.

In conclusion, the Mariners study successfully highlights the feasibility and importance of remote assessment for fall risk factors in maritime workers. It identifies key correlations between sleep quality, pre-sleep activities, and fall efficacy, providing valuable insights into early fall risk processes. These findings have significant implications for developing targeted interventions to reduce fall risks in this and similar occupational groups. Future research should continue to explore these relationships and validate these findings in larger, more diverse populations, ultimately contributing to the development of comprehensive and effective fall prevention strategies tailored to the unique needs of various occupational groups.

Chapter 3
Integrated Discussion: The Role of Postural Control in Sleep, Circadian Rhythms, and Fall Risk Across Populations

3.1 Overall Discussion

This thesis explored the complex interplay between sleep and postural control across different populations and contexts. In *Chapter 1*, two studies were conducted in cognitively healthy older adults: an observational study investigating the relationships among self-reported sleep, chronotype, and fall risk, and an experimental study examining how sleep restriction and time of day affect objectively measured postural control and sensorimotor integration as measured by a visuo-motor coordination test. Recognizing the well-documented sex differences in sleep quality, fall risk, and vulnerability to sleep loss, these studies also tested for potential sex-specific effects on both postural control and sensorimotor integration. The findings offer significant insights into how self-reported fall risk correlates with self-reported sleep and chronotype, as well as the causal impact of sleep restriction and time of day on balance control and associated sensorimotor integration. Notably, the data suggest that self-reported risk of falls is associated with both mental and physical health and sleep but these association are to some extent modulated by sex in healthy older adults. The results also show that postural control can differ considerably between men and women when sleep pressure is high in a way that men are more affected by sleep restriction as compared to women. The study also found interaction between sex differences in pursuit tracking time on target but revealed that men exhibited better precision with less deviation from the target when using their dominant hand, while other related measures showed no sex-based disparities.

Subsequently, in *Chapter 2*, the thesis shifted focus to mariners working onboard ships, evaluating the feasibility of measuring sleep and postural control via an epidemiological approach. This pilot/feasibility study demonstrated that online questionnaires and remote data collection are both feasible and acceptable to this highly mobile workforce. In doing so, it provided early evidence that meaningful data can be gathered to understand how sleep loss, adverse timing of tasks (e.g., circadian misalignment), and the resultant balance issues may interact to create occupational health hazards in maritime contexts.

While earlier sections of the thesis detailed these empirical outcomes in relation to existing literature, this chapter aims to integrate all three studies' findings more broadly. Specifically, it evaluates the feasibility and validity of the research designs, outlines key strengths and limitations, and addresses practical or

clinical implications. Particular attention will be shown to sex differences in postural control under increased sleep pressure, as well as to the viability of an online methodology for studying sleep factors (e.g. sleep timing, duration, quality) and fall risk among mariners which collectively modulate both self-perceived and objectively measured fall risk.

The findings from the three studies offer substantial insights into how self-reported falls risk interrelates with self-reported sleep, as well as how sleep restriction and time of day can causally influence balance control. Notably, postural stability may diverge considerably between men and women under conditions of increased sleep pressure. In addition, the feasibility evaluation from *Chapter 2* demonstrates that utilizing epidemiological methods in maritime workers is practical and can yield robust datasets. This approach promises a better understanding of how sleep loss and adverse timing such as circadian misalignment, may increase occupational hazards associated with balance control in the maritime sector.

3.2 Validity and Feasibility of the Research Methodology

Selecting an appropriate study design and outcome measures is a critical first step in ensuring that the chosen research questions can be effectively addressed. In this thesis, the overarching goal was to explore how sleep and postural control interrelate in two distinct populations: cognitively healthy older adults and maritime workers. Accordingly, the studies were designed to maximize both feasibility and validity to the research aims.

In Chapter 1, three key research questions were posed: (1) whether self-reported sleep parameters relate to postural control, and (2-3) how experimentally induced sleep restriction and time of day affect objectively measured balance and visuo-motor coordination. The first question was addressed with an observational, questionnaire-based study that used validated self-report tools to capture sleep quality, chronotype, and perceived falls risk. The second question used a randomized controlled experiment that compared total sleep deprivation with a multi-nap schedule. This design tested causal mechanisms by contrasting an experimentally induced high sleep pressure condition against one where sleep pressure was regularly dissipated by multiple nap opportunities throughout the protocol.

Both total sleep deprivation and multinap studies represent standard experimental methodology in human sleep research. However, these studies are infrequent in older adults and no known research has contrasted total sleep deprivation to a multi-nap approach in studying cognition or postural control in older adults. The validity of these protocols in experimental manipulating sleep pressure is well supported

with evidence showing that older adults can handle controlled sleep restrictions, supporting both practicality and ethical viability. Only two participants withdrew from the experimental study, indicating a low dropout rate. The observational component also saw high engagement, and a range of questionnaires provided detailed information on sleep patterns and subjective fall risk.

The multi-nap protocol is designed to dissipate sleep pressure throughout the protocol and allow to detect underlying circadian effects independent of sleep pressure. That is when participants had regular naps, sleep pressure remained lower than in a sleep deprivation condition. Any performance decline in that group was therefore more likely due to circadian modulation rather than a sleep history-dependent homeostatic effect. This design proved particularly valuable for repeated postural assessments over a 24-hour cycle.

In the experimental study balance control was measured using recognized methods from sleep and motor control research. *Posturography* served as a gold-standard approach to quantify sway and center-of-pressure under different sleep conditions and times of day. This setup allowed an examination of how accumulating sleep pressure influences balance. Visual and haptic inputs (e.g., eyes open vs. eyes closed, light touch vs. no touch) were also carefully controlled, given their effect on postural stability. Systematically adjusting these factors helped identify how sleep loss and time of the day interact with sensory feedback to shape balance control outcomes.

Polysomnography (PSG) is a recognized gold standard for objectively assessing sleep quality, but it can be expensive and challenging for large or long-duration studies. In the observational work, validated self-report questionnaires offered broad data on sleep and falls risk at a fraction of the cost, with minimal burden on participants. In contrast, the experimental study focused on changes in sleep opportunities, comparing total deprivation to a multi-nap, instead of tracking detailed sleep architecture. This approach tested how different sleep conditions directly affect postural control, clarifying a causal link. Excluding PSG data from the experimental phase prevented a detailed investigation of objective sleep quality in relation to postural control, but given the smaller ample size of the mechanistically driven experimental study this observational research question could not have been answered with sufficient statistical power to lead to conclusive results. Future work could address this gap by conducting larger observational studies or including PSG in a smaller subset to examine specific elements of sleep (e.g., sleep stages, fragmentation) in connection with balance.

Both studies demonstrated the feasibility of the chosen methodology to answer the formulated research questions. Including the multimodal assessment of assessing sleep and postural control in unique populations using complementary methods. The first study employed an observational and laboratory-based experimental design for healthy older adults, while the second utilized remote, online questionnaires tailored for mariners. The 73.33% completion rate in the Mariners study confirms the practicality of remote assessments, aligning with previous findings that highlight the accessibility and engagement potential of digital tools in health research (Pratap et al., 2020). The success of these methods underscores their potential for future research in diverse and high-risk populations.

3.3 Evaluation of Hypotheses, Key Findings, and Their Alignment with Existing Literature

This discussion evaluates whether the findings supported the initial hypotheses, relates the results to existing literature, speculates on underlying mechanisms, and revisits the initial mechanistic model to integrate new insights.

The study tested several hypotheses. First, the hypothesis that self-reported sleep quality correlates with postural control and fall risk in older adults was supported. Poor sleep quality and prolonged sleep onset latency were linked to heightened fall risk perceptions, particularly in women (Mallampalli & Carter, 2014; Min et al., 2016). Second, the experimental hypothesis that sleep restriction and circadian misalignment would impair postural control was partially supported. While objective postural measures showed resilience under sleep restriction, subjective reports of balance effort increased, particularly during the sleep-deprived condition (Tucker et al., 2017; Saraiva et al., 2021). Notably, men exhibited greater objectively measured postural instability in specific sensory contexts, such as the eyes-open condition, suggesting sex-specific vulnerabilities to sleep loss. Third, the hypothesis that remote methodologies could effectively assess sleep and fall risk in mariners was confirmed. High completion rates and significant associations between sleep latency and fall concerns validated the approach (Pratap et al., 2020).

The findings align with and expand upon prior research. Consistent with existing studies, poor sleep quality was a strong predictor of fall risk in older adults (Robillard et al., 2011). The observed sex differences, where women reported worse sleep but adapted better to balance tasks, echo prior reports on sex-based physiological and behavioral differences (Adan & Natale, 2002). However, the limited effect of sleep deprivation on objective balance metrics challenges studies suggesting universal postural instability under sleep loss (Aguiar & Barela, 2014). This discrepancy may arise from methodological differences between the experimental protocols or resilience features in the studied population of carefully screened healthy

older adults. Additionally, the weaker correlations between self-reported physical stability measures (e.g. ability to stand stable on various platforms and in different conditions) and perceived fall efficacy in mariners highlight the dominant role of psychological and behavioral factors, an area less explored in occupational contexts (Roberts et al., 2014). This finding underscores the importance of addressing pre-sleep routines and circadian alignment in high-risk professions.

Several mechanisms may explain these findings. Men's greater reliance on visual feedback and subsequent vulnerability under sensory-challenged conditions could stem from neural processing variations or differences in motor adaptation strategies (Horak, 2006). Hormonal influences may also contribute to the observed disparities. The role of circadian rhythms in shaping postural control emerged strongly. Tasks performed during circadian troughs likely exacerbated balance challenges, suggesting that temporal factors significantly influence stability (Åkerstedt & Wright, 2009).

The findings also highlight a notable sex difference in how aging influences concerns about falling. Aging men exhibit heightened concerns about falling compared to women, which aligns with existing evidence suggesting that fear of falling and related psychological factors may manifest differently across sexes. Research indicates that men might experience increased sensitivity to age-related declines in proprioception and physical function, potentially exacerbating their fear of falling as they age (Rubenstein, 2006; Sturnieks, St George, & Lord, 2008). This heightened concern may stem from the interplay between physiological changes, such as diminished muscle strength and proprioceptive function, and psychological factors like fear and anxiety, which are known to negatively influence balance and stability (Horak, 2006).

The difference in falls efficacy between men and women may also relate to their distinct approaches to aging and perceptions of physical vulnerability. While women often report higher rates of falls and poorer balance performance, studies suggest that men may be less likely to outwardly express concerns about balance until they perceive a significant decline in their abilities (Scheffer et al., 2008). This could contribute to an underestimation of fall-related anxiety among men until it becomes more pronounced in later years. Furthermore, the fear of falling has been linked to reduced physical activity and avoidance behavior, which can, in turn, compromise balance and mobility, creating a feedback loop that reinforces these concerns (Zijlstra et al., 2007).

Psychological factors, such as anxiety and depression, have been shown to correlate with increased fear of falling and poorer balance performance in older adults (Hita-Contreras et al., 2018). Fear of falling is often accompanied by heightened postural sway and poorer postural control, further increasing the risk of falls (Tinetti et al., 1990). For men, this psychological burden may be amplified by societal norms that

discourage the acknowledgment of vulnerability, potentially delaying intervention until concerns about falling become acute (Bertera & Bertera, 2008).

To account for independent effects, the study included all relevant factors in the same model. The analysis revealed that self-perceived physical health emerged as the strongest predictor of perceived risk of falls in both men and women, while the effects of other factors, such as psychological and sleep variables, diminished. This association was significantly stronger in women, highlighting the greater influence of physical health perceptions on fall-related concerns in this group.

While there were no significant sex differences in self-perceived risk of falls, objective measures of postural control revealed that men exhibited inferior balance performance, particularly under conditions of sleep deprivation. In contrast, women demonstrated greater resilience, showing smaller impacts of sleep deprivation on their postural stability.

Additionally, older men often face nocturnal challenges, such as frequent restroom visits due to prostate-related complaints, which further increase their risk of falls during the night. This highlights a compounded risk for older men with sleep problems compared to women.

The role of sleep and circadian rhythms also warrants consideration in understanding these sex differences. Disrupted sleep and circadian misalignment, common among older adults, have been linked to impaired cognitive function, slower motor response times, and reduced postural stability (Carrier & Bliwise, 2003; Robillard et al., 2011). These factors are particularly relevant given that older men may experience different patterns of sleep disruption than women, with implications for their balance and mobility (Mander et al., 2017). Poor sleep quality has been shown to predict poorer postural control, and its indirect effects on fear of falling highlight the complex interplay between physiological and psychological factors in aging populations (Hita-Contreras et al., 2018).

These findings have significant implications for practice. For older adults, interventions should prioritize enhancing sensory feedback and stabilizing circadian rhythms through tailored light exposure, scheduled naps, or physical therapy programs (Nakano et al., 2001; Woollacott & Shumway-Cook, 2002). For mariners, addressing sleep onset latency and pre-sleep routines could mitigate fall risks. Educational campaigns and organizational policy changes to align work schedules with circadian rhythms could enhance occupational safety (Beurskens et al., 2007).

The initial model posited that sleep quality, circadian alignment, and sensory feedback interact to determine postural control. Based on the findings, the model now includes sex as a moderating factor,

highlighting distinct sensory reliance and adaptation mechanisms. The influence of occupational and environmental contexts, such as maritime work conditions, has been integrated. The updated model also emphasizes the divergence between subjective and objective postural control measures, suggesting a layered understanding of balance resilience.

3.4 Shared Insights and Differences Across Study Populations

Both studies revealed significant associations between sleep quality and fall efficacy, consistent with existing literature linking poor sleep to increased fall risk (Mallampalli & Carter, 2014; Min et al., 2016). In both older adults and mariners, longer sleep onset latency and disrupted sleep patterns were correlated with reduced confidence in balance and higher fall concerns. These findings emphasize the pervasive influence of sleep-related factors across different age groups and occupational settings.

Sex-specific differences also emerged as a shared theme. In older adults, women exhibited poorer sleep quality but greater adaptability in balance tasks, while men demonstrated stronger reliance on visual feedback, experiencing greater impairment without it. However, the visual settings were limited due to dimmed light conditions, which may have further influenced the reliance on sensory inputs for maintaining balance. Similarly, the Mariners study identified heightened fall concerns among participants with disrupted sleep routines, with significant behavioral and psychological predictors, such as bedtime and pre-sleep activities.

Despite these shared findings, notable differences emerged, reflecting the unique characteristics of each population. In the older adult cohort, postural control measurements were strongly influenced by sensory feedback and circadian effects. Sleep deprivation exacerbated subjective instability but had limited impact on objective balance measures, such as path length and sway area (Robillard et al., 2011). In contrast, physical stability measures, such as one-leg stand and train stand tests, showed weaker correlations with fall efficacy in mariners, where behavioral and psychological factors played a more prominent role.

Additionally, age was a critical variable in the older adult study, as expected, influencing both sleep patterns and postural control outcomes. In the mariners' study, age exhibited minimal associations with fall efficacy, reflecting the younger demographic and their distinct physiological and occupational contexts.

3.5 Implications for Practice

The findings across both studies contribute to theoretical models of fall risk by highlighting the multifaceted role of sleep and sensory integration in balance control. In line with previous research, the results emphasize the dynamic interplay between cognitive, physiological, and behavioral factors in maintaining stability (Nakano et al., 2001; Woollacott & Shumway-Cook, 2002). The differences between populations also underscore the need for tailored frameworks that account for demographic and contextual variations.

From a clinical perspective, the findings highlight actionable opportunities for intervention. Tailored sleep programs, sensory training, and behavioral modifications could address specific vulnerabilities in both older adults and mariners. For older adults, interventions might focus on enhancing sensory feedback and stabilizing circadian rhythms through light exposure or scheduled naps. For mariners, addressing pre-sleep routines and sleep onset latency could mitigate fall risks, particularly in the context of disrupted work schedules.

3.6 Clinical and Theoretical Implications

A central finding of this thesis is the sex-specific vulnerability observed under conditions of sleep deprivation and circadian disruption. Specifically, older men demonstrated greater susceptibility to balance impairment compared to women, particularly in the early morning hours. This aligns with previous literature indicating circadian-related reductions in alertness and neuromuscular performance typically occurring in the early morning, corresponding to the nadir of the circadian rhythm (Monk et al., 1997; Van Dongen & Dinges, 2005).

From a clinical perspective, these results suggest that targeted interventions aimed at preventing falls should prioritize improving sleep hygiene and stabilizing sleep schedules, particularly for older men and occupational groups working irregular shifts. Given the pronounced impairment observed under eyes-open conditions following sleep deprivation, occupational settings characterized by prolonged wakefulness and circadian misalignment (e.g., maritime operations, healthcare workers, emergency services) should integrate structured sleep management and circadian-aware scheduling into their occupational health practices.

Theoretically, these findings highlight the critical role circadian modulation plays in neuromuscular and sensory integration pathways involved in postural control. Differences observed between men and

women further suggest that biological factors, potentially including hormonal influences and differences in circadian physiology, may underpin these sex-specific vulnerabilities. Future research exploring hormonal or biological markers could extend these findings, potentially informing personalized fall-prevention strategies.

3.7 Strengths and Limitations of All Studies

A unifying objective of these studies was to explore how sleep patterns, circadian rhythms, and self-perceived fall risk intersect in different adult populations: cognitively healthy older adults, and younger mariners working in challenging, mobile conditions. Despite their distinct designs, both projects share several notable strengths that underscore their collective contribution to the understanding of sleep, circadian regulation, and motor function in relation to fall risk.

3.7.1 Strengths

One of the key strengths of the *older adult study* lies in its robust, multi-method approach, which integrated both subjective (e.g., standardized questionnaires on sleep quality, fall efficacy, and mood) and objective measures (e.g., psychomotor vigilance, and static posturography). By employing repeated assessments across different circadian phases, the study captured how sleep deprivation and light conditions might alter cognitive and motor performance in real time. Moreover, this design enabled the detection of subtler effects, such as how subjective feelings of instability can precede measurable declines in postural metrics, thus enriching the broader literature on fall prevention in aging populations.

In contrast, the *Mariners pilot study* illustrates the feasibility of remote data collection among a highly dispersed occupational group that faces significant constraints on time and location. Conducted entirely through online questionnaires, the research successfully reached maritime workers across multiple regions, showcasing that digital methods can be a powerful tool for gathering health-related data even in logistically challenging contexts. This remote format facilitated broad participant recruitment and minimized the need for extensive in-person procedures, making large-scale follow-ups or interventions both more practical and cost-effective. Additionally, the Mariners study's focus on a younger, predominantly male population provides an important counterpoint to the older-adult literature, broadening the understanding of how sleep and fall risk factors might differ across life stages and occupational settings.

Across all studies, ethical rigor, including institutional approvals and adherence to data protection standards, ensured the safety and rights of participants. The projects also employed validated instruments

to gauge insomnia severity, general sleep quality, mental well-being, and fall risk. Such consistency in measurement fosters comparability with other research findings, facilitating meaningful integration into the wider field of sleep and balance studies.

In summary, a significant strength of this research is the experimental manipulation of sleep pressure and circadian timing. Unlike previous studies primarily reliant on observational methods, the current experimental protocols allowed for precise causal inferences regarding the impact of sleep loss and circadian disruption on postural stability (Killgore, 2010; Lim & Dinges, 2010). Moreover, assessing balance across multiple sensory conditions provided robust evidence regarding the context-dependent nature of postural control deficits.

The feasibility study conducted remotely with mariners further highlights an important methodological contribution. The success of remotely collecting comprehensive sleep, lifestyle, and fall-risk data demonstrates potential scalability and applicability to other occupational groups that are traditionally difficult to access for laboratory-based research.

3.7.2 Limitations

While the older adult study's combined use of subjective and objective methods enhances its comprehensiveness, it also introduced practical and technical challenges. Notably, participants were tested in a sleep laboratory environment that sometimes suffered from less-than-ideal sound insulation, potentially affecting their ability to sleep or concentrate. Equipment glitches with the force plate and data acquisition software occasionally disrupted data collection and distracted participants, underscoring the need for more reliable hardware and procedural streamlining. These logistical and technological hurdles, compounded by pandemic-related delays (i.e., recruitment and lab closures during COVID-19 lockdowns), slowed the research timeline and required adaptive planning. Although these issues were largely surmountable, they illustrate how complex, resource-intensive protocols can limit sample sizes and complicate data collection.

On the other hand, the Mariners pilot study's primary limitation stems from its exclusive reliance on self-report data. While validated questionnaires can capture valuable insights, subjective measures are prone to recall bias and may not accurately reflect actual sleep patterns or fall incidents. Moreover, the pilot's predominantly male sample, and its modest sample size, reduce the generalizability of findings to other demographics (e.g., female mariners, older mariners, or different occupational settings). Lack of control or comparison groups (e.g., those with different shift patterns) also prevents causal interpretations about how factors like sleep deprivation might contribute directly to fall risk. Thus, although the remote

approach was feasible, it remains a first step rather than a definitive investigation, signaling the need for more diverse, multi-method, and larger-scale studies.

A common limitation shared by both studies is that they each targeted specific populations, older adults with particular inclusion criteria, and younger mariners working at sea, which narrows their applicability to broader contexts. The nature of pilot or feasibility research likewise means that certain variables remain insufficiently explored, and significant interactions may go undetected due to smaller samples or lack of interventions. To strengthen future research, integrating *objective measures of sleep* (e.g., actigraphy for mariners, or more refined polysomnography setups for older adults) with more diverse participant pools and potentially interventional or comparative designs would help draw clearer inferences about causality and optimize fall prevention strategies.

In summary, despite these strengths, several limitations should be acknowledged. The experimental component of this thesis utilized laboratory-based sleep deprivation and multi-nap protocols. While providing robust experimental control, this approach inevitably limits ecological validity, as controlled laboratory conditions differ substantially from real-world scenarios (Akerstedt & Wright, 2009; Van Dongen et al., 2004). Thus, future research could benefit from naturalistic studies examining real-world sleep disruption and circadian misalignment to confirm these findings' ecological applicability.

Furthermore, while sex-specific differences were clearly demonstrated, the underlying biological mechanisms remain speculative. Additional research incorporating hormonal and neurophysiological assessments could elucidate the pathways contributing to these sex-specific effects.

Finally, although the remote assessment approach used in the mariner population showed promise, reliance on self-reported data poses potential limitations regarding accuracy and subjective bias. Integrating objective sleep assessments (e.g., actigraphy) in future remote occupational studies could enhance validity and reliability.

Taken together, these studies offer complementary insights into how sleep disruption, circadian misalignment, and self-perceived fall risk converge across the adult lifespan and differing occupational contexts. The older adult research stands out for its combination of subjective questionnaires and laboratory-based objective measures, whereas the Mariners pilot underscores remote methodological feasibility and extends the conversation to a younger, male-dominated workforce. By synthesizing these findings, researchers and practitioners can better appreciate the multifaceted nature of fall risk, one that

involves physiological, psychological, and environmental factors, and can design future studies or interventions with a sharper focus on both population-specific and universal determinants of safe mobility. Despite their respective challenges, the strengths of these studies provide a firm foundation upon which more extensive and inclusive research can build.

3.8 Unexpected Findings and Future Directions

Several unexpected findings warrant further exploration. In older adults, the limited impact of sleep deprivation on objective balance measurements suggests a resilience in motor functions despite cognitive impairments, challenging assumptions about the universal effects of sleep loss on balance (Tucker et al., 2017; Saraiva et al., 2021). Similarly, in mariners, the weaker correlations between physical stability measures and fall efficacy point to the dominant role of psychological and behavioral factors, offering a unique perspective on fall risk predictors in younger occupational groups.

Future research should aim to integrate these findings into longitudinal designs, exploring the sustained effects of tailored interventions on sleep and balance. Expanding the use of remote assessments could enhance accessibility, particularly in high-risk professions. Moreover, incorporating dynamic environments, such as virtual reality or real-world simulations, could provide deeper insights into balance challenges and intervention efficacy.

3.9 Conclusion

The combined findings from the three empirical studies advance our understanding of the interconnected factors influencing balance control and fall risks. The results highlight the importance of sleep and physical wellbeing in both self-reported and objectively measured postural control with marked differences between sex groups. The results suggest that while sleep problem may be more common in women, men may be more vulnerable to sleep impairment with regards to falls risk. Mariners, mostly represented by men in the current study, typically work in an occupational setting exposed to factors the confer an increased vulnerability of postural control by disrupting the normal sleep-wake pattern due to extend shift work schedule and adverse environmental factors. By addressing shared and distinct predictors of postural control across older adults and mariners, this research lays a foundation for comprehensive, context-sensitive prevention strategies. Future investigations should continue to refine these approaches, enhancing safety and quality of life in diverse populations and occupational settings.

References

Adan, A., & Natale, V. (2002). Gender differences in morningness-eveningness preference. *Chronobiology International*, 19(4), 709-720.

Aguiar, S. A., & Barela, J. A. (2014). Sleep deprivation affects sensorimotor coupling in postural control of young adults. Neuroscience Letters, 574, 47-52.

Åkerstedt, T., & Wright Jr, K. P. (2009). Sleep loss and fatigue in shift work and shift work disorder. *Sleep medicine clinics*, *4*(2), 257.

Åkerstedt, T., Torsvall, L., & Gillberg, M. (1982). Sleepiness and shift work: field studies. *Sleep: Journal of Sleep Research & Sleep Medicine*.

Alfonsi, P., Tononi, G., & Bromfield, E. B. (2019). Prefrontal–hippocampal coupling during REM sleep. Nature communications, 10(1), 1-9.

Alhola, P., & Polo-Kantola, P. (2007). Sleep deprivation: Impact on cognitive performance. *Neuropsychiatric disease and treatment*, *3*(5), 553-567.

Allain, H., Bentué-Ferrer, D., Polard, E., Akwa, Y., & Patat, A. (2005). Postural instability and consequent falls and hip fractures associated with use of hypnotics in the elderly: a comparative review. *Drugs & aging*, *22*, 749-765.

Ambrose, A. F., Paul, G., & Hausdorff, J. M. (2013). Risk factors for falls among older adults: a review of the literature. *Maturitas*, *75*(1), 51-61.

Amstrup, A. K., Sikjaer, T., Mosekilde, L., & Rejnmark, L. (2015). The effect of melatonin treatment on postural stability, muscle strength, and quality of life and sleep in postmenopausal women: a randomized controlled trial. *Nutrition journal*, *14*, 1-8.

Ancoli-Israel, S., Cole, R., Alessi, C., Chambers, M., Moorcroft, W., & Pollak, C. P. (2003). The role of actigraphy in the study of sleep and circadian rhythms. *Sleep*, *26*(3), 342-392.

Andersson, G., Hagman, J., Talianzadeh, R., Svedberg, A., & Larsen, H. C. (2002). Effect of cognitive load on postural control. Brain research bulletin, 58(1), 135-139.

Archer, S. N., Laing, E. E., Möller-Levet, C. S., van der Veen, D. R., Bucca, G., Lazar, A. S., Santhi, N., Slak, A., Kabiljo, R., von Schantz, M., Smith, C. P., & Dijk, D.-J. (2014). Mistimed sleep disrupts circadian regulation of the human transcriptome. Proceedings of the National Academy of Sciences of the United States of America, 111(6), E682-E691.

Avni, Noa, Isaac Avni, Erez Barenboim, Bella Azaria, David Zadok, R. E. U. V. E. N. KOHEN-RAZ, and Yair Morad. "Brief posturographic test as an indicator of fatigue." Psychiatry and clinical neurosciences 60, no. 3 (2006): 340-346.

Backhaus, J., Junghanns, K., Mueller-Popkes, K., Broocks, A., Riemann, D., Hajak, G., & Hohagen, F. (2002). Short-term training increases diagnostic and treatment rate for insomnia in general practice. *European Archives of Psychiatry and Clinical Neuroscience*, *252*, 99-104.

Balbo, M., Leproult, R., & Van Cauter, E. (2010). Impact of sleep and its disturbances on hypothalamo-pituitary-adrenal axis activity. *International journal of endocrinology*, *2010*(1), 759234.

Barrett-Connor, E., Weiss, T. W., McHorney, C. A., Miller, P. D., & Siris, E. S. (2009). Predictors of falls among postmenopausal women: results from the National Osteoporosis Risk Assessment (NORA). Osteoporosis international, 20(5), 715-722.

Basheer, R., Strecker, R. E., Thakkar, M. M., & McCarley, R. W. (2004). Adenosine and sleep–wake regulation. *Progress in neurobiology*, *73*(6), 379-396.

Basner, M., & Dinges, D. F. (2011). Maximizing sensitivity of the psychomotor vigilance test (PVT) to sleep loss. Sleep, 34(5), 581-591.

Bastien, C. H., Vallières, A., & Morin, C. M. (2001). Validation of the Insomnia Severity Index as an outcome measure for insomnia research. Sleep Medicine, 2(4), 297–307.

Belenky, G., Wesensten, N. J., Thorne, D. R., Thomas, M. L., Sing, H. C., Redmond, D. P., ... & Balkin, T. J. (2003). Patterns of performance degradation and restoration during sleep restriction and subsequent recovery: A sleep dose-response study. *Journal of sleep research*, *12*(1), 1-12.

Berg, K. O., Maki, B. E., Williams, J. I., Holliday, P. J., & Wood-Dauphinee, S. L. (1992). Clinical and laboratory measures of postural balance in an elderly population. *Archives of physical medicine and rehabilitation*, *73*(11), 1073-1080.

Berg, K., & Norman, K. E. (1996). Functional assessment of balance and gait. *Clinics in geriatric medicine*, *12*(4), 705-723.

Berg, K., Wood-Dauphine, S., Williams, J. I., & Gayton, D. (1989). Measuring balance in the elderly: preliminary development of an instrument. *Physiotherapy Canada*, *41*(6), 304-311.

Bergen, G., Stevens, M. R., & Burns, E. R. (2016). Falls and fall injuries among adults aged≥ 65 years—United States, 2014. MMWR. Morbidity and mortality weekly report, 65(37), 993-998.

Berger, L., Chuzel, M., Buisson, G., & Rougier, P. (2005). Undisturbed upright stance control in the elderly: Part 1. Age-related changes in undisturbed upright stance control. Journal of motor behavior, 37(5), 348-358.

Berry, R. B., Brooks, R., Gamaldo, C. E., Harding, S. M., Lloyd, R. M., Quan, S. F., ... & Vaughn, B. V. (2020). AASM scoring manual updates for 2017 (version 2.4). Journal of clinical sleep medicine, 16(7), 1153-1153.

Berry, R. B., Budhiraja, R., Gottlieb, D. J., Gozal, D., Iber, C., Kapur, V. K., ... & Tangredi, M. M. (2012). Rules for scoring respiratory events in sleep: update of the 2007 AASM manual for the scoring of sleep and associated events: deliberations of the sleep apnea definitions task force of the American Academy of Sleep Medicine. *Journal of clinical sleep medicine*, *8*(5), 597-619.

Bertera, E. M., & Bertera, R. L. (2008). Fear of falling and activity avoidance in a national sample of older adults in the United States. *Health & Social Work*, *33*(1), 54-62.

Beurskens, A. J., Bültmann, U., Kant, I., Vercoulen, J. H., Bleijenberg, G., & Swaen, G. M. (2000). Fatigue among working people: validity of a questionnaire measure. Occupational and environmental medicine, 57(5), 353-357.

Blackwell, T., Yaffe, K., Ancoli-Israel, S., Schneider, J. L., Cauley, J. A., Hillier, T. A., ... & Stone, K. L. (2006). Poor sleep is associated with impaired cognitive function in older women: the study of osteoporotic fractures. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *61*(4), 405-410.

Blume, C., Garbazza, C., & Spitschan, M. (2019). Effects of light on human circadian rhythms, sleep and mood. Somnologie (Berl), 23(3), 147-156.

Bolton, D. A. (2015). The role of the cerebral cortex in postural responses to externally induced perturbations. Neuroscience & Biobehavioral Reviews, 57, 142-155.

Borbély, A. A. (1982). A two process model of sleep regulation. *Hum neurobiol*, *1*(3), 195-204.

Borbely, A. A., Daan, S., Wirz-Justice, A., & Deboer, T. (2016). The two-process model of sleep regulation: a reappraisal. J Sleep Res, 25(2), 131-143.

Bougard, C., Gomez-Merino, D., Rabat, A., Arnal, P., Van Beers, P., Guillard, M., ... & Chennaoui, M. (2018). Daytime microsleeps during 7 days of sleep restriction followed by 13 days of sleep recovery in healthy young adults. *Consciousness and cognition*, *61*, 1-12.

Brandt, J., Janzen, D., Alessi-Severini, S., Singer, A., Chateau, D., Enns, M., & Leong, C. (2021). Risk of long-term benzodiazepine and Z-drug use following the first prescription among community-dwelling adults with anxiety/mood and sleep disorders: a retrospective cohort study. *BMJ open*, *11*(11), e046916.

Brown, I. D. (1989). Study into hours of work, fatigue and safety at sea. Medical Research Counsil, Cambridge.

Brown, R. E., Basheer, R., McKenna, J. T., Strecker, R. E., & McCarley, R. W. (2012). Control of sleep and wakefulness. *Physiological reviews*.

Bucci, M. P., Le, T. T., Bonnet, C. T., & Rougier, P. R. (2015). Effects of eye and head positions on postural stability in healthy subjects. Gait & posture, 41(1), 78-82.

Bunner, K. D., & Rebec, G. V. (2016). Corticostriatal dysfunction in Huntington's disease: the basics. *Frontiers in human neuroscience*, *10*, 317.

Buysse, D. J., Ancoli-Israel, S., Edinger, J. D., Lichstein, K. L., & Morin, C. M. (2006). Recommendations for a standard research assessment of insomnia. *Sleep*, *29*(9), 1155-1173.

Buysse, D. J., Reynolds III, C. F., Monk, T. H., Berman, S. R., & Kupfer, D. J. (1989). The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research. Psychiatry research, 28(2), 193-213.

Cajochen, C. (2007). Alerting effects of light. *Sleep medicine reviews*, *11*(6), 453-464.

Cajochen, C., Wyatt, J. K., Czeisler, C. A., & Dijk, D. J. (2002). Separation of circadian and wake duration-dependent modulation of EEG activation during wakefulness. Neuroscience, 114(4), 1047-1060.

Caplan, R. D. (1987). Person-environment fit theory and organizations: Commensurate dimensions, time perspectives, and mechanisms. Journal of Vocational behavior, 31(3), 248-267.

Cardoso, S. S. L. L. (2021). *Effects of Sleep Deprivation on Postural Control* (Master's thesis, Universidade de Lisboa (Portugal)).

Carney, C. E., Buysse, D. J., Ancoli-Israel, S., Edinger, J. D., Krystal, A. D., Lichstein, K. L., & Morin, C. M. (2012). The consensus sleep diary: standardizing prospective sleep self-monitoring. *Sleep*, *35*(2), 287-302.

Carrier, J., & Bliwise, D. (2003). Sleep and circadian rhythms in normal aging. In *Sleep: Physiology, Investigations, and Medicine* (pp. 297-332). Boston, MA: Springer US.

Carskadon, M. A., & Dement, W. C. (2005). Normal human sleep: an overview. Principles and practice of sleep medicine, 4(1), 13-23.

Carskadon, M. A., & Dement, W. C. (2011). Monitoring and staging human sleep. *Principles and practice of sleep medicine*, *5*, 16-26.

Carskadon, M. A., & Dement, W. C. (2017). Normal human sleep: an overview. Principles and practice of sleep medicine, 6, 15-25.

Cavdar, S., ŞAN, T., Aker, R. E. Z. Z. A. N., ŞEHİRLİ, Ü., & Onat, F. İ. L. İ. Z. (2001). Cerebellar connections to the dorsomedial and posterior nuclei of the hypothalamus in the rat. The Journal of Anatomy, 198(1), 37-45.

Cham, R., & Redfern, M. S. (2002). Changes in gait when anticipating slippery floors. *Gait & posture*, *15*(2), 159-171.

Cho, K. (2001). Chronic 'jet lag' produces temporal lobe atrophy and spatial cognitive deficits. Nature neuroscience, 4(6), 567-568.

Chokroverty, S. (2010). Overview of sleep & sleep disorders. *Indian Journal of Medical Research*, *131*(2), 126-140.

Cistulli, P. A., & Grunstein, R. R. (2005). Medical devices for the diagnosis and treatment of obstructive sleep apnea. *Expert Review of Medical Devices*, *2*(6), 749-763.

Cohen, Z. L., Eigenberger, P. M., Sharkey, K. M., Conroy, M. L., & Wilkins, K. M. (2022). Insomnia and Other Sleep Disorders in Older Adults. Psychiatr Clin North Am, 45(4), 717-734.

Collins, J. J., & De Luca, C. J. (1993). Open-loop and closed-loop control of posture: a random-walk analysis of center-of-pressure trajectories. Experimental brain research, 95(2), 308-318.

Court, J. H., & Raven, J. (1998). Raven's progressive matrices. Oxford: Oxford Psychologists Press.

Coutrot, A., Lazar, A. S., Richards, M., Manley, E., Wiener, J. M., Dalton, R. C., Hornberger, M., & Spiers, H. J. (2022). Reported sleep duration reveals segmentation of the adult life-course into three phases. Nat Commun, 13(1), 7697.

Crowley, K. (2011). Sleep and sleep disorders in older adults. *Neuropsychology review*, *21*, 41-53.

Cummings P, Koepsell TD, Moffat JM, Rivara FP. Drowsiness, counter-measures to drowsiness, and the risk of a motor vehicle crash. Inj Prev. 2001;7:194–199.

Czeisler, C. A., & Gooley, J. J. (2007). Sleep and circadian rhythms in humans. Cold Spring Harbor symposia on quantitative biology, 72, 579-597.

Dault, M. C., Frank, J. S., & Allard, F. (2001). Influence of a visuo-spatial, verbal and central executive working memory task on postural control. Gait & posture, 14(2), 110-116.

Dault, M. C., Geurts, A. C., Mulder, T. W., & Duysens, J. (2001). Postural control and cognitive task performance in healthy participants while balancing on different support-surface configurations. Gait & posture, 14(3), 248-255.

Day, B. L., Steiger, M. J., Thompson, P. D., & Marsden, C. D. (1993). Effect of vision and stance width on human body motion when standing: implications for afferent control of lateral sway. The Journal of physiology, 469(1), 479-499.

Delahoz, Y. S., & Labrador, M. A. (2014). Survey on fall detection and fall prevention using wearable and external sensors. *Sensors*, *14*(10), 19806-19842.

DeLong, M. R., & Wichmann, T. (2007). Circuits and circuit disorders of the basal ganglia. Archives of neurology, 64(1), 20–24.

Demanze Laurence, B., & Michel, L. (2017). The fall in older adults: physical and cognitive problems. *Current aging science*, *10*(3), 185-200.

Diamond, A. (2013). Executive functions. *Annual review of psychology*, *64*(1), 135-168.

Diekelmann, S., & Born, J. (2010). The memory function of sleep. Nature Reviews Neuroscience, 11(2), 114-126.

Dijk, D. J., & Czeisler, C. A. (1994). Paradoxical timing of the circadian rhythm of sleep propensity serves to consolidate sleep and wakefulness in humans. Neurosci Lett, 166(1), 63-68.

Dijk, D. J., & Lazar, A. S. (2012). The regulation of human sleep and wakefulness: Sleep homeostasis and circadian rhythmicity.

Dijk, D. J., & Lockley, S. W. (2002). Invited review: integration of human sleep-wake regulation and circadian rhythmicity. Journal of applied physiology, 92(2), 852-862.

Dijk, D. J., Groeger, J. A., Stanley, N., & Deacon, S. (2010). Age-related reduction in daytime sleep propensity and nocturnal slow wave sleep. Sleep, 33(2), 211-223.

Dijk, D.-J., & Lazar, A. S. (2012). The Regulation of Human Sleep and Wakefulness: Sleep Homeostasis and Circadian Rhythmicity. In C. M. Morin & C. A. Espie (Eds.), The Oxford Handbook of Sleep and Sleep Disorders. 'Oxford University Press'.

Dinges, D. F., & Powell, J. W. (1985). Microcomputer analyses of performance on a portable, simple visual RT task during sustained operations. Behavior research methods, instruments, & computers, 17(6), 652-655.

Donker, S. F., Roerdink, M., Greven, A. J., & Beek, P. J. (2007). Regularity of center-of-pressure trajectories depends on the amount of attention invested in postural control. Experimental brain research, 181(1), 1-11.

Duarte, M., & Freitas, S. M. (2010). Revision of posturography based on force plate for balance evaluation. Brazilian journal of physical therapy, 14(3), 183-192.

Duffy, J. F., & Czeisler, C. A. (2009). Effect of light on human circadian physiology. Sleep medicine clinics, 4(2), 165-177.

Duffy, J. F., Zitting, K. M., & Chinoy, E. D. (2015). Aging and Circadian Rhythms. Sleep Med Clin, 10(4), 423-434.

Ellis, L. M., Allen, P. J., & Burke, A. L. (2003). Sleep and vigilance in ship Operators. Work and Stress on Ships: Evaluation of the Psychosocial Maritime Environment and Occupational Stressors on Board Ships. Research Project 462. Tasmania: Australian Maritime College.

Fabbri, M., Martoni, M., Esposito, M. J., Brighetti, G., & Natale, V. (2006). Postural control after a night without sleep. Neuropsychologia, 44(12), 2520-2525.

Facer-Childs, E., & Brandstaetter, R. (2015). The impact of circadian phenotype and time since awakening on diurnal performance in athletes. *Current biology*, *25*(4), 518-522.

Fastame, M. C., Mulas, I., Putzu, V., Asoni, G., Viale, D., Mameli, I., & Pau, M. (2022). Executive and Motor Functions in Older Individuals with Cognitive Impairment. *Behavioral Sciences*, *12*(7), 214.

Figueiro, M. G., Rea, M. S., Bullough, J. D., & Rea, A. C. (2006). Does architectural lighting contribute to breast cancer?. Journal of carcinogenesis, 5(1), 20.

Fitzpatrick, R. C., & Day, B. L. (2004). Probing the human vestibular system with galvanic stimulation. *Journal of applied physiology*, *96*(6), 2301-2316.

Fitzpatrick, R., & McCloskey, D. I. (1994). Proprioceptive, visual and vestibular thresholds for the perception of sway during standing in humans. The Journal of Physiology, 478(1), 173-186.

Flynn-Evans, E. E., Barger, L. K., Kubey, A. A., Sullivan, J. P., & Czeisler, C. A. (2016). Circadian misalignment affects sleep and medication use before and during spaceflight. *npj Microgravity*, *2*(1), 1-6.

Foley, D., Ancoli-Israel, S., Britz, P., & Walsh, J. (2004). Sleep disturbances and chronic disease in older adults: results of the 2003 National Sleep Foundation Sleep in America Survey. J Psychosom Res, 56(5), 497-502.

Folkard, S., & Tucker, P. (2003). Shift work, safety and productivity. *Occupational medicine*, *53*(2), 95-101.

Foo, S. C., How, J., Siew, M. G., Wong, T. M., Vijayan, A., & Kanapathy, R. (1994). Effects of sleep deprivation on naval seamen: II. Short recovery sleep on performance. Annals of the Academy of Medicine, Singapore, 23(5), 676-679.

Formiga, F., Navarro, M., Duaso, E., Chivite, D., Ruiz, D., Perez-Castejon, J. M., ... & Pujol, R. (2008). Factors associated with hip fracture-related falls among patients with a history of recurrent falling. Bone, 43(5), 941-944.

Forsman, P., & Hæggström, E. (2013). Circadian amplitude and homeostatic buildup rate in postural control. Gait & Posture, 38(2), 192-197.

Foster, R. G., Hughes, S., & Peirson, S. N. (2020). Circadian Photoentrainment in Mice and Humans. Biology (Basel), 9(7).

Freeman, D., Sheaves, B., Waite, F., Harvey, A. G., & Harrison, P. J. (2020). Sleep disturbance and psychiatric disorders. Lancet Psychiatry, 7(7), 628-637.

Freitas, S. M., Wieczorek, S. A., Marchetti, P. H., & Duarte, M. (2005). Age-related changes in human postural control of prolonged standing. *Gait & posture*, *22*(4), 322-330.

Frith, C. (1973). Effects of stimulation of the sub-thalamic region on movement in the baboon (papio papio). Brain Research, 63, 325–334.

Furtado, F., Gonçalves, B. d. S. B., Abranches, I. L. L., Abrantes, A. F., & Forner-Cordero, A. (2016). Chronic low quality sleep impairs postural control in healthy adults. PLoS One, 11(10), e0163310.

Gabehart, R. J., & Van Dongen, H. P. (2017). Circadian rhythms in sleepiness, alertness, and performance. In *Principles and practice of sleep medicine* (pp. 388-395). Elsevier.

Gage, W. H., Winter, D. A., Frank, J. S., & Adkin, A. L. (2004). Kinematic and kinetic validity of the inverted pendulum model in quiet standing. *Gait & posture*, *19*(2), 124-132.

Gander, P., Hartley, L., Powell, D., Cabon, P., Hitchcock, E., Mills, A., & Popkin, S. (2011). Fatigue risk management: Organizational factors at the regulatory and industry/company level. Accident Analysis & Prevention, 43(2), 573-590.

Gao, Z., Liu, W., McDonough, D. J., Zeng, N., & Lee, J. E. (2021). The dilemma of analyzing physical activity and sedentary behavior with wrist accelerometer data: challenges and opportunities. *Journal of Clinical Medicine*, *10*(24), 5951.

Geerligs, L., Renken, R. J., Saliasi, E., Maurits, N. M., & Lorist, M. M. (2014). A brain-wide study of age-related changes in functional connectivity. Cerebral cortex, 25(7), 1987-1999.

Gillespie, L. (2013). Preventing falls in older people: the story of a Cochrane review. *The Cochrane Database of Systematic Reviews*, *2013*(2).

Glass, J., Lanctôt, K. L., Herrmann, N., Sproule, B. A., & Busto, U. E. (2005). Sedative hypnotics in older people with insomnia: meta-analysis of risks and benefits. *Bmj*, *331*(7526), 1169.

Goble, D. J., Coxon, J. P., Wenderoth, N., Van Impe, A., & Swinnen, S. P. (2009). Proprioceptive sensibility in the elderly: degeneration, functional consequences and plastic-adaptive processes. Neuroscience & Biobehavioral Reviews, 33(3), 271-278.

Goh, V. H. H., Tong, T. Y. Y., Lim, C. L., Low, E. C. T., & Lee, L. K. H. (2000). Circadian disturbances after night-shift work onboard a naval ship. Military Medicine, 165(2), 101-105.

Goldman, S. E., Stone, K. L., Ancoli-Israel, S., Blackwell, T., Ewing, S. K., Boudreau, R., ... & Newman, A. B. (2007). Poor sleep is associated with poorer physical performance and greater functional limitations in older women. Sleep, 30(10), 1317-1324.

Gomez, S., Patel, M., Berg, S., Magnusson, M., Johansson, R., & Fransson, P. A. (2008). Effects of proprioceptive vibratory stimulation on body movement at 24 and 36 h of sleep deprivation. Clinical neurophysiology, 119(3), 617-625.

Gómez-González, B., Domínguez-Salazar, E., Hurtado-Alvarado, G., Esqueda-León, E., Santana-Miranda, R., Rojas-Zamorano, J. Á., & Velázquez Moctezuma, J. (2012). Role of sleep in the regulation of the

immune system and the pituitary hormones. Annals of the New York Academy of Sciences, 1261(1), 97-106.

Gonçalves, D., Costa, J. P., Silva, S., Tavares, M., Barros, H., & Meireles, P. (2024). The association between probable post-COVID-19 condition and sleep-related parameters: a longitudinal study of non-hospitalised patients. *Journal of Sleep Research*, e14215.

Goswami, N., Abulafia, C., Vigo, D., Moser, M., Cornelissen, G., & Cardinali, D. (2020). Falls risk, circadian rhythms and melatonin: current perspectives. *Clinical interventions in aging*, 2165-2174.

Graw, P., Kräuchi, K., Knoblauch, V., Wirz-Justice, A., & Cajochen, C. (2004). Circadian and wake-dependent modulation of fastest and slowest reaction times during the psychomotor vigilance task. Physiology & behavior, 80(5), 695-701.

Grech, M. R., Horberry, T. J., & Humphreys, M. S. (2003). Fatigue and human error in the maritime domain.

Greene, L., Aryankhesal, A., Megson, M., Blake, J., Wong, G., Briscoe, S., Hilton, A., Killett, A., Reeve, J., Allan, L., Ballard, C., Broomfield, N., van Horik, J., Khondoker, M., Lazar, A., Litherland, R., Livingston, G., Maidment, I., Medina-Lara, A., . . . Fox, C. (2022). Understanding primary care diagnosis and management of sleep disturbance for people with dementia or mild cognitive impairment: a realist review protocol. BMJ Open, 12(11), e067424.

Greenspan, S. L., Myers, E. R., Maitland, L. A., Resnick, N. M., & Hayes, W. C. (1994). Fall severity and bone mineral density as risk factors for hip fracture in ambulatory elderly. *Jama*, *271*(2), 128-133.

Gribble, P. A., & Hertel, J. (2004). Changes in postural control during a 48-hr. sleep deprivation period. Perceptual and motor skills, 99(3), 1035-1045.

Gribble, P. A., Tucker, W. S., & White, P. A. (2007). Time-of-day influences on static and dynamic postural control. *Journal of athletic training*, *42*(1), 35.

Groeger, J. A., Lo, J. C., Santhi, N., Lazar, A. S., & Dijk, D. J. (2022). Contrasting Effects of Sleep Restriction, Total Sleep Deprivation, and Sleep Timing on Positive and Negative Affect. Front Behav Neurosci, 16, 911994.

Guerraz, M., & Bronstein, A. M. (2008). Mechanisms underlying visually induced body sway. *Neuroscience letters*, *443*(1), 12-16.

Guette, M., Gondin, J., & Martin, A. (2005). Time-of-day effect on the torque and neuromuscular properties of dominant and non-dominant quadriceps femoris. *Chronobiology international*, *22*(3), 541-558.

Gurfinkel, V. S., Lipshits, M. I., & Popov, K. E. (1977). A study of the upright stance regulation system by means of vibratory stimulation of the muscle spindles. *Fiziol Cheloveka*, *3*, 635-643.

Haeggstrom, E. O., Forsman, P. M., Wallin, A. E., Toppila, E. M., & Pyykko, I. V. (2006). Evaluating sleepiness using force platform posturography. IEEE Transactions on biomedical engineering, 53(8), 1578-1585.

Halpern, A. I., Jansen, J. A., Giladi, N., Mirelman, A., & Hausdorff, J. M. (2022). Does Time of Day influence postural control and gait? A review of the literature. Gait & Posture, 92, 153-166.

Hansen, H. L., Nielsen, D., & Frydenberg, M. (2002). Occupational accidents aboard merchant ships. Occupational and environmental medicine, 59(2), 85-91.

Harris, G. F., & Smith, P. A. (2007). *Foot and ankle motion analysis: clinical treatment and technology*. CRC press.

Harrison, J. E., Mandryk, J. A., & Frommer, M. S. (1993). Work-related road fatalities in Australia, 1982–1984. Accident Analysis & Prevention, 25(4), 443-451.

Harrison, Y., & Horne, J. A. (2000). The impact of sleep deprivation on decision making: a review. *Journal of experimental psychology: Applied*, *6*(3), 236.

Hartikainen, S., Lönnroos, E., & Louhivuori, K. (2007). Medication as a risk factor for falls: critical systematic review. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *62*(10), 1172-1181.

Hastings, M., O'Neill, J. S., & Maywood, E. S. (2007). Circadian clocks: regulators of endocrine and metabolic rhythms. *Journal of Endocrinology*, *195*(2), 187-198.

Hatch, J., Gill-Body, K. M., & Portney, L. G. (2003). Determinants of balance confidence in community-dwelling elderly people. *Physical therapy*, *83*(12), 1072-1079.

Heaver, T. D. (1993). The many facets of maritime economics, in association. Maritime policy and Management, 20(2), 121-132.

Hennig, T., Schlier, B., & Lincoln, T. M. (2020). Sleep and psychotic symptoms: An actigraphy and diary study with young adults with low and elevated psychosis proneness. *Schizophrenia Research*, *221*, 12-19.

Hinman, R. S., Bennell, K. L., Metcalf, B. R., & Crossley, K. M. (2002). Balance impairments in individuals with symptomatic knee osteoarthritis: a comparison with matched controls using clinical tests. *Rheumatology*, *41*(12), 1388-1394.

Hirshkowitz, M., Whiton, K., Albert, S. M., Alessi, C., Bruni, O., DonCarlos, L., Hazen, N., Herman, J., Adams Hillard, P. J., Katz, E. S., Kheirandish-Gozal, L., Neubauer, D. N., O'Donnell, A. E., Ohayon, M., Peever, J., Rawding, R., Sachdeva, R. C., Setters, B., Vitiello, M. V., & Ware, J. C. (2015). National Sleep Foundation's updated sleep duration recommendations: final report. Sleep Health, 1(4), 233-243.

Hita-Contreras, F., Zagalaz-Anula, N., Martínez-Amat, A., Cruz-Díaz, D., Sánchez-Montesinos, I., Aibar-Almazán, A., & Lomas-Vega, R. (2018). Sleep quality and its association with postural stability and fear of falling among Spanish postmenopausal women. *Menopause*, *25*(1), 62-69.

Hita-Yanez, E., Atienza, M., & Cantero, J. L. (2013). Polysomnographic and subjective sleep markers of mild cognitive impairment. Sleep, 36(9), 1327-1334.

Ho, L. Y., Jaeger, M., & Bardy, B. G. (2021). Aging and postural control. Gerontology, 67(5), 465-476.

Horak, F. B. (1997). Clinical assessment of balance disorders. *Gait & posture*, *6*(1), 76-84.

Horak, F. B. (2006). Postural orientation and equilibrium: what do we need to know about neural control of balance to prevent falls?. *Age and ageing*, *35*(suppl_2), ii7-ii11.

Horak, F. B., & Macpherson, J. M. (1996). Postural orientation and equilibrium. *Comprehensive physiology*, 255-292.

Horak, F. B., Diener, H. C., & Nashner, L. M. (1989). Influence of central set on human postural responses. *Journal of neurophysiology*, *62*(4), 841-853.

Horak, F. B., Nashner, L. M., & Diener, H. C. (1990). Postural strategies associated with somatosensory and vestibular loss. *Experimental brain research*, *82*, 167-177.

Horak, F. B., Nutt, J. G., & Nashner, L. M. (1992). Postural inflexibility in parkinsonian subjects. *Journal of the neurological sciences*, *111*(1), 46-58.

Horak, F. B., Wrisley, D. M., & Frank, J. (2009). The balance evaluation systems test (BESTest) to differentiate balance deficits. *Physical therapy*, *89*(5), 484-498.

Horne, J. A., & Östberg, O. (1976). A self-assessment questionnaire to determine morningness-eveningness in human circadian rhythms. International Journal of Chronobiology, 4(2), 97–110.

Horowitz, S. S., Blanchard, J. H., & Morin, L. P. (2004). Intergeniculate leaflet and ventral lateral geniculate nucleus afferent connections: An anatomical substrate for functional input from the vestibulo-visuomotor system. Journal of Comparative Neurology, 474(2), 227-245.

Horowitz, S. S., Blanchard, J., & Morin, L. P. (2005). Medial vestibular connections with the hypocretin (orexin) system. Journal of Comparative Neurology, 487(2), 127-146.

Huber, R., Ghilardi, M. F., Massimini, M., & Tononi, G. (2004). Local sleep and learning. Nature, 430(6995), 78-81.

Huxhold, O., Li, S. C., Schmiedek, F., & Lindenberger, U. (2006). Dual-tasking postural control: aging and the effects of cognitive demand in conjunction with focus of attention. Brain research bulletin, 69(3), 294-305.

Iber, C., Ancoli-Israel, S., Chesson, A. L., & Quan, S. F. (2007). The new sleep scoring manual–the evidence behind the rules. *Journal of Clinical Sleep Medicine*, *3*(02), 107-107.

IHS Fairplay "world fleet statistics 1999-2011; world casualty statistics 1999-2010," ed, 2012.

IMO Annual Report, IMO, (2019). , Accessed on June, 2019.

IMO, Guidelines on Fatigue. (2002). International Maritime Organization.

International Maritime Organization (2014). The international Maritime Industries: Contribution to the United Kingdom Economy. Report for Maritime London. Brentford, England.
IMHA. International Maritime Health Association. Newsletter. January 2012: 14.

International Maritime Organization (IMO). (2004). Fatigue: guidelines for the development of tables of seafarers' shipboard working arrangements and formats of records of seafarers' hours of work or hours of rest. Submitted by Norway (MSC/Circ.1014). London: IMO.

Ioannides, A. A., Kostopoulos, G. K., Liu, L., & Fenwick, P. B. (2009). MEG identifies dorsal medial brain activations during sleep. Neuroimage, 44(2), 455-468.

Ishak, W. W., Bagot, K., Thomas, S., Magakian, N., Bedwani, D., Larson, D., Brownstein, A., & Zaky, C. (2012). Quality of life in patients suffering from insomnia. Innov Clin Neurosci, 9(10), 13-26.

Ivanenko, Y. P., Grasso, R., & Lacquaniti, F. (1999). Effect of gaze on postural responses to neck proprioceptive and vestibular stimulation in humans. *The Journal of physiology*, *519*(1), 301-314.

Ivers, R. Q., Cumming, R. G., Mitchell, P., & Peduto, A. J. (2001). Diabetes and risk of fracture: the Blue Mountains Eye Study. *Diabetes care*, *24*(7), 1198-1203.

Izadi, M., Thomas, E., Thomas, A. C., & Bellafiore, M. (2022). The effect of time-of-day and sleep deprivation on postural control: A systematic review. Gait & Posture.

Jacobs, J. V., & Horak, F. (2007). Cortical control of postural responses. *Journal of neural transmission*, *114*, 1339-1348.

Janssen, N., Kant, I. J., Swaen, G. M. H., Janssen, P. P. M., & Schröer, C. A. P. (2003). Fatigue as a predictor of sickness absence: results from the Maastricht cohort study on fatigue at work. Occupational and environmental medicine, 60(suppl 1), i71-i76.

Jaremin, B. (2005). Work-site casualties and environmental risk assessment on board Polish vessels. International maritime health, 56(1-4), 17-27.

Johns, M. W. (1991). A new method for measuring daytime sleepiness: The Epworth Sleepiness Scale. Sleep, 14(6), 540–545.

Jorgensen, M. G., Rathleff, M. S., Laessoe, U., Caserotti, P., Nielsen, O. B. F., & Aagaard, P. (2012). Time-of-day influences postural balance in older adults. *Gait & posture*, *35*(4), 653-657.

Kaida, K., Takahashi, M., Åkerstedt, T., Nakata, A., Otsuka, Y., Haratani, T., & Fukasawa, K. (2006). Validation of the Karolinska sleepiness scale against performance and EEG variables. Clinical Neurophysiology, 117(7), 1574–1581.

Kakara, R. S., Lee, R., & Eckstrom, E. N. (2023). Cause-specific mortality among adults aged≥ 65 years in the United States, 1999 through 2020. Public Health Reports, 00333549231155869.Berger, R. A., Nicholas, J. A., Riemer, B. L., Lehmann, E. F., & Kaliferis, S. (2008). Falls in the elderly: risk assessment and management. The Harvard mental health letter, 24(8), 4.

Kamijantono, H., Sebayang, M. M., & Lesmana, A. (2024). Risk Factors and Ergonomic Influence on Musculoskeletal Disorders in the Work Environment. *Journal La Medihealtico*, *5*(3), 660-670.

Kato, M., Phillips, B. G., Sigurdsson, G., Narkiewicz, K., Pesek, C. A., & Somers, V. K. (2000). Effects of sleep deprivation on neural circulatory control. *Hypertension*, *35*(5), 1173-1175.

Kaufman, A. S., & Lichtenberger, E. O. (1999). Essentials of WAIS-III assessment. John Wiley & Sons Inc.

Kavounoudias, A., Roll, R., & Roll, J. P. (1998). The plantar sole is a ‘dynamometric map’for human balance control. *Neuroreport*, *9*(14), 3247-3252.

Kempen, G. I., Todd, C. J., Van Haastregt, J. C., Rixt Zijlstra, G. A., Beyer, N., Freiberger, E., ... & Yardley, L. (2007). Cross-cultural validation of the Falls Efficacy Scale International (FES-I) in older people: results from Germany, the Netherlands and the UK were satisfactory. *Disability and rehabilitation*, *29*(2), 155-162.

Kerkhof, G. A. (2017). Epidemiology of sleep and sleep disorders in The Netherlands. Sleep Med, 30, 229-239.

Killgore, W. D. (2010). Effects of sleep deprivation on cognition. Progress in brain research, 185, 105-129.

Kirshner, D., Spiegelhalder, K., Shahar, R. T., Shochat, T., & Agmon, M. (2022). The association between objective measurements of sleep quality and postural control in adults: A systematic review. Sleep Medicine Reviews, 101633.

Kivela, L., Papadopoulos, M. R., & Antypa, N. (2018). Chronotype and Psychiatric Disorders. Curr Sleep Med Rep, 4(2), 94-103.

Klerman, E. B., & Dijk, D. J. (2008). Age-related reduction in the maximal capacity for sleep--implications for insomnia. Curr Biol, 18(15), 1118-1123.

Knechel, N. A., & Chang, P. S. (2022). The relationships between sleep disturbance and falls: A systematic review. *Journal of sleep research*, *31*(5), e13580.

Komisar, V., Maki, B. E., & Novak, A. C. (2019). Effect of handrail height and age on the timing and speed of reach-to-grasp balance reactions during slope descent. *Applied ergonomics*, *81*, 102873.

Komisar, V., McIlroy, W. E., & Duncan, C. A. (2019). Individual, task, and environmental influences on balance recovery: a narrative review of the literature and implications for preventing occupational falls. *IISE Transactions on Occupational Ergonomics and Human Factors*, *7*(2), 91-118.

Krause, A. J., Simon, E. B., Mander, B. A., Greer, S. M., Saletin, J. M., Goldstein-Piekarski, A. N., & Walker, M. P. (2017). The sleep-deprived human brain. *Nature Reviews Neuroscience*, *18*(7), 404-418.

Krishnan, V., & Collop, N. A. (2006). Gender differences in sleep disorders. *Current Opinion in Pulmonary Medicine*, 12(6), 383-389.

Kroenke, K., Spitzer, R. L., & Williams, J. B. (2001). The PHQ-9: Validity of a brief depression severity measure. Journal of General Internal Medicine, 16(9), 606–613.

Kryger, M. H., Roth, T., & Dement, W. C. (2010). *Principles and Practice of Sleep Medicine-E-Book: Expert Consult-Online and Print*. Elsevier Health Sciences.

Krystal, A. D., & Edinger, J. D. (2008). Measuring sleep quality. Sleep medicine, 9, S10-S17.

Langeard, A., Zouabi, A., Martin, T., Quarck, G., & Gauthier, A. (2022). Circadian rhythm of postural control, sleepiness and verticality perception in older adults. Age Ageing, 51(3).

Lauber, J. K., & Kayten, P. J. (1988). Sleepiness, circadian dysrhythmia, and fatigue in transportation system accidents. Sleep: Journal of Sleep Research & Sleep Medicine.

Laurino, M., Menicucci, D., Piarulli, A., Mastorci, F., Bedini, R., Allegrini, P., & Gemignani, A. (2019). Disentangling different functional roles of evoked K-complex components: mapping the sleeping brain while quenching sensory processing. Neuroimage, 186, 439-448.

Lazar, A. S., Lazar, Z. I., & Dijk, D. J. (2015). Circadian regulation of slow waves in human sleep: Topographical aspects. Neuroimage, 116, 123-134.

Lazar, A. S., Santhi, N., Hasan, S., Lo, J. C., Johnston, J. D., Von Schantz, M., Archer, S. N., & Dijk, D. J. (2013). Circadian period and the timing of melatonin onset in men and women: predictors of sleep during the weekend and in the laboratory. J Sleep Res, 22(2), 155-159.

Lazar, A. S., Slak, A., Lo, J. C., Santhi, N., von Schantz, M., Archer, S. N., Groeger, J. A., & Dijk, D. J. (2012). Sleep, diurnal preference, health, and psychological well-being: a prospective single-allelic-variation study. Chronobiol Int, 29(2), 131-146.

Leproult, R., Holmback, U., & Van Cauter, E. (2014). Circadian misalignment augments markers of insulin resistance and inflammation, independently of sleep loss. Diabetes, 63(6), 1860-1869.

Leung, A. W., Chan, C. C., Ng, J. J., & Wong, P. C. (2006). Factors contributing to officers' fatigue in high-speed maritime craft operations. Applied ergonomics, 37(5), 565-576.

Lewis, O. D., Morkous, S., Strohl, K. P., & Rosen, C. L. (2015). Actigraphy as a "truth-buster". *Journal of Clinical Sleep Medicine*, *11*(12), 1466-1469.

Li, Y., Sahakian, B. J., Kang, J., Langley, C., Zhang, W., Xie, C., Xiang, S., Yu, J., Cheng, W., & Feng, J. (2022). The brain structure and genetic mechanisms underlying the nonlinear association between sleep duration, cognition and mental health. Nature Aging, 2(5), 425-437.

Lim, J., & Dinges, D. F. (2010). A meta-analysis of the impact of short-term sleep deprivation on cognitive variables. *Psychological bulletin*, *136*(3), 375.

Liu, C. J., & Latham, N. K. (2009). Progressive resistance strength training for improving physical function in older adults. *Cochrane database of systematic reviews*, (3).

Liu, J. H., Ma, Q. H., Sun, H. P., Xu, Y., & Pan, C. W. (2021). Depressive symptom as a mediator of the influence of self-reported sleep quality on falls: a mediation analysis. *Aging & mental health*, *25*(4), 728-733.

Liu, Y., Higuchi, S., & Motohashi, Y. (2001). Changes in postural sway during a period of sustained wakefulness in male adults. Occupational Medicine, 51(8), 490-495.

Lo, J. C., Groeger, J. A., Cheng, G. H., Dijk, D. J., & Chee, M. W. (2016). Self-reported sleep duration and cognitive performance in older adults: A systematic review and meta-analysis. Sleep Medicine, 17, 87-98.

Lo, J. C., Groeger, J. A., Santhi, N., Arbon, E. L., Lazar, A. S., Hasan, S., ... & Dijk, D. J. (2012). Effects of partial and acute total sleep deprivation on performance across cognitive domains, individuals and circadian phase. PloS one, 7(9), e45987.

Loram, I. D. (2015). Postural control and sensorimotor integration.

Lord S. R., & Menz H. B. (2000). Visual contributions to postural stability in older adults. Gerontology, 46(6), 306–310.

Lord, S. R. (2006). Visual risk factors for falls in older people. *Age and ageing*, *35*(suppl_2), ii42-ii45.

Lord, S. R., & Dayhew, J. (2001). Visual risk factors for falls in older people. Journal of the American Geriatrics Society, 49(5), 508–515.

Lord, S. R., & Ward, J. A. (1994). Age-associated differences in sensori-motor function and balance in community dwelling women. Age and ageing, 23(6), 452-460.

Lord, S. R., Menz, H. B., & Tiedemann, A. (2003). A physiological profile approach to falls risk assessment and prevention. *Physical therapy*, *83*(3), 237-252.

Ma, J., Yao, Y. J., Ma, R. M., Li, J. Q., Wang, T., Li, X. J., ... & Zhang, Z. M. (2009). Effects of sleep deprivation on human postural control, subjective fatigue assessment and psychomotor performance. *Journal of international medical research*, *37*(5), 1311-1320.

Macchi, M. M., & Bruce, J. N. (2004). Human pineal physiology and functional significance of melatonin. *Frontiers in neuroendocrinology*, *25*(3-4), 177-195.

Macedo, C., Gazzola, J. M., Ricci, N. A., Doná, F., & Ganança, F. F. (2015). Influence of sensory information on static balance in older patients with vestibular disorder. *Brazilian journal of otorhinolaryngology*, *81*, 50-57.

Magnavita, N., Di Prinzio, R. R., Arnesano, G., Cerrina, A., Gabriele, M., Garbarino, S., ... & Barbic, F. (2021). Association of occupational distress and low sleep quality with syncope, presyncope, and falls in workers. *International journal of environmental research and public health*, *18*(23), 12283.

Maki, B. E., & McIlroy, W. E. (1996). Postural control in the older adult. Clinics in geriatric medicine, 12(4), 635-658.

Maki, B. E., Holliday, P. J., & Topper, A. K. (1991). Fear of falling and postural performance in the elderly. *Journal of gerontology*, *46*(4), M123-M131.

Maki, B. E., Holliday, P. J., & Topper, A. K. (1994). A prospective study of postural balance and risk of falling in an ambulatory and independent elderly population. Journal of gerontology, 49(2), M72-M84.

Maldonado, J. R. (2018). Delirium pathophysiology: an updated hypothesis of the etiology of acute brain failure. *International journal of geriatric psychiatry*, *33*(11), 1428-1457.

Mallampalli, M. P., & Carter, C. L. (2014). Exploring sex and gender differences in sleep health: a Society for Women's Health Research Report. *Journal of Women's Health*, 23(7), 553-562.

Mancini, M., Horak, F. B., Zampieri, C., Carlson-Kuhta, P., Nutt, J. G., & Chiari, L. (2011). Trunk accelerometry reveals postural instability in untreated Parkinson's disease. *Parkinsonism & related disorders*, *17*(7), 557-562.

Mander, B. A., Marks, S. M., Vogel, J. W., Rao, V., Lu, B., Saletin, J. M., Ancoli-Israel, S., Jagust, W. J., & Walker, M. P. (2015). beta-amyloid disrupts human NREM slow waves and related hippocampus-dependent memory consolidation. Nat Neurosci, 18(7), 1051-1057.

Mander, B. A., Rao, V., Lu, B., Saletin, J. M., Lindquist, J. R., Ancoli-Israel, S., Jagust, W., & Walker, M. P. (2013). Prefrontal atrophy, disrupted NREM slow waves and impaired hippocampal-dependent memory in aging. Nat Neurosci, 16(3), 357-364.

Mander, B. A., Winer, J. R., & Walker, M. P. (2017). Sleep and human aging. Neuron, 94(1), 19-36.

Maquet, P., Schwartz, S., Passingham, R., & Frith, C. (2003). Sleep-related consolidation of a visuomotor skill: Brain mechanisms as assessed by functional magnetic resonance imaging. Journal of Neuroscience, 23(4), 1432–1440.

Marras, W. S. (1999). Occupational biomechanics. In W. Karwowski & W. S. Marras (Eds.), *Occupational ergonomics handbook*. Boca Raton, FL: CRC Press.

Martin, A., Carpentier, A., Guissard, N., Van Hoecke, J., & Duchateau, J. (1999). Effect of time of day on force variation in a human muscle. *Muscle & nerve*, *22*(10), 1380-1387.

Martin, J. L., & Alessi, C. A. (2006). Limited validity of minimum data set items on sleep and hypnotic use in predicting falls and hip fracture in nursing home residents. Journal of the American Geriatrics Society, 54(7), 1150-1151.

Martin, J. L., & Hakim, A. D. (2011). Wrist actigraphy. *Chest*, *139*(6), 1514-1527.

Martin, M., Shinberg, M., Kuchibhatla, M., Ray, L., Carollo, J. J., & Schenkman, M. L. (2002). Gait initiation in community-dwelling adults with Parkinson disease: Comparison with older and younger adults without the disease. Physical therapy, 82(6), 566-577.

Martin, T., Mauvieux, B., Bulla, J., Quarck, G., Davenne, D., Denise, P., ... & Besnard, S. (2015). Vestibular loss disrupts daily rhythm in rats. *Journal of Applied Physiology*, *118*(3), 310-318.

Martin, T., Moussay, S., Bulla, I., Bulla, J., Toupet, M., Etard, O., ... & Quarck, G. (2016). Exploration of circadian rhythms in patients with bilateral vestibular loss. *PloS one*, *11*(6), e0155067.

Massion, J. (1992). Movement, posture and equilibrium: interaction and coordination. *Progress in neurobiology*, *38*(1), 35-56.

Massion, J. (1994). Postural control system. *Current opinion in neurobiology*, *4*(6), 877-887.

Maylor, E. A., & Wing, A. M. (1996). Age differences in postural stability are increased by additional cognitive demands. The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 51(3), P143-P154.

McBean, A. L., Najjar, R. P., Schuchard, R. A., Hall, C. D., Wang, C. A., Ku, B., & Zeitzer, J. M. (2016). Standing balance and spatiotemporal aspects of gait are impaired upon nocturnal awakening in healthy late middle-aged and older adults. *Journal of clinical sleep medicine*, *12*(11), 1477-1486.

Melzer, I., Benjuya, N., & Kaplanski, J. (2001). Age-related changes of postural control: effect of cognitive tasks. *Gerontology*, *47*(4), 189-194.

Melzer, I., Benjuya, N., & Kaplanski, J. (2004). Postural stability in the elderly: a comparison between fallers and non-fallers. Age and ageing, 33(6), 602-607.

Melzer, I., Krasovsky, T., Oddsson, L. I. E., & Liebermann, D. G. (2010). Age-related differences in lower-limb force–time relation during the push-off in rapid voluntary stepping. *Clinical Biomechanics*, *25*(10), 989-994.

Meyer, N., Harvey, A. G., Lockley, S. W., & Dijk, D. J. (2022). Circadian rhythms and disorders of the timing of sleep. *The Lancet*, *400*(10357), 1061-1078.

Min, Y., Kirkwood, C. K., Mays, D. P., & Slattum, P. W. (2016). The effect of sleep medication use and poor sleep quality on risk of falls in community-dwelling older adults in the US: a prospective cohort study. *Drugs & aging*, *33*, 151-158.

Mohawk, J. A., Green, C. B., & Takahashi, J. S. (2012). Central and peripheral circadian clocks in mammals. Annu Rev Neurosci, 35, 445-462.

Moldofsky, H., Scarisbrick, P., England, R., & Smythe, H. (1975). Musculosketal symptoms and non-REM sleep disturbance in patients with “fibrositis syndrome” and healthy subjects. *Psychosomatic medicine*, *37*(4), 341-351.

Monti, J. M. (2011). Serotonin control of sleep-wake behavior. *Sleep medicine reviews*, *15*(4), 269-281.

Morin, C. M., Bootzin, R. R., Buysse, D. J., Edinger, J. D., Espie, C. A., & Lichstein, K. L. (2006). Psychological and behavioral treatment of insomnia:update of the recent evidence (1998-2004). Sleep, 29(11), 1398-1414.

Morin, C. M., Colecchi, C., Stone, J., Sood, R., & Brink, D. (1999). Behavioral and pharmacological therapies for late-life insomnia: a randomized controlled trial. *Jama*, *281*(11), 991-999.

Morin, C. M., Drake, C. L., Harvey, A. G., Krystal, A. D., Manber, R., Riemann, D., & Spiegelhalder, K. (2015). Insomnia disorder. *Nature reviews Disease primers*, *1*(1), 1-18.

Morin, C. M., Stone, J., Trinkle, D., Mercer, J., & Remsberg, S. (1993). Dysfunctional beliefs and attitudes about sleep among older adults with and without insomnia complaints. Psychology and aging, 8(3), 463.

Morris, C. J., Yang, J. N., Garcia, J. I., Myers, S., Bozzi, I., Wang, W., Buxton, O. M., Shea, S. A., & Scheer, F. A. (2015). Endogenous circadian system and circadian misalignment impact glucose tolerance via separate mechanisms in humans. Proc Natl Acad Sci U S A, 112(17), E2225-2234.

Morselli, L., Leproult, R., Balbo, M., & Spiegel, K. (2010). Role of sleep duration in the regulation of glucose metabolism and appetite. Best practice & research Clinical endocrinology & metabolism, 24(5), 687-702.

Murphy, M. A., Olson, S. L., Protas, E. J., & Overby, A. R. (2003). Screening for falls in community-dwelling elderly. *Journal of Aging and Physical Activity*, *11*(1), 66-80.

Murphy, S. L., Williams, C. S., & Gill, T. M. (2002). Characteristics associated with fear of falling and activity restriction in community-living older persons. *Journal of the american geriatrics society*, *50*(3), 516-520.

Muzni, K., Groeger, J. A., Dijk, D. J., & Lazar, A. S. (2021). Self-reported sleep quality is more closely associated with mental and physical health than chronotype and sleep duration in young adults: A multi-instrument analysis. Journal of Sleep Research, 30(1), e13152.

Mylonas, V., Nikodelis, T., & Kollias, I. (2023). Time of day influence on postural balance of young and older men. *Experimental aging research*, *49*(1), 58-69.

Nakano, T., Araki, K., Michimori, A., Inbe, H., Hagiwara, H., & Koyama, E. (2001). Nineteen-hour variation of postural sway, alertness and rectal temperature during sleep deprivation. Psychiatry and Clinical Neurosciences, 55(3), 277-278.

Natale, V., Léger, D., Martoni, M., Bayon, V., & Erbacci, A. (2014). The role of actigraphy in the assessment of primary insomnia: a retrospective study. *Sleep medicine*, *15*(1), 111-115.

Neubauer, D. N. (2007). The evolution and development of insomnia pharmacotherapies. *Journal of Clinical Sleep Medicine*, *3*(5 suppl), S11-S16.

Nielsen, D., & Panayides, P. M. (2005). Causes of casualties and the regulation of occupational health and safety in the shipping industry. *WMU Journal of Maritime Affairs*, *4*, 147-167.

Nielsen, D., & Roberts, S. (1999). Fatalities among the world's merchant seafarers (1990–1994). Marine Policy, 23(1), 71-80.

Nir, Y., Staba, R. J., Andrillon, T., Vyazovskiy, V. V., Cirelli, C., Fried, I., & Tononi, G. (2011). Regional slow waves and spindles in human sleep. Neuron, 70(1), 153-169.

Norman, R. W., & Wells, R. (1998). *Ergonomic interventions for reducing musculoskeletal disorders: an overview, related issues and future directions*. Royal Commission on Workers' Compensation in British Columbia.

Norrie, J., Heitger, M., Leathem, J., Anderson, T., Jones, R., & Flett, R. (2010). Mild traumatic brain injury and fatigue: a prospective longitudinal study. *Brain injury*, *24*(13-14), 1528-1538.

Nutt, J. G., & Wooten, G. F. (2005). Diagnosis and initial management of Parkinson's disease. *New England Journal of Medicine*, *353*(10), 1021-1027.

Ohayon, M. M., Carskadon, M. A., Guilleminault, C., & Vitiello, M. V. (2004). Meta-analysis of quantitative sleep parameters from childhood to old age in healthy individuals: developing normative sleep values across the human lifespan. *Sleep*, *27*(7), 1255-1273.

Ołpińska-Lischka, M., Kujawa, K., & Maciaszek, J. (2021). Differences in the effect of sleep deprivation on the postural stability among men and women. International journal of environmental research and public health, 18(7), 3796.

Onen, S. H., & Onen, F. (2018). Chronic medical conditions and sleep in the older adult. *Sleep medicine clinics*, *13*(1), 71-79.

Paillard, T. (2017). Plasticity of the postural function to sport and/or motor experience. *Neuroscience & Biobehavioral Reviews*, *72*, 129-152.

Paillard, T. (2023). Asymmetry of Movement and Postural Balance and Underlying Functions in Humans. *Symmetry*, *15*(3), 759.

Paillard, T. (2023). Detrimental effects of sleep deprivation on the regulatory mechanisms of postural balance: a comprehensive review. *Frontiers in Human Neuroscience*, *14*, 1146550.

Paillard, T., & Noé, F. (2015). Techniques and methods for testing the postural function in healthy and pathological subjects. *BioMed research international*, *2015*.

Palmieri, R. M., Ingersoll, C. D., Stone, M. B., & Krause, B. A. (2002). Center-of-pressure parameters used in the assessment of postural control. Journal of sport rehabilitation, 11(1), 51-66.

Patel, D., Steinberg, J., & Patel, P. (2018). Insomnia in the Elderly: A Review. J Clin Sleep Med, 14(6), 1017-1024.

Patel, M., Gomez, S., Berg, S., Almbladh, P., Lindblad, J., Petersen, H., Magnusson, M., & Johansson, R. (2008). Effects of 24-h and 36-h sleep deprivation on human postural control and adaptation. *Experimental Brain Research*, 185(2), 165-173.

Payne, J. D., Tucker, M. A., Ellenbogen, J. M., Wamsley, E. J., Walker, M. P., Schacter, D. L., & Stickgold, R. (2012). Memory for semantically related and unrelated declarative information: the benefit of sleep, the cost of wake. PloS one, 7(3), e33079.

Peterka, R. J. (2002). Sensorimotor integration in human postural control. *Journal of Neurophysiology*, 88(3), 1097-1118.

Peterka, R. J., & Loughlin, P. J. (2004). Dynamic regulation of sensorimotor integration in human postural control. Journal of neurophysiology, 91(1), 410-423.

Pham, Q. C., Mello, M. T. D., Narciso, F. V., Mônico Neto, M., Teixeira, C. W., Antonietti, L. S., ... & Tufik, S. (2014). Robust evaluation of time since awakening using force platform posturography. *Revista Brasileira de Engenharia Biomédica*, *30*, 322-329.

Pinter, J., Hansberger, K., Huck, L., & Kollegger, H. (2009). Reduced risk of falls in patients after total knee arthroplasty with improved postural control and flexibility--a prospective assessment using computerized posturography. BMC musculoskeletal disorders, 10(1), 1-7.

Podsiadlo, D., & Richardson, S. (1991). The timed "Up & Go": a test of basic functional mobility for frail elderly persons. *Journal of the American geriatrics Society*, *39*(2), 142-148.

Pollock, A. S., Durward, B. R., Rowe, P. J., & Paul, J. P. (2000). What is balance?. *Clinical rehabilitation*, *14*(4), 402-406.

Porkka-Heiskanen, T. (1999). Adenosine in sleep and wakefulness. *Annals of medicine*, *31*(2), 125-129.

Powell, L. E., & Myers, A. M. (1995). The activities-specific balance confidence (ABC) scale. *The journals of Gerontology Series A: Biological sciences and Medical sciences*, *50*(1), M28-M34.

Pratap, A., Neto, E. C., Snyder, P., Stepnowsky, C., Elhadad, N., Grant, D., ... & Omberg, L. (2020). Indicators of retention in remote digital health studies: a cross-study evaluation of 100,000 participants. *NPJ digital medicine*, *3*(1), 21.

Prieto, T. E., Myklebust, J. B., Hoffmann, R. G., Lovett, E. G., & Myklebust, B. M. (1996). Measures of postural steadiness: differences between healthy young and elderly adults. *IEEE Transactions on biomedical engineering*, *43*(9), 956-966.

Proske, U., & Gandevia, S. C. (2012). The proprioceptive senses: their roles in signaling body shape, body position and movement, and muscle force. *Physiological reviews*.

Punakallio, A., Hirvonen, M., & Grönqvist, R. (2005). Slip and fall risk among firefighters in relation to balance, muscular capacities and age. *Safety science*, *43*(7), 455-468.

Qian, J., Morris, C. J., Caputo, R., Wang, W., Garaulet, M., & Scheer, F. (2019). Sex differences in the circadian misalignment effects on energy regulation. Proc Natl Acad Sci U S A, 116(47), 23806-23812.

Ramlee, F., Sanborn, A. N., & Tang, N. K. (2017). What sways people's judgment of sleep quality? A quantitative choice-making study with good and poor sleepers. *Sleep*, *40*(7), zsx091.

Rapisarda, V., Valentino, M., Bolognini, S., & Fenga, C. (2004). Noise-related occupational risk aboard fishing vessels: considerations on prevention and the protection of exposed workers. Giornale Italiano di Medicina del Lavoro Ed Ergonomia, 26(3), 191-196.

Raslear, T. G., Gertler, J., & DiFiore, A. (2013). Work schedules, sleep, fatigue, and accidents in the US railroad industry. Fatigue: Biomedicine, Health & Behavior, 1(1-2), 99-115.

Raymakers, J. A., Samson, M. M., & Verhaar, H. J. (2005). The assessment of body sway and the choice of the stability parameter(s). Gait & posture, 21(1), 48-58.

Rechtschaffen, A., & Kales, A. (1968). A manual of standardized terminology, techniques and scoring system for sleep stages of human subjects. Brain Information Service/Brain Research Institute, University of California.

Redfern, M. S., Jennings, J. R., Martin, C., & Furman, J. M. (2001). Attention influences sensory integration for postural control in older adults. Gait & posture, 14(3), 211-216.

Redfern, M. S., Yardley, L., & Bronstein, A. M. (2001). Visual influences on balance. *Journal of Anxiety Disorders*, 15(1-2), 81-94.

Reichert, C. F., Maire, M., Gabel, V., Viola, A. U., Götz, T., Scheffler, K., ... & Schmidt, C. (2017). Cognitive brain responses during circadian wake-promotion: evidence for sleep-pressure-dependent hypothalamic activations. *Scientific reports*, *7*(1), 5620.

Reichert, C. F., Maire, M., Gabel, V., Viola, A. U., Kolodyazhniy, V., Strobel, W., ... & Schmidt, C. (2014). Insights into behavioral vulnerability to differential sleep pressure and circadian phase from a functional ADA polymorphism. Journal of Biological Rhythms, 29(2), 119-130.

Riemann, D., Spiegelhalder, K., Nissen, C., Hirscher, V., Baglioni, C., & Feige, B. (2012). REM sleep instability–a new pathway for insomnia?. *Pharmacopsychiatry*, *45*(05), 167-176.

Roberts, S. E. (2002). Hazardous occupations in great britain. The Lancet, 360(9332), 543-544.

Roberts, S. E. (2008). Fatal work-related accidents in UK merchant shipping from 1919 to 2005. Occupational Medicine, 58(2), 129-137.

Roberts, S. E., & Marlow, P. B. (2002). Casualties in dry bulk shipping (1963–1996). Marine Policy, 26(6), 437-450.

Roberts, S. E., & Marlow, P. B. (2005). Traumatic work related mortality among seafarers employed in British merchant shipping, 1976–2002. Occupational and environmental medicine, 62(3), 172-180.

Roberts, S. E., Nielsen, D., Kotłowski, A., & Jaremin, B. (2014). Fatal accidents and injuries among merchant seafarers worldwide. Occupational medicine, 64(4), 259-266.

Robillard, R., Lanfranchi, P. A., Prince, F., Filipini, D., & Carrier, J. (2011). Sleep deprivation increases blood pressure in healthy normotensive elderly and attenuates the blood pressure response to orthostatic challenge. Sleep, 34(3), 335.

Robillard, R., Prince, F., Boissonneault, M., Filipini, D., & Carrier, J. (2011). Effects of increased homeostatic sleep pressure on postural control and their modulation by attentional resources. Clinical Neurophysiology, 122(9), 1771-1778.

Robillard, R., Prince, F., Filipini, D., & Carrier, J. (2011). Aging worsens the effects of sleep deprivation on postural control. PLoS One, 6(12), e28731.

Robillard, R., Prince, F., Filipini, D., & Carrier, J. (2011). Effects of increased homeostatic sleep pressure on postural control and their modulation by circadian and wake-dependent processes. *BMC Neuroscience*, 12(1), 1-12.

Rösler, L., van Der Lande, G., Leerssen, J., Cox, R., Ramautar, J. R., & van Someren, E. J. (2023). Actigraphy in studies on insomnia: Worth the effort?. *Journal of Sleep Research*, *32*(1), e13750.

Roth, T. (2007). Sleep therapy: new generation pharmacologic agents for managing insomnia. *Journal of Clinical Sleep Medicine*, *3*(5 suppl), S5-S6.

Rubenstein, L. Z. (2006). Falls in older people: epidemiology, risk factors and strategies for prevention. *Age and ageing*, *35*(suppl_2), ii37-ii41.

Rubenstein, L. Z., & Josephson, K. R. (2006). Falls and their prevention in elderly people: what does the evidence show?. *Medical Clinics*, *90*(5), 807-824.

Ruhe, A., Fejer, R., & Walker, B. (2010). The test–retest reliability of centre of pressure measures in bipedal static task conditions–a systematic review of the literature. Gait & posture, 32(4), 436-445.

Sadeghniiat-Haghighi, K., & Yazdi, Z. (2015). Fatigue management in the workplace. *Industrial psychiatry journal*, *24*(1), 12-17.

Sambrook, T. D., & Goslin, J. (2014). Mediofrontal event-related potentials in response to positive, negative and unsigned prediction errors. *Neuropsychologia*, *61*, 1-10.

Sambrook, T. D., & Goslin, J. (2016). Principal components analysis of reward prediction errors in a reinforcement learning task. NeuroImage, 124, 276-286.

Sansom, B. A., Cheruku, A., Do, A. M., Sahota, P. K., Bierman, A., & Urry, H. L. (2023). Underestimation of waking-related inflammation using actigraphy. Biological psychology, 166, 108359.

Santhi, N., Lazar, A. S., McCabe, P. J., Lo, J. C., Groeger, J. A., & Dijk, D. J. (2016). Sex differences in the circadian regulation of sleep and waking cognition in humans. Proceedings of the National Academy of Sciences, 113(19), E2730-E2739.

Saper, C. B., & Fuller, P. M. (2017). Wake–sleep circuitry: an overview. Current opinion in neurobiology, 44, 186-192.

Saper, C. B., Fuller, P. M., Pedersen, N. P., Lu, J., & Scammell, T. E. (2010). Sleep state switching. *Neuron*, *68*(6), 1023-1042.

Saraiva, M., Marouvo, J., Fernandes, O., Castro, M. A., & Vilas-Boas, J. P. (2021). Postural control and sleep quality in cognitive dual tasking in healthy young adults. *J*, *4*(3), 257-265.

Scheffer, A. C., Schuurmans, M. J., Van Dijk, N., Van Der Hooft, T., & De Rooij, S. E. (2008). Fear of falling: measurement strategy, prevalence, risk factors and consequences among older persons. *Age and ageing*, *37*(1), 19-24.

Schlesinger, A., Redfern, M. S., Dahl, R. E., & Jennings, J. R. (1998). Postural control, attention and sleep deprivation. NeuroReport, 9(1), 49-52.

Schmidt, C., Collette, F., Cajochen, C., & Peigneux, P. (2007). A time to think: circadian rhythms in human cognition. *Cognitive neuropsychology*, *24*(7), 755-789.

Schmidt, C., Peigneux, P., & Cajochen, C. (2012). Age-related changes in sleep and circadian rhythms: impact on cognitive performance and underlying neuroanatomical networks. *Frontiers in neurology*, *3*, 118.

Schmitt, D. (2003). Insights into the evolution of human bipedalism from experimental studies of humans and other primates. Journal of Experimental Biology, 206(9), 1437-1448.

Schwartz, D. A., Vinnikov, D., & Blanc, P. D. (2017). Occupation and obstructive sleep apnea: a meta-analysis. *Journal of occupational and environmental medicine*, *59*(6), 502-508.

Segev-Jacubovski, O., Herman, T., Yogev-Seligmann, G., Mirelman, A., Giladi, N., & Hausdorff, J. M. (2011). The interplay between gait, falls and cognition: can cognitive therapy reduce fall risk?. *Expert review of neurotherapeutics*, *11*(7), 1057-1075.

Seidler, R. D., Bernard, J. A., Burutolu, T. B., Fling, B. W., Gordon, M. T., Gwin, J. T., ... & Lipps, D. B. (2010). Motor control and aging: links to age-related brain structural, functional, and biochemical effects. Neuroscience & Biobehavioral Reviews, 34(5), 721-733.

Sherrington, C., Whitney, J. C., Lord, S. R., Herbert, R. D., Cumming, R. G., & Close, J. C. (2008). Effective exercise for the prevention of falls: a systematic review and meta-analysis. *Journal of the American Geriatrics Society*, *56*(12), 2234-2243.

Shumway-Cook, A., & Woollacott, M. (2000). Attentional demands and postural control: the effect of sensory context. *Journals of Gerontology-Biological Sciences and Medical Sciences*, *55*(1), M10.

Siegel, J. M. (2005). Clues to the functions of mammalian sleep. Nature, 437(7063), 1264-1271.

Siu, K. C., & Woollacott, M. H. (2007). Attentional demands of postural control: the ability to selectively allocate information-processing resources. Gait & posture, 25(1), 121-126.

Skeldon, A. C., Derks, G., & Dijk, D. J. (2016). Modelling changes in sleep timing and duration across the lifespan: Changes in circadian rhythmicity or sleep homeostasis? Sleep Med Rev, 28, 96-107.

Skelin, I., Zhang, H., Zheng, J., Ma, S., Mander, B. A., Kim McManus, O., ... & Lin, J. J. (2021). Coupling between slow waves and sharp-wave ripples engages distributed neural activity during sleep in humans. *Proceedings of the National Academy of Sciences*, *118*(21), e2012075118.

Sletten, T. L., Cappuccio, F. P., Davidson, A. J., Van Cauter, E., Rajaratnam, S. M. W., & Scheer, F. (2020). Health consequences of circadian disruption. Sleep, 43(1).

Smith, A. P., & Ellis, N. (2002). Objective measurement of the effects of noise aboard ships on sleep and mental performance. In INTER-NOISE and NOISE-CON Congress and Conference Proceedings (Vol. 2002, No. 4, pp. 1519-1524). Institute of Noise Control Engineering.

Smith, A. P., Lane, A., Bloor, M. J., Allen, P. H., Burke, A., & Ellis, N. (2003). Fatigue Offshore: Phase 2. The short sea and coastal shipping industry.

Smith, A. P., Lane, T., & Bloor, M. (2001). Fatigue offshore: A comparison of offshore oil support shipping and the offshore oil industry. *Seafarers International research Centre/Centre for Occupational and health Psychology, Cardiff University, Cardiff*.

Smith, C., & MacNeill, C. (1994). Impaired motor memory for a pursuit rotor task following Stage 2 sleep loss in college students. *Journal of sleep research*, *3*(4), 206-213.

Smith, M. R., & Eastman, C. I. (2012). Shift work: health, performance and safety problems, traditional countermeasures, and innovative management strategies to reduce circadian misalignment. *Nature and science of sleep*, 111-132.

Smith, S. S., Cheng, T., & Kerr, G. K. (2012). The effect of extended wake on postural control in young adults. Experimental brain research, 221, 329-335.

Son, S. M. (2017). The circadian effects on postural stability in young adults. *The Journal of Korean Physical Therapy*, *29*(3), 142-144.

Speers, R. A., Kuo, A. D., & Horak, F. B. (2002). Contributions of altered sensation and feedback responses to changes in coordination of postural control due to aging. *Gait & posture*, *16*(1), 20-30.

Spiegel, K., Leproult, R., L'hermite-Balériaux, M., Copinschi, G., Penev, P. D., & Van Cauter, E. (2004). Leptin levels are dependent on sleep duration: relationships with sympathovagal balance, carbohydrate regulation, cortisol, and thyrotropin. The Journal of Clinical Endocrinology & Metabolism, 89(11), 5762-5771.

Spiegel, K., Tasali, E., Leproult, R., & Van Cauter, E. (2009). Effects of poor and short sleep on glucose metabolism and obesity risk. *Nature Reviews Endocrinology*, *5*(5), 253-261.

Spitzer, R. L., Kroenke, K., Williams, J. B., & Löwe, B. (2006). A brief measure for assessing generalized anxiety disorder: The GAD-7. Archives of Internal Medicine, 166(10), 1092–1097.

Steinach, M., & Gunga, H. C. (2020). Circadian rhythm and stress. *Stress Challenges and Immunity in Space: From Mechanisms to Monitoring and Preventive Strategies*, 145-179.

Sterling, D. A., O'Connor, J. A., & Bonadies, J. (2001). Geriatric falls: injury severity is high and disproportionate to mechanism. Journal of trauma and acute care surgery, 50(1), 116-119.

Stern, Y., Barnes, C. A., Grady, C., Jones, R. N., & Raz, N. (2019). Brain reserve, cognitive reserve, compensation, and maintenance: operationalization, validity, and mechanisms of cognitive resilience. *Neurobiology of aging*, *83*, 124-129.

Stevens, D., Jackson, B., Carberry, J., McLoughlin, J., Barr, C., Mukherjee, S., ... & Vakulin, A. (2020). The impact of obstructive sleep apnea on balance, gait, and falls risk: a narrative review of the literature. *The Journals of Gerontology: Series A*, *75*(12), 2450-2460.

Stevens, J. A., & Lee, R. (2018). The potential to reduce falls and avert costs by clinically managing fall risk. *American journal of preventive medicine*, *55*(3), 290-297.

Stevens, J. A., & Sogolow, E. D. (2005). Gender differences for non-fatal unintentional fall related injuries among older adults. *Injury prevention*, *11*(2), 115-119.

Stevens, J. A., Mack, K. A., Paulozzi, L. J., & Ballesteros, M. F. (2008). Self-reported falls and fall-related injuries among persons aged≥ 65 years–United States, 2006. *Journal of safety research*, *39*(3), 345-349.

Stickgold, R. (2005). Sleep-dependent memory consolidation. *Nature*, *437*(7063), 1272-1278.

Stickgold, R., & Walker, M. P. (2013). Sleep-dependent memory triage: evolving generalization through selective processing. *Nature neuroscience*, *16*(2), 139-145.

Stone, K. L., Blackwell, T. L., Ancoli-Israel, S., Cauley, J. A., Redline, S., Ensrud, K. E., & Group, O. S. M. R. (2008). Sleep disturbances and risk of falls in older community-dwelling men: the outcomes of sleep disorders in older men (MrOS sleep) study. *Journal of the American Geriatrics Society*, 56(11), 1911-1920.

Stone, K. L., Ewing, S. K., Lui, L. Y., Ensrud, K. E., Ancoli-Israel, S., Bauer, D. C., ... & Cummings, S. R. (2006). Self-reported sleep and nap habits and risk of falls and fractures in older women: the study of osteoporotic fractures. *Journal of the American Geriatrics Society*, *54*(8), 1177-1183.

Stuck, B. A., Maurer, J. T., Schlarb, A. A., Schredl, M., Weeß, H. G., & Weeß, H. G. (2021). Sleep-Related Movement Disorders. *Practice of Sleep Medicine: Sleep Disorders in Children and Adults*, 219-235.

Sturnieks, D. L., St George, R., & Lord, S. R. (2008). Balance disorders in the elderly. *Neurophysiologie Clinique/Clinical Neurophysiology*, *38*(6), 467-478.

Takakusaki, K. (2008). Forebrain control of locomotor behaviors. Brain research reviews, 57(1), 192-198.

Takakusaki, K., Tomita, N., & Yano, M. (2008). Substrates for normal gait and pathophysiology of gait disturbances with respect to the basal ganglia dysfunction. Journal of neurology, 255, 19-29.

Tamura, Y., Horiyasu, T., Sano, Y., Chonan, K., Kawada, T., Sasazawa, Y., ... & Suzuki, S. (2002). Habituation of sleep to a ship's noise as determined by actigraphy and a sleep questionnaire. *Journal of Sound and Vibration*, *250*(1), 107-113.

Tamura, Y., Kawada, T. & Sasazawa, Y. (1997). Effect of ship noise on sleep. Journal of Sound and Vibration. 205, 417-425.

Tepas, D. I., Carvalhais, A. B. (1990). Sleep patterns of shiftworkers. Occupational medicine (Philadelphia, Pa.). 1990 May-Jun;5(2):199-208.

Thomas, D. P., Whitney, R., Kay, B., & Zaman, A. (2003). Postural sway and gait patterns in elderly fallers and non-fallers. The Open Rehabilitation Journal, 6(1).

Thomas, M., Sing, H., Belenky, G., Holcomb, H., Mayberg, H., Dannals, R., ... & Redmond, D. (2000). Neural basis of alertness and cognitive performance impairments during sleepiness. I. Effects of 24 h of sleep deprivation on waking human regional brain activity. *Journal of sleep research*, *9*(4), 335-352.

Thomas, S. J., & Gamble, K. (2022). Actigraphy in the evaluation of sleep disorders. *2020-06-08)[2022-03-28]. https://www. uptodate. com/contents/actigraphy-in-the-evaluation-of-sleepdisorders*.

Tideiksaar, R. (2002). Sensory impairment and fall risk. *Generations: Journal of the American Society on Aging*, *26*(4), 22-27.

Tieland, M., Trouwborst, I., & Clark, B. C. (2018). Skeletal muscle performance and ageing. *Journal of cachexia, sarcopenia and muscle*, *9*(1), 3-19.

Tinetti, M. E., & Williams, C. S. (1998). The effect of falls and fall injuries on functioning in community-dwelling older persons. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *53*(2), M112-M119.

Tinetti, M. E., Richman, D., & Powell, L. (1990). Falls efficacy as a measure of fear of falling. *Journal of gerontology*, *45*(6), P239-P243.

Tirilly, G. (2004). The impact of fragmented sleep at sea on sleep, alertness and safety of seafarers. Medicina Maritima, 4(1), 96-105.

Tobaldini, E., Costantino, G., Solbiati, M., Cogliati, C., Kara, T., Nobili, L., & Montano, N. (2017). Sleep, sleep deprivation, autonomic nervous system and cardiovascular diseases. *Neuroscience & Biobehavioral Reviews*, *74*, 321-329.

Tononi, G., & Cirelli, C. (2014). Sleep and the price of plasticity: from synaptic and cellular homeostasis to memory consolidation and integration. Neuron, 81(1), 12-34.

Treves, N., Perlman, A., Kolenberg Geron, L., Asaly, A., & Matok, I. (2018). Z-drugs and risk for falls and fractures in older adults—a systematic review and meta-analysis. *Age and ageing*, *47*(2), 201-208.

Trimmel, K., Eder, H. G., Böck, M., Stefanic-Kejik, A., Klösch, G., & Seidel, S. (2021). The (mis) perception of sleep: factors influencing the discrepancy between self-reported and objective sleep parameters. Journal of Clinical Sleep Medicine, 17(5), 917-924.

Troncoso-Escudero, P., Sepulveda, D., Pérez-Arancibia, R., Parra, A. V., Arcos, J., Grunenwald, F., & Vidal, R. L. (2020). On the right track to treat movement disorders: promising therapeutic approaches for Parkinson's and Huntington's disease. *Frontiers in aging neuroscience*, *12*, 571185.

Tucker, M. A., Morris, C. J., Morgan, A., Yang, J., Myers, S., Pierce, J. G., ... & Scheer, F. A. (2017). The relative impact of sleep and circadian drive on motor skill acquisition and memory consolidation. *Sleep*, *40*(4), zsx036.

Tucker, P., Folkard, S., & Macdonald, I. (2003). Rest breaks and accident risk. *The Lancet*, *361*(9358), 680.

Van Amelsvoort, L. G. P. M., Kant, I. J., Beurskens, A. J. H. M., Schröer, C. A. P., & Swaen, G. M. H. (2002). Fatigue as a predictor of work disability. Occupational and environmental medicine, 59(10), 712-713.

Van Cauter, E., Leproult, R., & Plat, L. (2000). Age-related changes in slow wave sleep and REM sleep and relationship with growth hormone and cortisol levels in healthy men. *Jama*, *284*(7), 861-868.

van den Berg, P., Vu, T., & Molleman, L. (2023). Individual differences in social learning emerge through the evolution of developmental flexibility.

Van Dongen, H. P. A., Whitney, P., Hinson, J. M., Honn, K. A., & Chee, M. W. L. (Eds.). (2019). *Sleep deprivation and cognition.* Elsevier Academic Press.

Van Dongen, H. P., Maislin, G., Mullington, J. M., & Dinges, D. F. (2003). The cumulative cost of additional wakefulness: dose-response effects on neurobehavioral functions and sleep physiology from chronic sleep restriction and total sleep deprivation. *Sleep*, *26*(2), 117-126.

Vandewalle, G. (2021). Circadian, sleep-wake dependent or both? A preface to the special issue "Circadian rhythm and sleep-wake dependent regulation of behavior and brain function". Biochem Pharmacol, 191, 114535.

Videnovic, A., & Högl, B. (Eds.). (2015). *Disorders of Sleep and Circadian Rhythms in Parkinson's Disease* (No. 12170). Vienna: Springer Vienna.

Vitiello, M. V. (2006). Sleep in normal aging. Sleep Medicine Clinics, 1(2), 171-176.

Voysey, Z. J., Barker, R. A., & Lazar, A. S. (2021). The Treatment of Sleep Dysfunction in Neurodegenerative Disorders. Neurotherapeutics, 18(1), 202-216.

Vuillerme, N., Nougier, V., & Teasdale, N. (2000). Effects of a reaction time task on postural control in humans. Neuroscience Letters, 291(2), 77-80.

Vyas, M. V., Garg, A. X., Iansavichus, A. V., Costella, J., Donner, A., Laugsand, L. E., Janszky, I., Mrkobrada, M., Parraga, G., & Hackam, D. G. (2012). Shift work and vascular events: systematic review and meta-analysis. *BMJ*, 345, e4800.

Vyazovskiy, V. V., & Harris, K. D. (2013). Sleep and the single neuron: the role of global slow oscillations in individual cell rest. Nature Reviews Neuroscience, 14(6), 443-451.

Vyazovskiy, V. V., Olcese, U., Lazimy, Y. M., Faraguna, U., Esser, S. K., Williams, J. C., Cirelli, C., & Tononi, G. (2009). Cortical firing and sleep homeostasis. Neuron, 63(6), 865-878.

Wade, M. G., & Jones, G. (1997). The role of vision and spatial orientation in the maintenance of posture. Physical Therapy, 77(6), 619-628.

Wadsworth, E. J., Allen, P. H., Wellens, B. T., McNamara, R. L., & Smith, A. P. (2006). Patterns of fatigue among seafarers during a tour of duty. American Journal of Industrial Medicine, 49(10), 836-844.

Walker, M. P. (2005). A refined model of sleep and the time course of memory formation. Behavioral and Brain Sciences, 28(1), 51-64.

Walker, M. P. (2008). Cognitive consequences of sleep and sleep loss. *Sleep medicine*, *9*, S29-S34.

Walker, M. P. (2009). The role of sleep in cognition and emotion. *Annals of the New York Academy of Sciences*, *1156*(1), 168-197.

Walker, M. P., & Stickgold, R. (2006). Sleep, memory, and plasticity. Annual review of psychology, 57, 139-166.

Waterhouse, J., Reilly, T., Atkinson, G., & Edwards, B. (2007). Jet lag: trends and coping strategies. The lancet, 369(9567), 1117-1129.

Westermann, J., Lange, T., Textor, J., & Born, J. (2015). System consolidation during sleep–a common principle underlying psychological and immunological memory formation. *Trends in neurosciences*, *38*(10), 585-597.

Williamson A, Feyer AM. Moderate sleep deprivation produces impairments in cognitive and motor performance equivalent to legally prescribed levels of alcohol intoxication. Occup Environ Med. 2000;57:649–655.

Winer, J. R., Deters, K. D., Kennedy, G., Jin, M., Goldstein-Piekarski, A., Poston, K. L., & Mormino, E. C. (2021). Association of Short and Long Sleep Duration With Amyloid-beta Burden and Cognition in Aging. JAMA Neurol, 78(10), 1187-1196.

Winer, J. R., Mander, B. A., Kumar, S., Reed, M., Baker, S. L., Jagust, W. J., & Walker, M. P. (2020). Sleep Disturbance Forecasts beta-Amyloid Accumulation across Subsequent Years. Curr Biol, 30(21), 4291-4298 e4293.

Winter D.A.(1995) A.B.C. (Anatomy, Biomechanics and Control) of Balance During Standing and Walking. Waterloo Biomechanics, Waterloo, Canada

Winter, D. A., Patla, A. E., Ishac, M., & Gage, W. H. (2003). Motor mechanisms of balance during quiet standing. *Journal of electromyography and kinesiology*, *13*(1), 49-56.

Winter, D. A., Patla, A. E., Prince, F., Ishac, M., & Gielo-Perczak, K. (1998). Stiffness control of balance in quiet standing. Journal of neurophysiology, 80(3), 1211-1221.

Winter, D. A., Prince, F. R. A. N. C. O. I. S., Frank, J. S., Powell, C. O. R. R. I. E., & Zabjek, K. F. (1996). Unified theory regarding A/P and M/L balance in quiet stance. Journal of neurophysiology, 75(6), 2334-2343.

Winter, D. A., Ruder, G. K., & MacKinnon, C. D. (1990). Control of balance of upper body during gait. In *Multiple muscle systems: biomechanics and movement organization* (pp. 534-541). New York, NY: Springer New York.

Wolf, S. L., Sattin, R. W., Kutner, M., O'Grady, M., Greenspan, A. I., & Gregor, R. J. (2003). Intense tai chi exercise training and fall occurrences in older, transitionally frail adults: a randomized, controlled trial. *Journal of the American geriatrics Society*, *51*(12), 1693-1701.

Woollacott, M., & Shumway-Cook, A. (2002). Attention and the control of posture and gait: a review of an emerging area of research. *Gait & posture*, *16*(1), 1-14.

Wright, K. P., Lowry, C. A., & LeBourgeois, M. K. (2012). Circadian and wakefulness-sleep modulation of cognition in humans. *Frontiers in molecular neuroscience*, *5*, 50.

Yalçin, M., Mundorf, A., Thiel, F., Amatriain-Fernández, S., Kalthoff, I. S., Beucke, J. C., ... & Relógio, A. (2022). It's about time: the circadian network as time-keeper for cognitive functioning, locomotor activity and mental health. *Frontiers in Physiology*, *13*, 873237.

Yardley, L., Beyer, N., Hauer, K., Kempen, G., Piot-Ziegler, C., & Todd, C. (2005). Development and initial validation of the Falls Efficacy Scale-International (FES-I). Age and Ageing, 34(6), 614–619.

Yogev-Seligmann, G., Hausdorff, J. M., & Giladi, N. (2008). The role of executive function and attention in gait. *Movement disorders: official journal of the Movement Disorder Society*, *23*(3), 329-342.

Zhang, B., & Wing, Y. K. (2006). Sex differences in insomnia: a meta-analysis. *Sleep*, 29(1), 85-93.

Zhdanova, I. V., Wurtman, R. J., Balcioglu, A., Kartashov, A. I., & Lynch, H. J. (1998). Endogenous melatonin levels and the fate of exogenous melatonin: age effects. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *53*(4), B293-B298.

Zijlstra, G. A. R., Van Haastregt, J. C. M., Van Eijk, J. T. M., van Rossum, E., Stalenhoef, P. A., & Kempen, G. I. (2007). Prevalence and correlates of fear of falling, and associated avoidance of activity in the general population of community-living older people. *Age and ageing*, *36*(3), 304-309.

Zouabi, A., Quarck, G., Martin, T., Grespinet, M., & Gauthier, A. (2016). Is there a circadian rhythm of postural control and perception of the vertical? Chronobiology international, 33(10), 1320-1330.

Zuurbier, L. A., Ikram, M. A., Luik, A. I., Hofman, A., Van Someren, E. J., Vernooij, M. W., & Tiemeier, H. (2015). Cerebral small vessel disease is related to disturbed 24-h activity rhythms: a population-based study. European journal of neurology, 22(11), 1482-1487.

APPENDIX 1:

Full questionnaires and other supporting documents for the study

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This survey is for people employed as a marine industrial worker. To check your eligibility for the study please answer the following questions:

- Are you currently employed as a marine industrial worker (mariner)?

  YES / NO

- Do you work at least one shift or day per week?

  YES / NO

- Are you currently off work, and have been for at least 3 months (for any reason including sick-leave)?

  YES / NO

In this first part of the survey we are interested to know more about your working life and patterns, as they may influence your levels of fatigue and sleep.

Which job title most closely matches your current role as a mariner?

- Deck Crew, please specify……(e.g. Captain, Chief, 2nd Officer, 3rd Officer, Bosun, Able Seamen etc.)
- Engine Crew, please specify……(e.g. Chief Engineer, 2nd Engineer, 3rd Engineer, Welder, Oiler etc.)
- Catering Staff, please specify……..(Chef Cook, Stewards etc.)
- Other, please specify……(Pilots, Porth Authority etc.)

When on service, how many days do you usually work per week?

- Less than 3 days
- 3 days
- 5 days
- 7 days

When on service, how many hours do you usually work per day?

- Less than 8 hours
- 8 hours
- 8 to 12 hours
- More than 12

On a long short shift what is your average hours of work?

- Less than 8 hours
- 8 hours
- 8 to 12 hours
- More than 12

On a long shift what is your average hours of work?

- Less than 8 hours
- 8 hours
- 8 to 12 hours
- More than 12

How many days per week you have long shifts?

- Less than 3 days
- 3 days
- 5 days
- 7 days

How many additional paid hours have you worked in the past week? (Please include paid overtime, bank shifts, and additional paid hours on call over and above your normal contracted hours)

- 0
- up to 5
- 6 to 10
- 11 or more

How many additional unpaid hours have you worked in the past week?

- 0
- up to 5
- 6 to 10
- 11 or more

In the past month have you had to stay later than the end of your shift or working day overtime?

- always
- most of the time
- sometimes
- hardly at all
- never

How many days or shifts have you worked in the past 28 days?

- 1-7
- 8-14
- 15-21
- 22-28

Where are you in your current run of shifts or days?

- At the beginning
- In the middle
- At the end

What is your total allocated break time during your day or shift? (Please answer even if you are not usually able to take all of this allocation)

- Less than 30 minutes
- Up to 30 minutes
- Up to 45 minutes
- Up to 1 hour
- More than an hour

Do you take all of your allocated break time in full during your working day or shift?

- always
- most of the time

- sometimes
- hardly at all
- never

How long have you worked in the maritime sector?

- Less than 3 months
- Between 3 and 12 months
- 1-2 years
- 3-5 years
- 6-10 years
- 11-15 years
- More than 15 years

GENERAL MEDICAL QUESTIONNAIRE

It is very important that you provide full and accurate answers to the questions detailed below. If you have any concerns or questions when completing this information please speak to a member of the study team. If you experience any change to your medication or health while enrolled onto the study you should advise the study team of any changes as soon as possible. We will ask you to sign this document, which is going to be reviewed by a medical professional.

General health

1. Do you suffer from sleep disorders/ sleep problems? YES / NO

   If YES give details.....

   ……

2. **a)** Have you received a diagnosis of sleep apnoea or any other sleep related disorder?

   YES/NO

   b) If YES to the question detailed above are you receiving treatment for the sleep disorder? YES/NO

   If YES provide details

   ……
   ……

3. **a)** Do you have any physical health conditions? This includes chronic or acute diseases (e.g. arthritis, osteoporosis, cancer, vitamin deficiency, cardio vascular diseases/ conditions, asthma, diabetes etc) YES / NO

   If YES give details

   ……
   ……
   ……
   ……

4. Have you ever been diagnosed with a neurological, psychiatric/ mental health condition (e.g. depression, anxiety, brain injury, panic disorders, schizophrenia, multiple sclerosis, motor neurone disease etc.)? YES / NO

   If YES give details

   ……
   ……
   ……

5. Have you had a recent acute illness/ infection or chronic illness/ infection? YES / NO

   If YES give details ……..

   ……

   ……

6. Do you have high blood pressure? YES / NO

   If YES give details.....

   .....

7. Have you ever suffered from heart trouble/stroke/TIA? YES / NO

   If YES give details.....

   .....

8. Have you had a fall in the past year or have you been told that you are at an increased risk of falling? YES / NO

   If YES give details

   ……
   ……

   10. Do you ever have pains in your heart and chest? YES / NO

   11. Do you ever feel faint / have spells of dizziness? YES / NO

   12. Have you been in hospital at all in the last 2 years? YES / NO

If YES give reason and outcome.....

.....

13. Have you had any operations or major illness in the last 6 months? YES / NO

If YES give details.....

.....

14. **a)** Are you undergoing treatment or are you taking any medication at the moment (**please include details of contraception if appropriate**) It is very important that you provide full details to us. YES / NO

If YES give details.....

.....
.....

.....
.....

b) If YES, do you experience any side effects from this medication including any side effects that may influence/ disrupt your sleep? YES/ NO

If YES give details.....

.....
.....
.....
.....

16. Do you have any disabilities of any kind? YES / NO

If YES give details.....

.....

17. Do you have dyslexia, other specific learning difficulty or other learning difficulty? YES / NO

If YES give details.....

.....

26. Do you currently have/ have had any alcohol/ substance abuse related disorders? YES / NO

If YES give details.....

.....

27. What is your average weekly intake of alcohol? ..... units per week.

(One unit is half a pint beer / one glass of wine / one measure of spirits)

28. Has there been a time when you regularly consumed more than 14 units of alcohol per week? YES / NO

If YES give details.....

29. What is your average daily intake of caffeinated beverages? (e.g. coffee/tea/coke/ caffeinated energy drinks)?

.....cups per day

30. Are you smoker/vaper? YES / NO

If YES how many cigarettes (or equivalent) do you smoke per day.....

35. Have you travelled across more than three time zones in the past 2 months? YES / NO

37. Do you work shifts? YES / NO

PATIENT HEALTH QUESTIONNAIRE-9 (PHQ-9)

Instruction

Over the last 2 weeks, how often have you been bothered by any of the following problems?

		Not at all	Several days	More than half the days	Nearly every day
1.	Little interest or pleasure in doing things	0	1	2	3
2.	Feeling down, depressed, or hopeless	0	1	2	3
3.	Trouble falling or staying asleep, or sleeping too much	0	1	2	3
4.	Feeling tired or having little energy	0	1	2	3
5.	Poor appetite or overeating	0	1	2	3
6.	Feeling bad about yourself — or that you are a failure or have let yourself or your family down	0	1	2	3
7.	Trouble concentrating on things, such as reading the newspaper or watching television	0	1	2	3
8.	Moving or speaking so slowly that other people could have noticed? Or the opposite — being so fidgety or restless that you have been moving around a lot more than usual	0	1	2	3
9.	Thoughts that you would be better off dead or of hurting yourself in some way	0	1	2	3

GENERALISED ANXIETY DISORDER-7 (GAD-7)

Instruction

Over the last 2 weeks, how often have you been bothered by any of the following problems?

		Not at all	Several days	More than half the days	Nearly every day
1.	Feeling nervous, anxious, or on edge	0	1	2	3
2.	Not being able to stop or control worrying	0	1	2	3
3.	Worrying too much about different things	0	1	2	3
4.	Trouble relaxing	0	1	2	3
5.	Being so restless that it's hard to sit still	0	1	2	3
6.	Becoming easily annoyed or irritable	0	1	2	3
7.	Feeling afraid as if something awful might happen	0	1	2	3

EPWORTH SLEEPINESS SCALE

Instructions:

How likely are you to doze off or fall asleep in the following situations, in contrast to just feeling tired? This refers to your usual way of life in recent times. Even if you have not done some of these things recently, try to work out how they would have affected you. Use the following scale to choose the most appropriate number for each situation:

0 = Would never doze; 1 = Slight chance; 2 = Moderate chance; 3 = High chance

Situation	**Chance of dozing off**			
	Would never doze	**Slight chance**	**Moderate chance**	**High chance**
1. Sitting and reading	0	1	2	3
2. Watching TV	0	1	2	3
3. Sitting inactive in a public place (e.g. a theatre or a meeting)	0	1	2	3
4. As a passenger in a car for an hour without a break	0	1	2	3
5. Lying down to rest in the afternoon when circumstances permit	0	1	2	3
6. Sitting and talking to someone	0	1	2	3
7. Sitting quietly after a lunch without alcohol	0	1	2	3
8. In a car, while stopped for a few minutes in the traffic	0	1	2	3

PITTSBURGH SLEEP QUALITY INDEX (PSQI)

Instructions:

The following questions relate to your usual sleep habits during the past month *only*. Your answers should indicate the most accurate reply for the *majority* of days and nights in the past month. Please answer all the questions.

1. During the past month, when have you usually gone to bed at night?

   Usual bed time: .....

2. During the past month, how long (in minutes) has it usually taken you to fall asleep each night?

   Number of minutes: .....

3. During the past month, when have you usually got up in the morning?

   Usual getting up time: .....

4. During the past month, how many hours of actual sleep did you get at night? (This may be different from the number of hours you spend in bed.)

   Hours of sleep per night: .....

For each of the remaining questions, check the one best response. Please answer all questions

5. During the past month, how often have you had trouble sleeping because you…..

a) Cannot get to sleep within 30 minutes

Not during the past month	.....	Less than once a week	.....	Once or twice a week	.....	Three or more times a week	.....

b) Wake up in the middle of the night or early morning

Not during the past month	.....	Less than once a week	.....	Once or twice a week	.....	Three or more times a week	.....

c) Have to get up to use the bathroom

Not during the past month ..... Less than once a week ..... Once or twice a week ..... Three or more times a week .....

d) Cannot breathe comfortably

Not during the past month ..... Less than once a week ..... Once or twice a week ..... Three or more times a week .....

e) Cough or snore loudly

Not during the past month ..... Less than once a week ..... Once or twice a week ..... Three or more times a week .....

f) Feel too cold

Not during the past month ..... Less than once a week ..... Once or twice a week ..... Three or more times a week .....

g) Feel too hot

Not during the past month ..... Less than once a week ..... Once or twice a week ..... Three or more times a week .....

h) Had bad dreams

Not during the past month ..... Less than once a week ..... Once or twice a week ..... Three or more times a week .....

i) Have pain

Not during the past month ..... Less than once a week ..... Once or twice a week ..... Three or more times a week .....

j) Other reason(s), please describe

.....

.....

How often during the past month have you had trouble sleeping because of this?

Not during the past month ..... Less than once a week ..... Once or twice a week ..... Three or more times a week .....

6. During the past month, how would you rate your sleep quality overall?

Very good ..... Fairly good ..... Fairly bad ..... Very bad .....

7. During the past month, how often have you taken medicine (prescribed or "over the counter") to help you sleep?

Not during the past month ..... Less than once a week ..... Once or twice a week ..... Three or more times a week .....

8. During the past month, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity?

Not during the past month ..... Less than once a week ..... Once or twice a week ..... Three or more times a week .....

9. During the past month, how much of a problem has it been for you to keep up enough enthusiasm to get things done?

No problem at all ..... Only a very slight problem ..... Somewhat of a problem ..... A very big problem .....

10. Do you have a bed partner or roommate?

No bed partner or roommate? ..... Partner/roommate in other room ..... Partner in same room, but not same bed ..... Partner in same bed .....

If you have a roommate or bed partner, ask him/her how often in the past month you have had)…

a) Loud snoring

Not during the past month ..... Less than once a week ..... Once or twice a week ..... Three or more times a week .....

b) Long pauses between breaths while asleep

Not during the past month ..... Less than once a week ..... Once or twice a week ..... Three or more times a week .....

c) Legs twitching or jerking while you sleep

Not during the past month	.....	Less than once a week	.....	Once or twice a week	.....	Three or more times a week	.....

d) Episodes of disorientation or confusion during sleep?

Not during the past month	.....	Less than once a week	.....	Once or twice a week	.....	Three or more times a week	.....

e) Other restlessness while you sleep; please describe

.....

.....

Not during the past month	.....	Less than once a week	.....	Once or twice a week	.....	Three or more times a week	.....

Participant ID:

THE MUNICH CHRONOTYPE QUESTIONNAIRE

Please enter your age, gender, etc.. This information is important for our evaluations.

Age : .....

Gender: Male / Female

Height: ..... cm

Weight: ..... kg

On workdays

I have to get up at ..... o'clock

I need ..... min to wake up

I regularly wake up ..... min before the alarm / with the alarm (please delete one)

From ..... o'clock, I am fully awake

At around ..... o'clock, I have an energy dip

On nights before workdays, I go to bed at ..... o'clock…

… and it then takes me ..... min to fall asleep

If I get the chance, I like to take a siesta/nap…

correct I then sleep for ..... min

not correct I would feel terrible afterwards

On free days (please only judge normal free days, i.e., without parties etc.)…

My dream would be to sleep until ..... o'clock

I normally wake up at ..... o'clock

If I wake up at around the normal (workday) alarm time, I try to get back to sleep

Correct / Not correct

If I get back to sleep, I sleep for another ..... min

I need ..... min to wake up

From ..... o'clock, I am fully awake

At around ..... o'clock, I have an energy dip

On nights before free days, I go to bed at ..... o'clock

… and it then takes me ..... min to fall asleep

If I get the chance, I like to take a siesta/nap…

correct I then sleep for ..... min

not correct I would feel terrible afterwards

Once I am in bed, I would like to read for ..... min,…

… but generally fall asleep after no more than ..... min

I prefer to sleep in a completely dark room Correct / Not correct

I wake up more easily when morning light shines into my room Correct / Not correct

How long per day do you spend on average outside (really outside) exposed to day light?

On work days: ..... hrs ..... min

On free days: ..... hrs ..... min

Self assessment

After you have answered the preceding questions, you should have a feeling of the chronotype (time-of-day-type) you belong to. If, for example, you like (and manage) to sleep quite a bit longer on free days than on workdays, or if you cannot get out of bed on Monday mornings, even without a Sunday-night party, then you are more a late type. If, however, you regularly wake up and feel perky once you jump out of bed, and if you would rather go to bed early than to an evening concert, then you are an early type. In the following questions, you should categorise yourself and your family members. Please tick only one possibility!

	Extreme early type	**Moderate early type**	**Slight early type**	**Normal Type**	**Slight late type**	**Moderate late type**	**Extreme late type**
I am…	0	1	2	3	4	5	6

DEMOGRAPHICS

Participant identification code ..... Date of birth ...../...../.....

Age ..... Sex: Male / Female

Please note that the following 3 questions are optional.

1. What is your profession? ……
2. You work:
    - Full time (employed / self-employed)
    - Part time (employed / self-employed)
3. Do you currently work onboard ship? YES / NO

   If Yes, how long have you been working onboard (current time)?

   ……
4. What is your overall sea service? (years of service)

   ……

5. Are you retired? YES/ NO

6. Weight …… Height ……

   BMI (Investigator use) ……

7. What is your ethnicity?
    - ……
    - Prefer not to say

FALLS EFFICACY SCALE – FES-I

FES-I

Now we would like to ask some questions about how concerned you are about the possibility of falling. Please reply thinking about how you usually do the activity. If you currently don't do the activity (e.g. if someone does your shopping for you), please answer to show whether you think you would be concerned about falling IF you did the activity. For each of the following activities, please tick the box which is closest to your own opinion to show how concerned you are that you might fall if you did this activity.

		Not at all concerned 1	*Somewhat concerned* 2	*Fairly concerned* 3	*Very concerned* 4
1	Cleaning the house (e.g. sweep, vacuum or dust)	1 ☐	2 ☐	3 ☐	4 ☐
2	Getting dressed or undressed	1 ☐	2 ☐	3 ☐	4 ☐
3	Preparing simple meals	1 ☐	2 ☐	3 ☐	4 ☐
4	Taking a bath or shower	1 ☐	2 ☐	3 ☐	4 ☐
5	Going to the shop	1 ☐	2 ☐	3 ☐	4 ☐
6	Getting in or out of a chair	1 ☐	2 ☐	3 ☐	4 ☐
7	Going up or down stairs	1 ☐	2 ☐	3 ☐	4 ☐
8	Walking around in the neighbourhood	1 ☐	2 ☐	3 ☐	4 ☐
9	Reaching for something above your head or on the ground	1 ☐	2 ☐	3 ☐	4 ☐
10	Going to answer the telephone before it stops ringing	1 ☐	2 ☐	3 ☐	4 ☐
11	Walking on a slippery surface (e.g. wet or icy)	1 ☐	2 ☐	3 ☐	4 ☐
12	Visiting a friend or relative	1 ☐	2 ☐	3 ☐	4 ☐
13	Walking in a place with crowds	1 ☐	2 ☐	3 ☐	4 ☐
14	Walking on an uneven surface (e.g. rocky ground, poorly maintained pavement)	1 ☐	2 ☐	3 ☐	4 ☐
15	Walking up or down a slope	1 ☐	2 ☐	3 ☐	4 ☐
16	Going out to a social event (e.g. religious service, family gathering or club meeting)	1 ☐	2 ☐	3 ☐	4 ☐

FES-I: Prof Lucy Yardley and Prof Chris Todd

SHIFT WORK AND FATIGUE SURVEY

Use this survey at your workplace as a way of starting the discussions about the health and safety effects of fatigue, working shifts and long hours.

Remember: Shiftwork affects health & safety, so consultation with H&S Reps & workers is required under H&S laws.

1. Why do you work shift work?

- ☐ Job must be done at those hours
- ☐ Better pay
- ☐ Prefer working those hours
- ☐ More time off
- ☐ Other (please specify)_____

2. Do you have any input into your roster?

- ☐ Yes
- ☐ No

3. What shift do you normally work?

- ☐ day shift
- ☐ afternoon shift
- ☐ night shift
- ☐ rotating shifts

4. What is the normal length of your shift?

- ☐ 8 hr
- ☐ 10 hr
- ☐ 12 hr
- ☐ more than 14 hrs

5. How many total hours do you usually work each week? (averaged over 4 weeks)

- ☐ Less than 35
- ☐ 35 - 39
- ☐ 40 - 49
- ☐ 50 +

6. How many hours per week of paid overtime do you usually work?

- ☐ None - I don't usually work paid overtime
- ☐ Less 5 hours
- ☐ Between 5 and 10 hours
- ☐ More than 10 hours

7. How many hours per week of unpaid overtime do you usually?

- ☐ None - I don't usually work unpaid overtime
- ☐ Less than 5 hours
- ☐ Between 5 and 10 hours
- ☐ More than 10 hours

8. **Do you often have less than 12 hours break between shifts?**

- ☐ Yes
- ☐ No

9. **Do you usually work more than 5 days in a row?**

- ☐ No – I usually work less than 5 days in a row
- ☐ Between 5-7 days in a row
- ☐ Between 7-15 days in a row
- ☐ More than 15 days in a row

10. **Has your health suffered because of your roster?**

- ☐ Yes
- ☐ No

11. **If yes, indicate if you have had any of the following symptoms:**

- ☐ sleep difficulties
- ☐ continual tiredness
- ☐ feeling depressed
- ☐ indigestion
- ☐ high blood pressure
- ☐ panic/anxiety attacks
- ☐ menstrual problems
- ☐ frequent colds or respiratory illnesses

12. **Does your family complain about your roster?**

- ☐ Never
- ☐ Sometimes
- ☐ Frequently

13. **Do you have sufficient access to the following facilities on your roster?**

Canteen and/or eating facilities

- ☐ Yes
- ☐ No

First aid

- ☐ Yes
- ☐ No

Training and information

- ☐ Yes
- ☐ No

14. **Does training include information on the effects of shift work?**

- ☐ Yes
- ☐ No

JISHA'S STF RISK ASSESSMENT TEST

Q1 Can you walk without bumping into a person in a crowd? YES / NO

Q2 Do you feel confident of physical strength in comparison with the same age? YES / NO

Q3 Do you think that your body respond quickly to sudden situation? YES / NO

Q4 Can you take a step forward immediately when you trip over a small step? YES / NO

Q5 Can you put on your socks while standing on one leg? YES / NO

Q6 Can you walk easily with a tandem gait (the toes of the back foot touch the heel of the front foot at each step) on the straight line? YES / NO

Q7 In your own estimation, how long can you remain standing on one leg with eyes closed?

……_____ min

Q8 On a train, how long can you stand without holding the strap?

……_____ min

Q9 In your own estimation, how long can you remain standing on one leg with eyes open?

……_____ min

Q10 Are you always careful not to be injured? (e.g. holding the handrail on stairs; not holding something in each hand on the move; keeping things tidy and in order) YES / NO

Q11 Do you take measures such as construction of barrier-free environments or railings in your house? Q12 Do you run while at work?" YES / NO

Q13 Do you sometimes not follow correct procedure in order to observe the delivery date? YES / NO

Q14 While at work, do you sometimes think that this operation is so dangerous that you are injured if not be careful? YES / NO

Q15 If a floor gets wet, do you warry about slipping? YES / NO

Q16 Do you think that the safety is influenced by the luck? YES / NO

Q17 Do you think that you can prevent injuries with your effort? YES / NO

Q18 Have you slipped, tripped and fallen at work in the past year? YES / NO

Q19 Have you (nearly) got injured at work in the past year? YES / NO

Q20 Do you take prescription or non-prescription drugs? YES / NO

Q21 Do you always worry about darkness of the illumination while at work? YES / NO

Q22 Is it heavy exercise for you to bend a knee and raise a thigh? YES / NO

Q23 Can you walk while talking with someone? YES / NO

Q24 Can you talk on the phone while checking a calendar and a schedule book? YES / NO

Q25 Can you think of an answer to a person's question while listening to him or her talk? YES / NO

EXPERIENCES OF FATIGUE

We would like to know more about any problems you have with feeling tired, weak or lacking in energy in the past month. Please answer all questions by ticking the answer which applies to you most closely.

Do you have problems with tiredness?

- Less than usual
- No more than usual
- More than usual
- Much more than usual

Do you need to rest more? Do you feel sleepy or drowsy?

- Less than usual
- No more than usual
- More than usual
- Much more than usual

Do you have problems starting things? (e.g. tasks)

- Less than usual
- No more than usual
- More than usual
- Much more than usual

Are you lacking in energy? Do you have less strength in your muscles?

- Less than usual
- No more than usual
- More than usual
- Much more than usual

Do you feel weak? Do you have difficulty concentrating?

- Less than usual
- No more than usual
- More than usual
- Much more than usual

Do you make slips of the tongue when speaking?

- Less than usual
- No more than usual
- More than usual
- Much more than usual

Do you find it more difficult to find the correct word?

- Less than usual
- No more than usual
- More than usual
- Much more than usual

How is your memory?

- Better than usual
- No worse than usual
- Worse than usual
- Much worse than usual

How do you rate your eye sight on a scale of 6?

- 1
- 2
- 3
- 4
- 5
- 6

Do you often feel drowsy?

- never
- rarely
- sometimes
- frequently
- always

Do you often feel dizzy?

- never
- rarely
- sometimes
- frequently
- always

Does changing a position gets you dizzy?

- never
- rarely
- sometimes
- frequently
- always

Do you have any issues balancing while:

- Standing
- Walking
- Wet surfaces
- Other conditions
- never

Do you suffer from a chronic ear infection?

Do you feel you may encounter risk of fall during:

- Day time
- Night time
- Both
- Never

Do you find any difficulties maintaining your balance in:

Early morning hours

- never
- rarely
- sometimes
- frequently
- always

Evening hours

- never
- rarely
- sometimes
- frequently
- always

Unstable weather conditions

- never
- rarely
- sometimes
- frequently
- always

Working aloft

- never
- rarely
- sometimes
- frequently
- always

Do you often feel jet lagged due to time zone change?

- never
- rarely
- sometimes
- frequently
- always

Do you have trouble walking in the dark?

- never
- rarely
- sometimes
- frequently
- always

How many days do you do night shifts per week?

- 1
- 2
- 3
- 4
- 5
- 6
- 7

STAYING ALERT AT WORK

In this section we ask you to report how common it is for you to feel tired or fatigued whilst at work, whether you are able to effectively manage tiredness and fatigue, and any strategies you use to stay awake and alert at work. Firstly please can you let us know which of the strategies below you use to stay awake and alert when feeling tired or sleepy at work?

Drink caffeinated and/or energy drinks (e.g. tea, coffee, soft drinks)

- Never
- Occasionally
- Sometimes
- Most days/shifts
- Every day/shift
- Not applicable to me

Talk to colleague(s) including using humour and/or banter

- Never
- Occasionally
- Sometimes
- Most days/shifts
- Every day/shift
- Not applicable to me

Listen to music or the radio Get some fresh air (e.g. open the window or go outside)

- Never
- Occasionally
- Sometimes
- Most days/shifts
- Every day/shift
- Not applicable to me

Go for a walk or move about Take a brief nap (micro-nap)

- Never
- Occasionally
- Sometimes
- Most days/shifts
- Every day/shift
- Not applicable to me

Use social media

- Never
- Occasionally
- Sometimes
- Most days/shifts
- Every day/shift
- Not applicable to me

Phone or message friends/family

- Never
- Occasionally

- Sometimes
- Most days/shifts
- Every day/shift
- Not applicable to me

Smoke a cigarette

- Never
- Occasionally
- Sometimes
- Most days/shifts
- Every day/shift
- Not applicable to me

Smoke an e-cigarette

- Never
- Occasionally
- Sometimes
- Most days/shifts
- Every day/shift
- Not applicable to me

Manage personal life (plan upcoming events, family calendar etc)

- Never
- Occasionally
- Sometimes
- Most days/shifts
- Every day/shift
- Not applicable to me

Consume high sugar content foods (e.g. sweets or chocolate)

- Never
- Occasionally
- Sometimes
- Most days/shifts
- Every day/shift
- Not applicable to me

Go into a lit place

- Never
- Occasionally
- Sometimes
- Most days/shifts
- Every day/shift
- Not applicable to me

Turn the flashing lights up

- Never

- Occasionally
- Sometimes
- Most days/shifts
- Every day/shift
- Not applicable to me

Turn the flashing lights down

- Never
- Occasionally
- Sometimes
- Most days/shifts
- Every day/shift
- Not applicable to me

Another strategy not listed

- Never
- Occasionally
- Sometimes
- Most days/shifts
- Every day/shift
- Not applicable to me

Please write here any additional strategies you have used to stay awake and/or alert at work that are not listed above ……..

We would like you to let us know how much you agree or disagree with the statements below regarding feeling fatigued at work:

I frequently show up to work feeling fatigued

- strongly disagree
- disagree
- slightly disagree
- slightly agree
- agree
- strongly agree

Working while fatigued is something I do without thinking about

- strongly disagree
- disagree
- slightly disagree
- slightly agree
- agree
- strongly agree

I work while feeling fatigued because I do this all the time

- strongly disagree
- disagree
- slightly disagree
- slightly agree
- agree
- strongly agree

I am trying to improve my alertness at work and avoid feeling sleepy or fatigued

- strongly disagree
- disagree
- slightly disagree
- slightly agree
- agree
- strongly agree

I do not plan to do anything to reduce my feeling sleepy at work

- strongly disagree
- disagree
- slightly disagree
- slightly agree
- agree
- strongly agree

I do not plan to do anything when I am at work to improve or maintain alertness

- strongly disagree
- disagree
- slightly disagree
- slightly agree
- agree
- strongly agree

We would like to know how easy it is for you to manage feelings of fatigue and sleepiness. Please state how much you agree or disagree with the statements below

Reducing fatigue or sleepiness in staff is a priority of my work organization

- strongly disagree
- disagree
- slightly disagree
- slightly agree
- agree
- strongly agree

My work organization has policies or procedures that address fatigue or sleepiness

- strongly disagree
- disagree
- slightly disagree
- slightly agree
- agree
- strongly agree

My responsibilities away from work prevent me from doing things to reduce my fatigue or sleepiness when I'm at work

- strongly disagree
- disagree
- slightly disagree
- slightly agree
- agree
- strongly agree

My obligations to my family inhibit me from getting the sleep I need to recover between my work days or shifts

- strongly disagree
- disagree
- slightly disagree
- slightly agree
- agree
- strongly agree

I have multiple jobs that prevent me from getting the rest I need between work days or shifts

- strongly disagree
- disagree
- slightly disagree
- slightly agree
- agree
- strongly agree

I have too many competing commitments and do not have time to get adequate sleep when at home to reduce feelings or sleepiness while at work

- strongly disagree
- disagree
- slightly disagree
- slightly agree

- agree
- strongly agree

If you think there is anything that could be done to improve staff fatigue and its management at your workplace, please mention it.

……
……
……
……..

SAFETY AND CULTURE AT WORK

Fatigue and sleepiness can be associated with safety incidents. Most of the questions in this part of the survey were developed about safety incidents, behaviours and culture. Please follow the instructions below and check the most relevant answer to you for each question:

During the past 3 months:

I was injured during a shift

- Definitely not
- Probably not
- I'm not sure
- Probably yes
- Definitely yes
- Do not wish to answer
- Not applicable to me

I was overly stressed during a shift

- Definitely not
- Probably not
- I'm not sure
- Probably yes
- Definitely yes
- Do not wish to answer
- Not applicable to me

I found myself at an unsafe scene

- Definitely not
- Probably not
- I'm not sure
- Probably yes
- Definitely yes
- Do not wish to answer
- Not applicable to me

I was involved in a collision incident

- Definitely not
- Probably not
- I'm not sure
- Probably yes
- Definitely yes
- Do not wish to answer
- Not applicable to me

I have reported for my shift without getting adequate rest beforehand

- Definitely not
- Probably not
- I'm not sure
- Probably yes
- Definitely yes
- Do not wish to answer

- Not applicable to me

I have reported for my shift after drinking alcohol within the previous 8 hours

- Definitely not
- Probably not
- I'm not sure
- Probably yes
- Definitely yes
- Do not wish to answer
- Not applicable to me

Please indicate below how much you agree or disagree with the statements about the safety and culture of your work organization below:

I like my job

- Disagree strongly
- Disagree slightly
- Neutral
- Agree slightly
- Agree strongly

Staff input is well-received

- Disagree strongly
- Disagree slightly
- Neutral
- Agree slightly
- Agree strongly

Procedures and policies preventing falls extra safety measures

- Disagree strongly
- Disagree slightly
- Neutral
- Agree slightly
- Agree strongly

Your work organization does a good job in training new staff

- Disagree strongly
- Disagree slightly
- Neutral
- Agree slightly
- Agree strongly

Working at this job is like being part of a large family

- Disagree strongly
- Disagree slightly
- Neutral
- Agree slightly
- Agree strongly

The management team of this work organization support my daily efforts

- Disagree strongly
- Disagree slightly
- Neutral
- Agree slightly
- Agree strongly

I receive appropriate feedback about my performance

- Disagree strongly
- Disagree slightly
- Neutral
- Agree slightly
- Agree strongly

In this work place it is difficult to discuss errors

- Disagree strongly
- Disagree slightly
- Neutral
- Agree slightly
- Agree strongly

This work environment is a good place to work at

- Disagree strongly
- Disagree slightly
- Neutral
- Agree slightly
- Agree strongly

The management team do not knowingly compromise the safety of personnel

- Disagree strongly
- Disagree slightly
- Neutral
- Agree slightly
- Agree strongly

The level of staffing on board are sufficient to handle the number of duties

- Disagree strongly
- Disagree slightly
- Neutral
- Agree slightly
- Agree strongly

I am encouraged by my colleagues to report any safety concerns I may have

- Disagree strongly
- Disagree slightly
- Neutral
- Agree slightly
- Agree strongly

The culture on board makes it easy to learn from the errors of others

- Disagree strongly
- Disagree slightly
- Neutral
- Agree slightly
- Agree strongly

This work organization deals constructively with staff problems

- Disagree strongly
- Disagree slightly
- Neutral
- Agree slightly
- Agree strongly

When my workload becomes excessive, my performance is impaired

- Disagree strongly
- Disagree slightly
- Neutral
- Agree slightly
- Agree strongly

I am provided with adequate, timely information about events that might affect my work

- Disagree strongly
- Disagree slightly
- Neutral
- Agree slightly
- Agree strongly

I am proud to work on board ship

- Disagree strongly
- Disagree slightly
- Neutral
- Agree slightly
- Agree strongly

Disagreements on board ship are resolved appropriately

- Disagree strongly
- Disagree slightly
- Neutral
- Agree slightly
- Agree strongly

I am less effective at work when fatigued

- Disagree strongly
- Disagree slightly
- Neutral
- Agree slightly
- Agree strongly

I am more likely to make errors in tense or hostile situations

- Disagree strongly
- Disagree slightly
- Neutral
- Agree slightly
- Agree strongly

I have the support I need from colleagues to carry on my duties

- Disagree strongly
- Disagree slightly
- Neutral
- Agree slightly
- Agree strongly

It is easy for staff to ask questions when there is something that they do not understand

- Disagree strongly
- Disagree slightly
- Neutral
- Agree slightly
- Agree strongly

Staff here work together as a well-coordinated team

- Disagree strongly
- Disagree slightly
- Neutral
- Agree slightly
- Agree strongly

Morale on board ship is high

- Disagree strongly
- Disagree slightly
- Neutral
- Agree slightly
- Agree strongly

Trainees in my discipline are adequately supervised

- Disagree strongly
- Disagree slightly
- Neutral

- Agree slightly
- Agree strongly

Fatigue impairs my performance during emergency situations

- Disagree strongly
- Disagree slightly
- Neutral
- Agree slightly
- Agree strongly

YOUR NATURAL BODY CLOCK

This part of the survey which will ask about different aspects of your sleep, including duration and quality. We appreciate some items may sound similar, and that this part has a number of sections, but please answer as best you can as this will help us work out which questions are best for assessing sleep amongst maritime sector personnel.

In this questionnaire you report on your typical sleep behaviour over the PAST 4 WEEKS. We ask about work days and free days separately. Please respond to the questions according to your perception of a standard week that includes your usual work days and free days. (If you do not have a standard week, please use the past week, month etc. or even the past few days).

How many days per week do you usually work?

- 1
- 2
- 3
- 4
- 5
- 6
- 7

Please answer the following questions about your WORK DAYS

What time do you go to bed?

……
……

(Please use 24 hour time scale (e.g. 23:00 instead of 11:00PM), and use a colon (:) rather than a a full stop (.) between the hour and minute numbers.)

Some people stay awake for some time when in bed. What time do you actually get ready to fall asleep?

……
……

(Please use 24 hour time scale (e.g. 23:00 instead of 11:00PM), and use a colon (:) rather than a a full stop (.) between the hour and minute numbers.)

How many minutes do you need to fall asleep?

……
……

(Write minutes as a number (e.g. 20))

What time do you wake up?

……
……

(Please use 24 hour time scale and use a colon (:) rather than a a full stop (.) between the hour and minute numbers.)

After how many minutes do you get up?

……
……

(Write minutes as a number (e.g. 20))

Do you use an alarm clock on workdays?

- Yes
- No

Do you regularly wake up BEFORE the alarm rings?

- Yes
- No

Please answer the following questions about your FREE DAYS (please only judge normal free days, i.e., without parties etc) ...

What time do you go to bed?

……
……

(Please use 24 hour time scale (e.g. 23:00 instead of 11:00PM), and use a colon (:) rather than a full stop (.) between the hour and minute numbers.)

Some people stay awake for some time when in bed. What time do you actually get ready to fall asleep?

……
……

(Please use 24 hour time scale (e.g. 23:00 instead of 11:00PM), and use a colon (:) rather than a full stop (.) between the hour and minute numbers.)

How many minutes do you need to fall asleep?

……
……

(Write minutes as a number (e.g. 20))

What time do you wake up?

……
……

(Please use 24 hour time scale and use a colon (:) rather than a full stop (.) between the hour and minute numbers.)

After how many minutes do you get up?

……
……

(Write minutes as a number (e.g. 20))

My wake up time is due to the use of an alarm clock:

- Yes
- No

Are there are particular reasons why you cannot freely choose your sleep times on free days?

- Yes
- No

Reasons I cannot choose sleep times on free days: (See below to explain other)

- child(ren)/pets
- Hobbies
- Other

Please use the text box to list any other reasons why you are unable to choose your sleep times on free days:

……
……

One hears about "morning" and "evening" types of people. Which one of these types do you consider yourself to be?

- Definitely a morning type
- Rather more a 'morning' than an 'evening' type
- Rather more an 'evening' type than a 'morning' type
- Definitely an evening type
- I don't know
- I would prefer not to say

SLEEP QUALITY

The following questions relate to your usual sleep habits for the majority of days and nights during the past month. During the past month, how often have you had trouble sleeping because you ...

Cannot get to sleep within 30 minutes

- Not during the past month
- Less than once a week
- Once or twice a week
- Three or more times a week

Wake up in the middle of the night or early in the morning

- Not during the past month
- Less than once a week
- Once or twice a week
- Three or more times a week

Have to get up to use the bathroom

- Not during the past month
- Less than once a week
- Once or twice a week
- Three or more times a week

Cannot breathe comfortably

- Not during the past month
- Less than once a week
- Once or twice a week
- Three or more times a week

Cough or snore loudly

- Not during the past month
- Less than once a week
- Once or twice a week
- Three or more times a week

Feel too cold

- Not during the past month
- Less than once a week
- Once or twice a week
- Three or more times a week

Feel too hot

- Not during the past month
- Less than once a week
- Once or twice a week

- Three or more times a week

Had bad dreams

- Not during the past month
- Less than once a week
- Once or twice a week
- Three or more times a week

Have pain

- Not during the past month
- Less than once a week
- Once or twice a week
- Three or more times a week

Other reason(s), please describe

……
……

How often during the past month have you had trouble sleeping because of this?

- Not during the past month
- Less than once a week
- Once or twice a week
- Three or more times a week

During the past month, how would you rate your sleep quality overall?

- Very good
- Fairly good
- Fairly bad
- Very bad

During the past month, how often have you taken medicine to help you sleep (prescribed or "over the counter")?

- Not during the past month
- Less than once a week
- Once or twice a week
- Three or more times a week

During the past month, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity?

- Not during the past month
- Less than once a week
- Once or twice a week
- Three or more times a week

During the past month, how much of a problem has it been for you to keep up enough enthusiasm to get things done?

- No problem at all
- Only a very slight problem
- Somewhat of a problem
- A very big problem

How many hours of sleep did you get in the past 24 hours?

- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10
- 11
- 12
- 13
- 14
- 15

How many hours of sleep did you get in the 24 hours before that?

- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10
- 11
- 12
- 13
- 14
- 15

On your most recent working day, how many hours did you spent outdoors in daylight (without a roof above your head)?

……
……

(Please state in minutes, even when it is over 60 minutes)

On your most recent free-day, how many hours did you spent outdoors in daylight (without a roof above your head)?

……
……

(Please state in minutes, even when it is over 60 minutes)

SLEEP HABITS

Below you will find a list of statements about your sleep habits. Please rate how true each statement is for you:

I take daytime naps lasting two or more hours

- never
- rarely
- sometimes
- frequently
- always

I go to bed at different times from day to day

- never
- rarely
- sometimes
- frequently
- always

I get out of bed at different times from day to day

- never
- rarely
- sometimes
- frequently
- always

I exercise to the point of sweating within 1 hour of going to bed

- never
- rarely
- sometimes
- frequently
- always

I stay in bed longer than I should two or three times a week

- never
- rarely
- sometimes
- frequently
- always

I use alcohol, tobacco, or caffeine within 4 hours of going to bed or after going to bed

- never
- rarely
- sometimes
- frequently
- always

I do something that may wake me up before bedtime (for example: gaming, web use, or cleaning/housework)

- never
- rarely
- sometimes
- frequently
- always

I go to bed feeling stressed, angry, upset, or nervous

- never
- rarely
- sometimes
- frequently
- always

I use my bed for things other than sleeping or sex (e.g. watch television, read, eat, study)

- never
- rarely
- sometimes
- frequently
- always

I sleep on an uncomfortable bed (e.g. poor mattress or pillow, too much or not enough blankets)

- never
- rarely
- sometimes
- frequently
- always

I sleep in an uncomfortable bedroom (e.g. too bright, too stuffy, too hot, too cold, or too noisy)

- never
- rarely
- sometimes
- frequently
- always

I do important work before bedtime (e.g. pay bills, schedule, or study)

- never
- rarely
- sometimes
- frequently
- always

I think, plan, or worry when I am in bed

- never
- rarely
- sometimes
- frequently
- always

EXPERIENCES OF SLEEPINESS

In the following questions we are interested to know how likely are you to doze off or fall asleep in the following situations, in contrast to just feeling tired. This refers to your usual way of life in recent times. Even if you have not done some of these things recently, try to work out how they would have affected you.

Use the following scale to choose the most appropriate option for each situation:

Sitting and reading

Watching TV

Sitting inactive in a public place (e.g. a theatre or a meeting)

As a passenger in a car for an hour without a break

Lying down to rest in the afternoon when circumstances permit

Sitting and talking to someone

Sitting quietly after a lunch without alcohol In a car, while stopped for a few minutes in the traffic

Are you currently taking any medication that could affect your sleep and/or daytime sleepiness (e.g. antihistamines, sedatives)

- Yes
- No

Please list any medications (and doses if known) you are taking that could affect your sleep and/or daytime sleepiness:

……
……

YOUR HEALTH AND LIFESTYLE

The next sections ask about your health-related behaviours and your physical and mental health, as these are known to interact with sleep quality and feelings of fatigue.

Do you currently have any of the following conditions?

Arthritis or rheumatism

- Yes
- No

Chronic back pain

- Yes
- No

Migraine headaches

- Yes
- No

Other frequent or severe headaches

- Yes
- No

Any other chronic pain

- Yes
- No

High blood pressure or hypertension

- Yes
- No

Coronary heart disease

- Yes
- No

Hight blood cholesterol

- Yes
- No

An ulcer in your stomach or intestine

- Yes
- No

Irritable bowel disorder

- Yes
- No

Chronic heart burn or gastrointestinal reflux disease

- Yes
- No

Asthma

- Yes
- No

Chronic bronchitis or emphysema

- Yes
- No

Seasonal allergies or hayfever

- Yes
- No

Urinary or bladder problems

- Yes
- No

Diabetes

- Yes
- No

Obesity

- Yes
- No

Chronic sleeping problems such as insomnia or sleep apnoea

- Yes
- No

Osteoporosis

- Yes
- No

Skin cancer

- Yes
- No

Any other type of cancer

- Yes
- No

Any other conditions not listed above:

……
……

How would you describe your general health?

- Excellent
- Good
- Fair
- Poor

How often do you have a drink containing alcohol?

- Never
- Monthly or less
- Two to four times a month
- Two to three times a week
- Four or more times a week

How many units of alcohol do you have on a typical day when you are drinking? (One unit of alcohol = half a pint of beer, 1 small glass of wine, 1 single measure of spirits)

- 1 or 2
- 3 or 4
- 5 or 6
- 7 to 9
- 10 or more

How often have you had 6 or more units if female, or 8 or more if male, on a single occasion in the last year? (One unit of alcohol = half a pint of beer, 1 small glass of wine, 1 single measure of spirits)

- Never
- Less than monthly
- Monthly
- Weekly
- Daily or almost daily

Do you currently smoke tobacco on a daily basis, less than daily, or not at all?

- Daily
- Less than daily
- Not at all
- Would rather not say

Have you smoked tobacco daily in the past?

- Yes
- No
- Would rather not say

In the past, have you smoked tobacco on a daily basis, less than daily, or not at all?

- Daily
- Less than daily
- Not at all
- Would rather not say

PHYSICAL ACTIVITY

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives.

Please think about the activities you do at work, as part of your house and garden work, to get from place to place, and in your spare time for recreation, exercise or sport. The questions will ask you about the time you spent being physically active in the last seven days.

During the last 7 days, on how many days did you do vigorous physical activities like heavy lifting, digging, aerobics, or fast bicycling? Think about only those physical activities that you did for at least 10 minutes at a time.

(Vigorous physical activities refer to activities that take hard physical effort and make you breathe much harder than normal)

- No vigorous physical activities
- 1 day per week
- 2 days per week
- 3 days per week
- 4 days per week
- 5 days per week
- 6 days per week
- 7 days per week

How much time in total did you usually spend on one of those days doing vigorous physical activities?

……
……

(Please state in minutes, even if over an hour (e.g. write "70" for one hr 10 mins))

Again, think only about those physical activities that you did for at least 10 minutes at a time. During the last 7 days, on how many days did you do moderate physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking, as there is a separate question.

(Moderate activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal)

- No moderate physical activities
- 1 day per week
- 2 days per week
- 3 days per week
- 4 days per week
- 5 days per week
- 6 days per week
- 7 days per week

How much time in total did you usually spend on one of those days doing moderate physical activities?

……
……

(Please state in minutes, even if over an hour (e.g. write "70" for one hr 10 mins))

During the last 7 days, on how many days did you walk for at least 10 minutes at a time? This includes walking at work and at home, walking to travel from place to place, and any other walking that you did solely for recreation, sport, exercise or leisure.

- No walking
- 1 day per week
- 2 days per week
- 3 days per week
- 4 days per week
- 5 days per week
- 6 days per week
- 7 days per week

How much time in total did you usually spend walking on one of those days?

……
……

(Please state in minutes, even if over an hour (e.g. write "70" for one hr 10 mins))

The last question is about the time you spent sitting on weekdays during the last seven days. Include time spent sitting at work, at home, while studying and during leisure time. This may include time spent sitting at a desk, visiting friends, reading, or sitting or lying down to watch television.

During the last 7 days, how much time in total did you usually spend sitting on a week day? (This time please state the number of hours plus the number of additional minutes up to 60 minutes in the separate boxes).

Hours……
……_____ (Please write as a whole number (e.g. write "10" for 10 hours))

minutes
……
…….._____ (Please white as a whole number (e.g. write "30" for 30 minutes))

WELLBEING AND RESILIENCE

Overall our thoughts and feelings about our wellbeing and resilience are known to interact with sleep quality and fatigue. Below are some statements about your feelings and thoughts over the last 2 weeks. Please tick the box that best describes your experience of each.

I've been feeling optimistic about the future

- None of the time
- Rarely
- Some of the time
- Often
- All of the time

I've been feeling useful

- None of the time
- Rarely
- Some of the time
- Often
- All of the time

I've been feeling relaxed

- None of the time
- Rarely
- Some of the time
- Often
- All of the time

I've been dealing with problems well

- None of the time
- Rarely
- Some of the time
- Often
- All of the time

I've been thinking clearly

- None of the time
- Rarely
- Some of the time
- Often
- All of the time

I've been feeling close to other people

- None of the time
- Rarely

- Some of the time
- Often
- All of the time

I've been able to make up my own mind about things

- None of the time
- Rarely
- Some of the time
- Often
- All of the time

Please indicate the extent to which you agree with each of the following statements:

I tend to bounce back quickly after hard times

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree

I have a hard time making it through stressful events

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree

It does not take me long to recover from a stressful event

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree

It is hard for me to snap back when something bad happens

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree

I usually come through difficult times with little trouble

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree

I tend to take a long time to get over set-backs in my life

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree

MENTAL HEALTH

Over the last 2 weeks how often have you been bothered by any of the following problems? (Click the circle to indicate your answer)

Little interest or pleasure in doing things

- Not at all
- Several days
- More than half the days
- Nearly every day

Feeling down, depressed or hopeless

- Not at all
- Several days
- More than half the days
- Nearly every day

Trouble falling or staying aleep, or sleeping too much

- Not at all
- Several days
- More than half the days
- Nearly every day

Feeling tired or having little energy

- Not at all
- Several days
- More than half the days
- Nearly every day

Poor appetite or overeating

- Not at all
- Several days
- More than half the days
- Nearly every day

Feeling bad about yourself - or that you are a failure or have let yourself or your family down

- Not at all
- Several days
- More than half the days
- Nearly every day

Trouble concentrating on things, such as reading the newspaper or watching television

- Not at all
- Several days
- More than half the days
- Nearly every day

Moving or speaking so slowly that other people could have noticed? Or the opposite - being so fidgety or restless that you have been moving around a lot more than usual

- Not at all
- Several days
- More than half the days
- Nearly every day

Thoughts that you would be better off dead or of hurting yourself in some way

- Not at all
- Several days
- More than half the days
- Nearly every day

Over the last 2 weeks, how often have you been bothered by the following problems?

Feeling nervous, anxious, or on edge

- Not at all
- Several days
- More than half the days
- Nearly every day

Not being able to stop or control worrying

- Not at all
- Several days
- More than half the days
- Nearly every day

Worrying too much about different things

- Not at all
- Several days
- More than half the days
- Nearly every day

Trouble relaxing

- Not at all
- Several days
- More than half the days
- Nearly every day

Being so restless that it's hard to sit still

- Not at all
- Several days
- More than half the days
- Nearly every day

Becoming easily annoyed or irritable

- Not at all
- Several days
- More than half the days
- Nearly every day

Feeling afraid as if something awful might happen

- Not at all
- Several days
- More than half the days
- Nearly every day

Sometimes things happen to people that are unusually or especially frightening, horrible, or traumatic. For example:
* a serious accident or fire,

* a physical or sexual assault or abuse,

* an earthquake or flood,

* a war,

* seeing someone killed or seriously injured,

* having a loved one die through homicide or suicide.

We know that some of you will be exposed to various potentially traumatic incidents as part of your work, and also that such incidents can occur in our lives when we are not at work. We are asking about any experience you have, whether it was at work or away from work.

Have you ever experienced any of these events?

- Yes
- No

In the past month have you:

Had nightmares about the event(s) or thought about the event(s) when you did not want to?

- Yes
- No

Tried hard not to think about the event(s) or went out of your way to avoid situations that reminded you of the event(s)?

- Yes
- No

Been constantly on guard, watchful, or easily startled?

- Yes
- No

Felt numb or detached from people, activities, or your surroundings?

- Yes
- No

Felt guilty or unable to stop blaming yourself or others for the event(s) or any problems the event(s) may have caused?

- Yes
- No

DIGITAL TOOLS FOR YOUR OWN HEALTH

There are two sections to go now: this section, which asks about your use of digital technology and Apps for your health, and the last section which asks a few questions about you. They are not long sections, so should only take no more than 5 minutes to complete.

Do you currently own, for your personal use, the following devices (please check all that apply)?

- Yes
- No

A smartphone

- Yes
- No

A smartwatch (e.g. Apple Watch; Android Wear)

- Yes
- No

A wearable fitness watch/band (e.g. Fitbit; Jawbone; Garmin; Polar)

- Yes
- No

An iPad or other tablet device

- Yes
- No

SmartTV (e.g. TV with internet connectivity)

- Yes
- No

Laptop or desktop computer

- Yes
- No

How often do you use each of the devices that you own?

Smartphone

- Yes
- No

Smartwatch

- Yes
- No

Wearable fitness watch/band iPad or other tablet device

- Yes
- No

Smart TV

- Yes
- No

Laptop or desktop computer

- Yes
- No

In the past 6-months have you used at least one of these devices to search for personal health information and advice online?

- Rarely
- Sometimes
- Often
- Daily

In the past 6-months have you thought about using or actually used any of the following types of Apps for your personal health and wellbeing. This includes those that are accessed using a smartphone or through a smartwatch, fitness watch or tablet.

Exercise or activity tracking (e.g. Strava; Couch to 5K; MapMyWalk)

- Never seen
- Seen but never downloaded
- Downloaded but never used
- Used occasionally
- Used less than once a week
- Used more than once a week

Virtual training (e.g. Zwift; Virtual Trainer; Rouvy)

- Never seen
- Seen but never downloaded
- Downloaded but never used
- Used occasionally
- Used less than once a week
- Used more than once a week

Calorie or diet tracking for health or weight loss (e.g. Lose it!; Fooducate; DietBet)

- Never seen
- Seen but never downloaded
- Downloaded but never used
- Used occasionally
- Used less than once a week
- Used more than once a week

General health and wellness (e.g. Headspace; MyFitnessPal)

- Never seen
- Seen but never downloaded
- Downloaded but never used
- Used occasionally
- Used less than once a week
- Used more than once a week

Tracking your sleep (e.g. Sleep Cycle; or through Fitbit/Jawbone)

- Never seen
- Seen but never downloaded
- Downloaded but never used
- Used occasionally
- Used less than once a week
- Used more than once a week

Stress management or mental health (e.g. RCPsych Mental Health App)

- Never seen
- Seen but never downloaded
- Downloaded but never used
- Used occasionally
- Used less than once a week

- Used more than once a week

Smoking cessation or alcohol reduction (e.g. smokefree; Drinkfreedays)

- Never seen
- Seen but never downloaded
- Downloaded but never used
- Used occasionally
- Used less than once a week
- Used more than once a week

Pain management (e.g. my pain diary)

- Never seen
- Seen but never downloaded
- Downloaded but never used
- Used occasionally
- Used less than once a week
- Used more than once a week

Health Education (e.g. patient choice myth-buster; blood pressure readings; pregnancy week-by-week)

- Never seen
- Seen but never downloaded
- Downloaded but never used
- Used occasionally
- Used less than once a week
- Used more than once a week

APPENDIX 2 :

Full questionnaires and other supporting documents for the study

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LAB FORMS 1-3

THE ACTIVITY AND SLEEP DIARY

TELEPHONE INTERVIEW

GENERAL MEDICAL QUESTIONNAIRE

It is very important that you provide full and accurate answers to the questions detailed below. If you have any concerns or questions when completing this information please speak to a member of the study team. If you experience any change to your medication or health while enrolled onto the study you should advise the study team of any changes as soon as possible. We will ask you to sign this document, which is going to be reviewed by a medical professional.

General health

1. Do you suffer from sleep disorders/ sleep problems? YES / NO

   If YES give details.....

   …..……..

2. Have you received a diagnosis of sleep apnoea or any other sleep related disorder? YES/NO

   b) If YES to the question detailed above are you receiving treatment for the sleep disorder? YES/NO

   If YES provide details
   ……
   ……
   ……

3. Have you been diagnosed or are you currently being investigated for a dementia related disorder (this includes mild cognitive impairment)? YES/NO

   If YES provide details
   ……
   ……
   ……
   ……

4. **a)** Do you have any physical health conditions? This includes chronic or acute diseases (e.g. arthritis, osteoporosis, cancer, vitamin deficiency, cardio vascular diseases/ conditions, asthma, diabetes etc) YES/NO

   If YES give details

   ……
   ……
   ……
   ……
   ……

   b) Are any of your health conditions made worse by exercise? YES/ NO

   If YES give details

   ……
   ……
   ……

5. Have you ever been diagnosed with a neurological, psychiatric/ mental health condition (e.g. depression, anxiety, brain injury, panic disorders, schizophrenia, multiple sclerosis, motor neurone disease etc.)? YES/NO

   If YES give details

   ……
   ……
   ……
   ……

6. Have you had a recent acute illness/ infection or chronic illness/ infection?

   YES / NO

   If YES give details.....

   ……

7. Do you have high blood pressure? YES / NO

   If YES give details.....

   .....

8. Have you ever suffered from heart trouble/stroke/TIA? YES / NO

   If YES give details.....

   .....

9. Have you had a fall in the past year or have you been told that you are at an increased risk of falling? YES/NO

   If YES give details

   ……
   ……

   10. Do you ever have pains in your heart and chest? YES / NO

   11. Do you ever feel faint / have spells of dizziness? YES / NO

   12. Have you been in hospital at all in the last 2 years? YES / NO

If YES give reason and outcome.....

.....

13. Have you had any operations or major illness in the last 6 months? YES / NO

If YES give details.....

.....

14. **a)** Are you undergoing treatment or are you taking any medication at the moment (**please include details of contraception if appropriate**) It is very important that you provide full details to us.

YES / NO

If YES give details.....

.....
.....
.....
.....

b) If YES, do you experience any side effects from this medication including any side effects that may influence/ disrupt your sleep? YES/ NO

If YES give details.....

.....
.....
.....
.....

15. Have you ever been informed that you are at risk of deep vein thrombosis/ blood clots? YES/NO

If YES give details.....

.....
.....
.....
.....

16. Do you have any disabilities of any kind? YES / NO

If YES give details.....

.....

17. Do you have dyslexia, other specific learning difficulty or other learning difficulty?

YES / NO

If YES give details.....

.....

18. Do you suffer from claustrophobia? YES/NO

19. Have you ever suffered any complications from previous research, clinical trials or treatment?

YES / NO

If YES give details.....

.....

20. Do you suffer from any allergies? YES / NO

(Please include details of food allergies/ food intolerance / medication adverse effects)

If YES give details.....

.....

21. Have you ever had a bad reaction to a medicine or a food? YES / NO

If YES give details.....

22. Have you been diagnosed/ do you experience eye problems (eye strain, retinal damage, glaucoma, light sensitivity etc)

YES / NO

If YES give details.....

…..…….……..

23. Do you have any skin conditions?

YES / NO

If YES give details.....

…..…….……..

24. **If female:** are you pregnant? YES/NO

<u>Lifestyle</u>

25. How many hours do you sleep per night on average?……..

26. Do you currently have/ have had any alcohol/ substance abuse related disorders? YES/ NO

If YES give details.....

…..…….……..

27. What is your average weekly intake of alcohol? ..... units per week.

(One unit is half a pint beer / one glass of wine / one measure of spirits)

28. Has there been a time when you regularly consumed more than 14 units of alcohol per week? YES / NO

If YES give details.....…

29. What is your average daily intake of caffeinated beverages? (e.g. coffee/tea/coke/ caffeinated energy drinks)?

.

.....cups per day

30. Are you smoker/vaper? YES / NO

If YES how many cigarettes (or equivalent) do you smoke per day.....

31. Has there been a time when you smoked/vaped regularly? YES / NO

If YES, how many cigarettes/ecigarettes per day in average.....

For how many years……

When did you stop…….months/years ago

32. During the last 7 days, on how many days did you do moderate physical activities like gardening, cleaning, bicycling at a regular pace, swimming or other fitness activities.

Think *only* about those physical activities that you did for at least 10 minutes at a time. Do not include walking.

_____ Days ⇒ How much time did you usually spend doing moderate physical activities on one of those days?

or

☐ No day

___ hours ___ minutes (total)

33. During the last 7 days, on how many days did you do vigorous physical activities like heavy lifting, heavier garden or construction work, chopping woods, aerobics, jogging/running or fast bicycling?

Think *only* about those physical activities that you did for at least 10 minutes at a time.

_____ Days ⇒ How much time did you usually spend doing vigorous physical activities on one of those days?

or

☐ No days

____ hours ___ minutes (total)

34. Have you got any dependents or other responsibilities that could be affected by your participation in the study? YES / NO

If YES give details.....

…..……..

Any other details.....

.....

35. Have you travelled across more than three time zones in the past 2 months?

YES / NO

36. Are you currently or have you recently participated in a drug trial? YES/NO

If YES please give details of when your participation in this trial ended?
……

37. Do you work shifts? YES / NO

Please read and complete the fields below

To the best of my knowledge I have given true and complete information. I agree to my GP/ medical practice being informed of my participation in this study and of any unexpected findings, such as identification of a sleep disorder that may require treatment. I provide their contact details below:

Name and address of GP/ medical practice:

....

....

....

....

Participant's Signature.....Date.....

Participant's name.....……..…….

EDINBURGH HANDEDNESS INVENTORY

Edinburgh Handedness Inventory

Participant ID:

Please indicate your preferences in the use of hands in the following activities by *putting + in the appropriate column*. Where the preference is so strong that you would never try to use the other hand unless absolutely forces to, *put* ++. If any case you are really indifferent put + in both columns.

Some of the activities require both hands. In these cases the part of the task, or object, for which hand preference is wanted is indicated in brackets.

Please try to answer all the questions, and only leave a blank if you have no experience at all of the object or task.

	Left	Right
1. Writing		
2. Drawing		
3. Throwing		
4. Scissors		
5. Toothbrush		
6. Knife (without fork)		
7. Spoon		
8. Broom (upper hand)		
9. Striking Match (match)		
10. Opening box (lid)		
i. Which foot do you prefer to kick with?		
ii. Which eye do you use when using only one?		

L.Q.	Leave the spaces blank	DECLE

Participant ID:

SF36 HEALTH SURVEY

Instructions:

This set of questions asks for your views about your health. This information will help keep track of how you feel and how well you are able to do your usual activities. Answer every question by marking the answer as indicated. If you are unsure about how to answer a question please give the best answer you can.

1. In general, would you say your health is: (Please tick **one** box.)

   Excellent ☐
   Very good ☐
   Good ☐
   Fair ☐
   Poor ☐

2. Compared to one year ago, how would you rate your health in general now? (Please tick **one** box.)

   Much better than one year ago ☐
   Somewhat better now than one year ago ☐
   About the same as one year ago ☐
   Somewhat worse now than one year ago ☐
   Much worse now than one year ago ☐

3. The following questions are about activities you might do during a typical day. Does your health now limit you in these activities? If so, how much? **(Please circle one number on each line.)**

Activities	Yes, limited a lot	Yes, limited a little	No, not limited at all
a) **Vigorous activities**, such as running, lifting heavy objects, participating in strenuous sports	1	2	3
b) **Moderate activities**, such as moving a table, pushing a vacuum cleaner, bowling, or playing golf	1	2	3
c) Lifting or carrying groceries	1	2	3
d) Climbing **several** flights of stairs	1	2	3
e) Climbing **one** flight of stairs	1	2	3
f) Bending, kneeling, or stooping	1	2	3
g) Walking **more than a mile**	1	2	3
h) Walking **several hundred yards**	1	2	3
i) Walking **one hundred yards**	1	2	3
j) Bathing or dressing yourself	1	2	3

4. During the past 4 weeks, how much of the time have you had any of the following problems with your work or other regular daily activities as a result of your physical health? **(Please circle one number on each line.)**

	All of the time	**Most of the time**	**Some of the time**	**A little of the time**	**None of the time**
a) Cut down on the **amount of time** you spent on work or other activities	1	2	3	4	5
b) **Accomplished less** than you would like	1	2	3	4	5
c) Were **limited** in the **kind** of work or other activities	1	2	3	4	5
d) Had **difficulty** performing the work or other activities (for example, it took extra effort)	1	2	3	4	5

5. During the past 4 weeks, how much of the time have you had any of the following problems with your work or other regular daily activities as a result of any emotional problems (such as feeling depressed or anxious)? **(Please circle one number on each line.)**

	All of the time	**Most of the time**	**Some of the time**	**A little of the time**	**None of the time**
a) Cut down on the **amount of time** you spent on work or other activities	1	2	3	4	5
b) **Accomplished less** than you would like	1	2	3	4	5
c) Did work or other activities **less carefully than usual**	1	2	3	4	5

6. During the past 4 weeks, to what extent has your physical health or emotional problems interfered with your normal social activities with family, friends, neighbours, or groups? (Please tick **one** box.)

Not at all ☐
Slightly ☐
Moderately ☐
Quite a bit ☐
Extremely ☐

7. How much bodily pain have you had during the past 4 weeks? (Please tick **one** box.)

   None ☐
   Very mild ☐
   Mild ☐
   Moderate ☐
   Severe ☐
   Very severe ☐

8. During the past 4 weeks, how much did pain interfere with your normal work (including both work outside the home and housework)? (Please tick **one** box.)

   Not at all ☐
   A little bit ☐
   Moderately ☐
   Quite a bit ☐
   Extremely ☐

9. These questions are about how you feel and how things have been with you during the past 4 weeks. For each question, please give the one answer that comes closest to the way you have been feeling. How much of the time during the past 4 weeks… **(Please circle one number on each line.)**

		All of the time	**Most of the time**	**Some of the time**	**A little of the time**	**None of the time**
a)	Did you feel full of life?	1	2	3	4	5
b)	Have you been very nervous?	1	2	3	4	5
c)	Have you felt so down in the dumps that nothing could cheer you up?	1	2	3	4	5
d)	Have you felt calm and peaceful?	1	2	3	4	5
e)	Did you have a lot of energy?	1	2	3	4	5
f)	Have you felt downhearted and low?	1	2	3	4	5
g)	Did you feel worn out?	1	2	3	4	5
h)	Have you been happy?	1	2	3	4	5
i)	Did you feel tired?	1	2	3	4	5

10. During the past 4 weeks, how much of the time has your physical health or emotional problems interfered with your social activities (like visiting with friends, relatives etc.) (Please tick **one** box.)

All of the time ☐
Most of the time ☐
Some of the time ☐
A little of the time ☐
None of the time ☐

11. How **TRUE** or **FALSE** is each of the following statements for you? **(Please circle one number on each line.)**

	Definitely True	**Mostly True**	**Don't Know**	**Mostly False**	**Definitely False**
a) I seem to get ill more easily than other people	1	2	3	4	5
b) I am as healthy as anybody I know	1	2	3	4	5
c) I expect my health to get worse	1	2	3	4	5
d) My health is excellent	1	2	3	4	5

KAROLINSKA SLEEP DIARY (KSD)

Instructions:

Please refer to your last overnight sleep episode, i.e. not a daytime nap, when answering the following questions. Please indicate whether the time is am or pm.

What time did you go to bed?		AM/PM
What time did you try starting to sleep at?		AM/PM
How long did it take you to fall asleep? (min)		
How many times did you wake up?		
How long were you awake for? (min) Please estimate the time and duration of each night awakening.		
What time did you wake up?		AM/PM
What time did you get up?		AM/PM
Did your alarm clock wake you up?		
Did you do any strenuous activity during the last 24 hours (if yes, please specify)		

How would you rate your quality of sleep?

Best sleep ever								**Worst sleep ever**
1	2	3	4	5	6	7	8	9

How difficult did you find to wake up/get up?

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
Very easy										**Quite hard**

KAROLINSKA SLEEPINESS SCALE (KSS)

Instructions:

Please indicate your level of sleepiness for the previous 5 minutes using the scale below.

Extremely alert	1
	2
Alert	3
	4
Neither sleepy nor alert	5
	6
Sleepy, but not fighting sleep	7
	8
Extremely sleepy; it is an effort to stay awake	9

THE INSOMNIA SEVERITY INDEX

1. Please rate the current (i.e., last 2 weeks) **SEVERITY** of your insomnia problem(s).

	None	Mild	Moderate	Severe	Very
Difficulty falling asleep:	0	1	2	3	4
Difficulty staying asleep:	0	1	2	3	4
Problem waking up too early:	0	1	2	3	4

2. How **SATISFIED**/dissatisfied are you with your current sleep pattern?

Very satisfied				Very dissatisfied
0	1	2	3	4

3. To what extent do you consider your sleep problem to **INTERFERE** with your daily functioning (e.g. daytime fatigue, ability to function at work/daily chores, concentration, memory, mood, etc.).

Not at all Interfering	A Little	Somewhat	Much	Very Much Interfering
0	1	2	3	4

4. How **NOTICEABLE** to others do you think your sleeping problem is in terms of impairing the quality of your life?

Not at all Noticeable	Barely	Somewhat	Much	Very Much Noticeable
0	1	2	3	4

5. How **WORRIED**/distressed are you about your current sleep problem?

Not at all	A Little	Somewhat	Much	Very Much
0	1	2	3	4

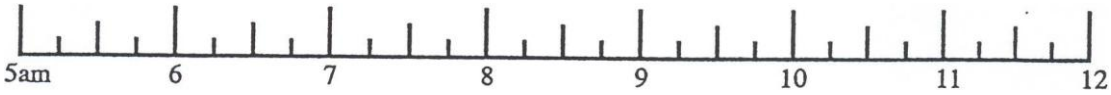
HORNE-ÖSTBERG QUESTIONNAIRE (Morning- eveningness questionnaire)

Participant Code:_____ Date:_____

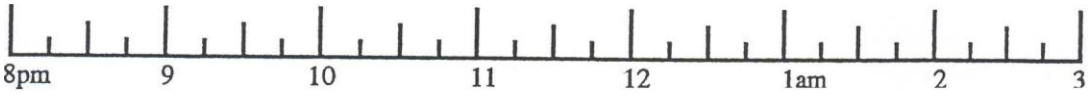
Instructions

1. Please read each question very carefully before answering.
2. Answer ALL questions.
3. Answer questions in numerical order.
4. Each question should be answered independently of others. DO NOT go back and check your answers
5. All questions have a selection of answers. For each question place a cross alongside ONE answer only. Some questions have a scale instead of a selection of answers. Place a cross at the appropriate point along the scale.

1. Considering only your own –"feeling best" rhythm, at what time would you get up if you were entirely free to plan your day?



2. Considering only your "feeling best" rhythm, at what time would you go to bed if you were entirely free to plan your own evening?



3. If there is a specific time at which you have to getup in the morning, to what extent are you dependent on being woken up by an alarm clock?

- Not at all dependent ☐
- Slightly dependent ☐
- Fairly dependent ☐
- Very dependent ☐

4. Assuming adequate environmental conditions, how easy do you find getting up in the morning?

- Not at all easy ☐
- Not very easy ☐
- Fairly easy ☐
- Very easy ☐

5. How alert do you feel during the first half hour after having woken in the mornings?

- Not at all alert ☐
- Slightly alert ☐
- Fairly alert ☐
- Very alert ☐

6. How is your appetite during the first half-hour after having woken in the mornings?

- Very poor ☐
- Fairly poor ☐
- Fairly good ☐
- Very good ☐

7. During the first half-hour after having woken in the morning, how tired do you feel?

- Very tired ☐
- Fairly tired ☐
- Fairly refreshed ☐
- Very refreshed ☐

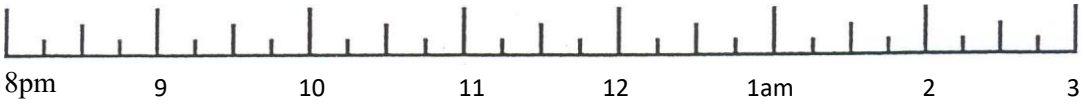
8. When you have no commitments the next day, at what time do you go to bed compared to your usual bedtime?

- Seldom or never later ☐
- Less than one hour later ☐
- 1-2 hours later ☐
- More than 2 hours later ☐

9. You have decided to engage in some physical exercise. A friend suggests that you do this 1 hr form twice a week and the best time for him is between 7.00-8.00AM. Bearing in mind nothing else but your own "feeling best" rhythm how do you think you would perform ?

- Would be in good form ☐
- Would be in reasonable ☐
- Would find it difficult ☐
- Would find it very difficult ☐

10. At what time in the evening do you feel tired and as a result in need of sleep?



11. You wish to be at your peak performance for a test which you know is going to be mentally exhausting and lasting for two hours. You are entirely free to plan your day and considering only your own "feeling best" rhythm which ONE of the 4 testing times would you choose?

- 8.00-10.00AM ☐
- 11.00AM-1.00PM ☐
- 3.00-5.00PM ☐
- 7.00-9.00PM ☐

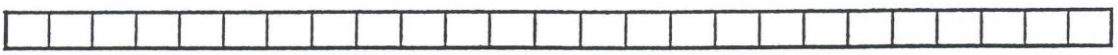
12 If you went to bed at 11.00PM at what level of tiredness would you be ?

- Not at all tired ☐
- A little tired ☐
- Fairly tired ☐
- Very tired ☐

13. For some reason you have gone to bed several hours later than usual, but there is no need to get up at any particular time the next morning. Which ONE of the following events are you most likely to experience?	Will wake at usual time and NOT go back sleep	☐
	Will wake at usual time and doze thereafter	☐
	Will wake up at usual time but fall asleep again	☐
	Will NOT wake up until later than usual	☐
14. One night you have to remain awake between 4.00-6.00AM in order to carry out a night watch. You have no commitments the next day. Which ONE of the following alternatives will suit you best?	Would NOT go to bed until watch was over	☐
	Would take a nap before and sleep after	☐
	Would take a good sleep and nap after	☐
	Would take ALL sleep before watch	☐
15. You have to do 2 hours of hard physical work. You are entirely free to plan your day and considering only your own "feeling best" rhythm which ONE of the following times would you choose?	8.00-10.00AM	☐
	11.00AM-1.00PM	☐
	3.00-5.00PM	☐
	7.00-9.00PM	☐
16. You have decided to engage in hard physical exercise. A friend suggests that you do this for one hour twice a week and the best time for him is between 10.00-11.00PM	Would be in good form	☐
	Would be in reasonable form	☐
	Would find it difficult.	☐
	Would find it very difficult	☐

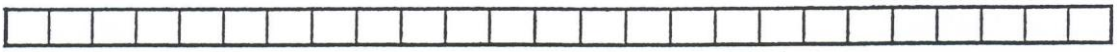
Bearing in mind nothing else but your own "feeling best" rhythm how well do you think you would perform?

17. Suppose that you can choose your own work hours. Assume that you work a FIVE-hour day (including breaks) and that your job was interesting and paid by results. Which FIVE CONSECUTIVE HOURS would you select?



12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
MIDNIGHT NOON MIDNIGHT

18. At what time of the day do you think that you reach you "feeling best" peak?



12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
MIDNIGHT NOON MIDNIGHT

19. One hears about "morning" and "evening" types of people. Which one of these types do you consider yourself to be?

- Definitely "morning" type ☐
- Rather more a "morning" than an "evening" type ☐
- Rather more an "evening" than a "morning" type ☐
- Definitely an "evening" type ☐

Self assessment

After you have answered the preceding questions, you should have a feeling of the chronotype (time-of-day-type) you belong to. If, for example, you like (and manage) to sleep quite a bit longer on free days than on workdays, or if you cannot get out of bed on Monday mornings, even without a Sunday-night party, then you are more a late type. If, however, you regularly wake up and feel perky once you jump out of bed, and if you would rather go to bed early than to an evening concert, then you are an early type. In the following questions, you should categorise yourself and your family members. Please tick only one possibility!

	Extreme early type	**Moderate early type**	**Slight early type**	**Normal Type**	**Slight late type**	**Moderate late type**	**Extreme late type**
I am…	0	1	2	3	4	5	6
As a child, I was…	0	1	2	3	4	5	6
As a teenager, I was…	0	1	2	3	4	5	6
In case you are older than 65: in the middle of my life, I was…							
	0	1	2	3	4	5	6
My parents are/were…							
Mother…	0	1	2	3	4	5	6
Father…	0	1	2	3	4	5	6
My siblings are/were… (please underline Brother or Sister)							
Brother/Sister	0	1	2	3	4	5	6
Brother/Sister	0	1	2	3	4	5	6
Brother/Sister	0	1	2	3	4	5	6
Brother/Sister	0	1	2	3	4	5	6
Brother/Sister	0	1	2	3	4	5	6
Brother/Sister	0	1	2	3	4	5	6
Brother/Sister	0	1	2	3	4	5	6
My partner (girl/boy friend, spouse, significant other) is/was…							
	0	1	2	3	4	5	6

COGNITIVE CHANGE INDEX (CCI-20-S) (SELF REPORT VERSION)

Participant identification code ..... Date of birth ...../...../.....

Completed in -person phone

A. Do you feel like your memory is becoming worse? (Check only one)

☐ **No** ☐ **Yes, but this does not worry me** ☐ **Yes and this worries me**

B. Instructions:

This self-rating scale asks about your abilities, problem areas, daily functioning and activities. Please rate your **current** level of ability **compared to 5 years ago** and the severity of any current problems. Remember, you are describing how you are functioning now (meaning during the past month including today) compared to 5 years ago. Please rate any changes in your ability on the following 5-point scale, choosing the best fitting rating for each item describing a cognitive function or ability:

1. **Normal Ability (No Change or Better than 5 years ago):** not a problem; no effect on daily activities; no assistance needed

2. **Slight/Occasional Problem (Minimal Change from 5 years ago):** subtle; occurs less than once a week; may be slightly slower or less efficient; no assistance needed with ability; probably not noticeable to most other people

3. **Mild Problem (Some Change from 5 years ago):** A bit worse, may perform related activity more slowly or less efficiently; occasionally may need a little help; may be noticeable to others

4. **Moderate Problem (Clearly Noticeable Change from 5 years ago):** frequent problem; may affect complex activities on a daily basis or several times per week; often needs some assistance to perform complex activity

5. **Severe Problem (Much Worse than 5 years ago):** continuous problem; unable to independently perform complex activity; requires ongoing assistance or supervision

Circle the number that best fits your current ability level compared to 5 years ago, using the scale from 1 to 5 below. Select the best choice for each item and *please do not skip any questions*:

Normal Ability	**Slight/Occasional Problem**	**Mild Problem**	**Moderate Problem**	**Severe Problem**
No Change ***(compared to 5 years ago)***	**Minimal Change** ***(compared to 5 years ago)***	**Some Change** ***(compared to 5 years ago)***	**Clearly Noticeable Change** ***(compared to 5 years ago)***	**Much Worse** ***(compared to 5 years ago)***
1	**2**	**3**	**4**	**5**

1. Recalling information when I really try	**1**	**2**	**3**	**4**	**5**

2. Remembering names and faces of new people I meet:	**1**	**2**	**3**	**4**	**5**
3. Remembering things that have happened recently:	**1**	**2**	**3**	**4**	**5**
4. Recalling conversations a few days later:	**1**	**2**	**3**	**4**	**5**
5. Remembering where things are usually kept:	**1**	**2**	**3**	**4**	**5**
6. Remembering new information told to me:	**1**	**2**	**3**	**4**	**5**
7. Remembering where I placed familiar objects:	**1**	**2**	**3**	**4**	**5**
8. Remembering what I intended to do:	**1**	**2**	**3**	**4**	**5**
9. Remembering names of family members and friends:	**1**	**2**	**3**	**4**	**5**
10. Remembering without notes and reminders:	**1**	**2**	**3**	**4**	**5**
11. People who know me would find that my memory is:	**1**	**2**	**3**	**4**	**5**
12. Remembering things compared to my age group:	**1**	**2**	**3**	**4**	**5**
13. Making decisions about everyday matters:	**1**	**2**	**3**	**4**	**5**
14. Reasoning through a complicated problem:	**1**	**2**	**3**	**4**	**5**
15. Focusing on goals and carrying out a plan:	**1**	**2**	**3**	**4**	**5**
16. Shifting easily from one activity to the next:	**1**	**2**	**3**	**4**	**5**
17. Organizing my daily activities:	**1**	**2**	**3**	**4**	**5**
18. Understanding conversations:	**1**	**2**	**3**	**4**	**5**
19. Expressing myself when speaking:	**1**	**2**	**3**	**4**	**5**
20. Following a story in a book, movie or TV:	**1**	**2**	**3**	**4**	**5**

Demographics

Participant identification code ..... Date of birth ...../...../.....

Age ..... Sex: Male / Female

Please note that the following 3 questions are optional.

1. How many years have you spent in education? ……

2. What is your highest qualification level (e.g. postgraduate, undergraduate, A Levels (or equivalent)?

   ……

3. In what range is you annual income:
   a. <10,000 /year
   b. 10,000-20,000 /year
   c. 20,000-30,000 /year
   d. 30,000-40,000 /year
   e. 40,000-50,000 /year
   f. > 50,000 /year
4. What is your profession: ……
5. You work:
   a. Full time (employed / self-employed)
   b. Part time (employed / self-employed)

6. Are you retired? YES/ NO

7. Weight ……. Height ……...

   BMI (Investigator use) ……..

FES-I

Now we would like to ask some questions about how concerned you are about the possibility of falling. Please reply thinking about how you usually do the activity. If you currently don't do the activity (e.g. if someone does your shopping for you), please answer to show whether you think you would be concerned about falling IF you did the activity. For each of the following activities, please tick the box which is closest to your own opinion to show how concerned you are that you might fall if you did this activity.

		Not at all concerned 1	*Somewhat concerned 2*	*Fairly concerned 3*	*Very concerned 4*
1	Cleaning the house (e.g. sweep, vacuum or dust)	*1* ☐	*2* ☐	*3* ☐	*4* ☐
2	Getting dressed or undressed	*1* ☐	*2* ☐	*3* ☐	*4* ☐
3	Preparing simple meals	*1* ☐	*2* ☐	*3* ☐	*4* ☐
4	Taking a bath or shower	*1* ☐	*2* ☐	*3* ☐	*4* ☐
5	Going to the shop	*1* ☐	*2* ☐	*3* ☐	*4* ☐
6	Getting in or out of a chair	*1* ☐	*2* ☐	*3* ☐	*4* ☐
7	Going up or down stairs	*1* ☐	*2* ☐	*3* ☐	*4* ☐
8	Walking around in the neighbourhood	*1* ☐	*2* ☐	*3* ☐	*4* ☐
9	Reaching for something above your head or on the ground	*1* ☐	*2* ☐	*3* ☐	*4* ☐
10	Going to answer the telephone before it stops ringing	*1* ☐	*2* ☐	*3* ☐	*4* ☐
11	Walking on a slippery surface (e.g. wet or icy)	*1* ☐	*2* ☐	*3* ☐	*4* ☐
12	Visiting a friend or relative	*1* ☐	*2* ☐	*3* ☐	*4* ☐
13	Walking in a place with crowds	*1* ☐	*2* ☐	*3* ☐	*4* ☐
14	Walking on an uneven surface (e.g. rocky ground, poorly maintained pavement)	*1* ☐	*2* ☐	*3* ☐	*4* ☐
15	Walking up or down a slope	*1* ☐	*2* ☐	*3* ☐	*4* ☐
16	Going out to a social event (e.g. religious service, family gathering or club meeting)	*1* ☐	*2* ☐	*3* ☐	*4* ☐

FES-I: Prof Lucy Yardley and Prof Chris Todd

COVID-19 Yorkshire Rehabilitation Screening (C19-YRS)

Self-report version

Participant ID: ……. Date: …….

*The purpose of this questionnaire is to find out if you are experiencing problems, if applicable, related to your previous illness with COVID-19. Please continue to questions **1** and **2**, even if you have not previously tested positive with COVID-19.*

1. **Do you consent for this information to be used in this research?** **Yes ☐ No ☐**

2. **Have you ever tested positive for Covid-19?** **Yes ☐ No ☐**

*If you answered **No** to the above question, you do not need to complete the rest of this questionnaire.*

*If you answered **Yes** to the above question, please proceed to the remainder of the questionnaire.*

This questionnaire will take around 15 minutes. If there are any topics you do not wish to talk about you can choose not to respond.

3. When did you test positive for Covid-19?

Month: …….

Year: ……

Have you had any medical problems related to COVID-19 that needed hospital admission? **Yes** ☐ **No** ☐ Details:
Have you used any other health services to manage COVID-19 symptoms (e.g., your GP?) **Yes** ☐ **No** ☐ Details:

Please respond to the below questions to the best of your knowledge. *'Now' refers to how you feel now/this week.* *"Pre-COVID" refers to how you were feeling prior to contracting the illness.* *If you are unable to recall this, just state 'dont know'*			
1. Breathlessness	On a scale of 0-10, with 0 being not breathless at all, and 10 being extremely breathless, how breathless are you: (n/a if you do not perform this activity)	Now	Pre-Covid
	a) At rest?	0-10: ____	0-10: ____
	b) On dressing yourself?	0-10: ____ n/a ☐	0-10: ____ n/a ☐
	c) On walking up a flight of stairs?	0-10: ____ n/a ☐	0-10: ____ n/a ☐
2. Cough/ throat sensitivity/ voice change	Have you got any of the below symptoms that is new since contracting the illness? • cough/ throat sensitivity **Yes** ☐ **No** ☐ • voice change **Yes** ☐ **No** ☐ • noisy breathing **Yes** ☐ **No** ☐ Which of these three is the worst symptom - Rate the severity of this problem (0 being not present, 10 being severe and life disturbing)		

	Now: **0** ☐ **1** ☐ **2** ☐ **3** ☐ **4** ☐ **5** ☐ **6** ☐ **7** ☐ **8** ☐ **9** ☐ **10** ☐ Pre-Covid: **0** ☐ **1** ☐ **2** ☐ **3** ☐ **4** ☐ **5** ☐ **6** ☐ **7** ☐ **8** ☐ **9** ☐ **10** ☐
3. Swallowing/ nutrition	Are you having difficulties eating, drinking or swallowing such as coughing, choking or avoiding any food or drinks? **Yes** ☐ **No** ☐ Rate the severity of swallowing problem (0 being no symptom, 10 being severe and life disturbing) Now: **0** ☐ **1** ☐ **2** ☐ **3** ☐ **4** ☐ **5** ☐ **6** ☐ **7** ☐ **8** ☐ **9** ☐ **10** ☐ Pre-Covid: **0** ☐ **1** ☐ **2** ☐ **3** ☐ **4** ☐ **5** ☐ **6** ☐ **7** ☐ **8** ☐ **9** ☐ **10** ☐ Are you or your family concerned that you have ongoing weight loss or any ongoing nutritional concerns as a result of Covid-19? **Yes** ☐ **No** ☐
4. Fatigue	Do you become fatigued more easily compared to before your illness? **Yes** ☐ **No** ☐ Rate the severity of fatigue (0 being not present, 10 being severe and life disturbing) Now: **0** ☐ **1** ☐ **2** ☐ **3** ☐ **4** ☐ **5** ☐ **6** ☐ **7** ☐ **8** ☐ **9** ☐ **10** ☐ Pre-Covid: **0** ☐ **1** ☐ **2** ☐ **3** ☐ **4** ☐ **5** ☐ **6** ☐ **7** ☐ **8** ☐ **9** ☐ **10** ☐
5. Continence	Since your illness are you having any <u>new</u> problems with: • controlling your bowel **Yes** ☐ **No** ☐ • controlling your bladder **Yes** ☐ **No** ☐ Which of these two is the worst symptom - Rate the severity of this problem (0 being not present, 10 being severe and life disturbing) Now: **0** ☐ **1** ☐ **2** ☐ **3** ☐ **4** ☐ **5** ☐ **6** ☐ **7** ☐ **8** ☐ **9** ☐ **10** ☐ Pre-Covid: **0** ☐ **1** ☐ **2** ☐ **3** ☐ **4** ☐ **5** ☐ **6** ☐ **7** ☐ **8** ☐ **9** ☐ **10** ☐
6. Pain/ discomfort	Have you got any pain that is new since contracting the illness? **Yes** ☐ **No** ☐ If Yes, • chest pain **Yes** ☐ **No** ☐ • joint pain **Yes** ☐ **No** ☐ • muscle pain **Yes** ☐ **No** ☐ • headache **Yes** ☐ **No** ☐ • abdominal pain **Yes** ☐ **No** ☐

	• other pain **Yes** ☐ **No** ☐ Within the last week, which of the these was the worst problem – Rate the severity of this problem (0 being no pain or discomfort, 10 being severe and life disturbing pain) Now: **0** ☐ **1** ☐ **2** ☐ **3** ☐ **4** ☐ **5** ☐ **6** ☐ **7** ☐ **8** ☐ **9** ☐ **10** ☐ Pre-Covid: **0** ☐ **1** ☐ **2** ☐ **3** ☐ **4** ☐ **5** ☐ **6** ☐ **7** ☐ **8** ☐ **9** ☐ **10** ☐
7. Cognition	Since your illness have you had new or worsened difficulty with: • concentrating? **Yes** ☐ **No** ☐ • short term memory? **Yes** ☐ **No** ☐ • planning? **Yes** ☐ **No** ☐ Which of these three is the worst symptom – Rate the severity of this problem (0 being not present, 10 being severe and life disturbing) Now: **0** ☐ **1** ☐ **2** ☐ **3** ☐ **4** ☐ **5** ☐ **6** ☐ **7** ☐ **8** ☐ **9** ☐ **10** ☐ Pre-Covid: **0** ☐ **1** ☐ **2** ☐ **3** ☐ **4** ☐ **5** ☐ **6** ☐ **7** ☐ **8** ☐ **9** ☐ **10** ☐
8. Anxiety	On a 0-10 scale, how severe is any anxiety you are experiencing? 0 means I am not anxious, 10 means I am extremely anxious. Now: **0** ☐ **1** ☐ **2** ☐ **3** ☐ **4** ☐ **5** ☐ **6** ☐ **7** ☐ **8** ☐ **9** ☐ **10** ☐ Pre-Covid: **0** ☐ **1** ☐ **2** ☐ **3** ☐ **4** ☐ **5** ☐ **6** ☐ **7** ☐ **8** ☐ **9** ☐ **10** ☐
9. Depression	On a 0-10 scale, how severe is any depression you are experiencing? 0 means I am not depressed, 10 means I have extreme depression. Now: **0** ☐ **1** ☐ **2** ☐ **3** ☐ **4** ☐ **5** ☐ **6** ☐ **7** ☐ **8** ☐ **9** ☐ **10** ☐ Pre-Covid: **0** ☐ **1** ☐ **2** ☐ **3** ☐ **4** ☐ **5** ☐ **6** ☐ **7** ☐ **8** ☐ **9** ☐ **10** ☐ Are you currently having thoughts about harming yourself in any way? **Yes** ☐ **No** ☐
10. PTSD screen	a) Have you had any unwanted memories of your illness or hospital admission whilst you were awake, so not counting dreams? **Yes** ☐ **No** ☐ b) Have you had any unpleasant dreams about your illness or hospital admission? **Yes**☐ **No**☐ c) Have you tried to avoid thoughts or feelings about your illness or hospital admission? **Yes** ☐ **No** ☐

	Rate the severity of these stress problems (0 being not present, 10 being severe and life disturbing) Now: **0** ☐ **1** ☐ **2** ☐ **3** ☐ **4** ☐ **5** ☐ **6** ☐ **7** ☐ **8** ☐ **9** ☐ **10** ☐ Pre-Covid: **0** ☐ **1** ☐ **2** ☐ **3** ☐ **4** ☐ **5** ☐ **6** ☐ **7** ☐ **8** ☐ **9** ☐ **10** ☐
11. Communication	Since your illness have you had new or worsened difficulty with communication/word finding difficulty/ understanding others ? **Yes** ☐ **No** ☐ Rate the severity of communication problem (0 being not present, 10 being severe and life disturbing) Now: **0** ☐ **1** ☐ **2** ☐ **3** ☐ **4** ☐ **5** ☐ **6** ☐ **7** ☐ **8** ☐ **9** ☐ **10** ☐ Pre-Covid: **0** ☐ **1** ☐ **2** ☐ **3** ☐ **4** ☐ **5** ☐ **6** ☐ **7** ☐ **8** ☐ **9** ☐ **10** ☐
12. Mobility	On a 0-10 scale, how severe are any problems you have in walking about? *Or moving about if you normally walk using aids* 0 means no problems, 10 means severe or completely unable to walk about. Now: **0** ☐ **1** ☐ **2** ☐ **3** ☐ **4** ☐ **5** ☐ **6** ☐ **7** ☐ **8** ☐ **9** ☐ **10** ☐ Pre-Covid: **0** ☐ **1** ☐ **2** ☐ **3** ☐ **4** ☐ **5** ☐ **6** ☐ **7** ☐ **8** ☐ **9** ☐ **10** ☐
13. Personal-Care	On a 0-10 scale, how severe are any problems you have in personal cares such as using the toilet, washing and dressing yourself? 0 means no problems, 10 means completely unable to do or fully dependent on others to help. Now: **0** ☐ **1** ☐ **2** ☐ **3** ☐ **4** ☐ **5** ☐ **6** ☐ **7** ☐ **8** ☐ **9** ☐ **10** ☐ Pre-Covid: **0** ☐ **1** ☐ **2** ☐ **3** ☐ **4** ☐ **5** ☐ **6** ☐ **7** ☐ **8** ☐ **9** ☐ **10** ☐
14. Other Activities of Daily Living	On a 0-10 scale, how severe are any problems you have in doing your usual activities, such as your household work, leisure activities, work, study or shopping ? 0 means no problems, 10 means completely unable to do or fully dependent on others to help. Now: **0** ☐ **1** ☐ **2** ☐ **3** ☐ **4** ☐ **5** ☐ **6** ☐ **7** ☐ **8** ☐ **9** ☐ **10** ☐ Pre-Covid: **0** ☐ **1** ☐ **2** ☐ **3** ☐ **4** ☐ **5** ☐ **6** ☐ **7** ☐ **8** ☐ **9** ☐ **10** ☐
15. Social role	On a 0-10 scale, how severe are any problems you have in caring for family members and/or your interaction with friends that are related to your illness (and not due to the social distancing/lockdown measures) ? 0 means no problems, 10 means completely unable to do Now: **0** ☐ **1** ☐ **2** ☐ **3** ☐ **4** ☐ **5** ☐ **6** ☐ **7** ☐ **8** ☐ **9** ☐ **10** ☐ Pre-Covid: **0** ☐ **1** ☐ **2** ☐ **3** ☐ **4** ☐ **5** ☐ **6** ☐ **7** ☐ **8** ☐ **9** ☐ **10** ☐

What is your employment situation and has your illness affected your ability to do your usual work?

Occupation: _____

Employment status before Covid-19 Lockdown: _____

Employment status before you became ill: _____

Employment status now: _____

Do you think your family or carer would have anything to add from their perspective?

Are you experiencing any other new problems since your illness we haven't mentioned? Rate the severity of the problem (0 being not present, 10 being severe and life disturbing)

Palpitations: **0** ☐ **1** ☐ **2** ☐ **3** ☐ **4** ☐ **5** ☐ **6** ☐ **7** ☐ **8** ☐ **9** ☐ **10** ☐

Dizziness/ falls: **0** ☐ **1** ☐ **2** ☐ **3** ☐ **4** ☐ **5** ☐ **6** ☐ **7** ☐ **8** ☐ **9** ☐ **10** ☐

Weakness: **0** ☐ **1** ☐ **2** ☐ **3** ☐ **4** ☐ **5** ☐ **6** ☐ **7** ☐ **8** ☐ **9** ☐ **10** ☐

Sleep problems: **0** ☐ **1** ☐ **2** ☐ **3** ☐ **4** ☐ **5** ☐ **6** ☐ **7** ☐ **8** ☐ **9** ☐ **10** ☐

Fever: **0** ☐ **1** ☐ **2** ☐ **3** ☐ **4** ☐ **5** ☐ **6** ☐ **7** ☐ **8** ☐ **9** ☐ **10** ☐

Skin rash: **0** ☐ **1** ☐ **2** ☐ **3** ☐ **4** ☐ **5** ☐ **6** ☐ **7** ☐ **8** ☐ **9** ☐ **10** ☐

Other symptoms –

How good or bad is your health overall?

For this question, a score of 10 means the BEST health you can imagine. 0 means the WORST health you can imagine.

a) Now: WORST HEALTH 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐ BEST HEALTH

b) Pre-Covid: WORST HEALTH 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐ BEST HEALTH

Lab form 1

Subject code: _____ Date: _____ Time: _____ (To be completed by study team)

Over the last 4 hours, how often have you been bothered by the following problems? *Circle the most appropriate number below for the following statements.*

	Not at all	Several times	More than half the time	Nearly all the time
1. Feeling nervous, anxious or on edge	**0**	**1**	**2**	**3**
2. Not being able to stop or control worrying	**0**	**1**	**2**	**3**

Choose the answer on how you have felt, behaved or thought, based on the rate of occurrence in the last 4 hours: *(Tick the statement that applies)*

1.I am able to focus on a task until it is finished

- ☐ Almost always
- ☐ Often
- ☐ Occasionally
- ☐ Hardly Ever

2. I feel indifferent to what is going on around me
   - ☐ Almost always
   - ☐ Often
   - ☐ Occasionally
   - ☐ Hardly Ever

3. I set goals for myself
   - ☐ Almost always
   - ☐ Often
   - ☐ Occasionally
   - ☐ Hardly Ever

Over the last 4 hours, how often have you been bothered by any of the following problems? *Circle the most appropriate number below for the following statements.*

	Not at all	Several times	More than half the time	Nearly all the time
1. Little interest or pleasure in doing things	**0**	**1**	**2**	**3**
2. Feeling down, depressed or hopeless	**0**	**1**	**2**	**3**

Describe HOW YOU FEEL RIGHT NOW *by circling the most appropriate number below***:**

	Not at all	A little	Moderate	Quite a bit	Extremely
Confusion	**1**	**2**	**3**	**4**	**5**

Please detail what you feel confused about below (if applicable):

Time ☐ Tests/ assessments ☐ Place ☐

Other (please provide details below):

……
……

Over the last 4 hours has there been anything that has distracted you?

☐ Light

☐ People

☐ Sound

☐ Other (if selecting this box please detail the nature of the distraction below)

……
……

Study team to record

Exercise taken: ☐ *Yes* ☐ No *Details*: …… *Duration:* ……

Lab form 2

*Subject code:_____ Date:_____ Time: _____(*To be completed by study team)*

This form is to be completed after each sleep episode/ nap.
Please indicate whether you think the time is/was am or pm and provide an estimate of the time for the following questions.

			Study team to record time	
What time did you go to bed?		AM/PM		AM/PM
What time did you try starting to sleep at?		AM/PM		AM/PM
How long did it take you to fall asleep? (min)				
How many times did you wake up?				
How long were you awake for? (min) Please estimate the time and duration of each night awakening.				
What time did you wake up?		AM/PM		AM/PM
What time did you get up?		AM/PM		AM/PM

How would you rate your quality of sleep?

1 2 3 4 5 6 7 8 9

Best sleep ever. **Worst sleep ever**

How difficult did you find to wake up/get up?

1 2 3 4 5 6 7 8 9

Very easy **Quite hard**

1. Do you recall your dream/s from your last sleep episode/nap?

   Yes ☐ No ☐

If yes, how intense were your dreams emotionally *(please tick the box that applies)?*

Not at all intense	Not that intense	Somewhat intense	Quite intense	Very intense
☐	☐	☐	☐	☐

2. What **was** the emotional tone of your dream/s on average **(please tick the box that applies)?**

Very negative	Somewhat negative	Neutral	Somewhat positive	Very positive
☐	☐	☐	☐	☐

3. Did you experience a so-called lucid dream/s (see definition)? Definition: In a lucid dream, one is aware that one is dreaming during the dream. Thus it is possible to wake up deliberately, or to influence the action of the dream actively, or to observe the course of the dream passively.

☐ Yes ☐ No

If **yes** and you feel comfortable providing details please provide these below:

……
……
…….....
.....

4. Did you dream about the lab session?

☐ Yes ☐ No

If yes, please indicate what you dreamt about below:

☐ the tests ☐ the lab itself ☐ the people in the lab

If other please detail below if you are happy to disclose this:

……
……
…….....

Lab form 3

*Subject code:*_____ *Date:*_____ *Time:* _____*(To be completed by study team)*

KSS Instructions:

Please indicate your level of sleepiness for the previous 5 minutes using the scale below.

Extremely alert	1
	2
Alert	3
	4
Neither sleepy nor alert	5
	6
Sleepy, but not fighting sleep	7
	8
Extremely sleepy; it is an effort to stay awake	9

Answer the following questions by placing a vertical mark through the line for each question. Mark the line according to how you feel at this moment. Regard both the ends of the lines as indicating the most extreme sensations you have ever felt.

How hungry do you feel?

I am not hungry at all ——— I have never been more hungry

How thirsty do you feel?

Not at all thirsty ——— Extremely thirsty

Would you like to eat something sweet?

No, not at all ——— Yes, very much

Would you like to eat something salty?

No, not at all ——— Yes, very much

Would you like to eat something savoury?

No, not at all ——— Yes, very much

Would you like to eat something fatty?

No, not at all ——— Yes, very much

This scale below consists of words that describe different feelings and emotions. *Read each item and then circle the appropriate number next to the word indicating the extent to which you feel this way*

	Very slightly or not at all	A little	Moderately	Quite a bit	Extremely
Enthusiastic	**1**	**2**	**3**	**4**	**5**
Irritable	**1**	**2**	**3**	**4**	**5**

Please indicate how you feel at the moment by placing a vertical mark on the scales below for the following items. Regard both the ends of the lines as indicating the most extreme sensations you have ever felt.

Mood

Worst ever ——————————— Best ever

Tension

Worst ever ——————————— Best ever

Physical comfort

Worst ever ——————————— Best ever

Study team to record

Blood pressure= ……

Temperature=…….

Participant ID…….

Activity and food diary

Form-1 Morning questionnaire

Date:……. Time:…….

The following sleep questions should be completed in the morning after you have woken up. Please fill in the date and time above. You should try to complete these questions at the time rather than providing answers retrospectively if possible. *Please indicate whether the time is AM or PM.*

What time did you go to bed?		**AM/PM**
What time did you try starting to sleep at?		**AM/PM**
How long did it take you to fall asleep? (min)		
How many times did you wake up?		
How long were you awake for? (min) Please estimate the time and duration of each night awakening.		
What time did you wake up?		**AM/PM**
What time did you get up?		**AM/PM**
Did your alarm clock wake you up?		
Did you do any strenuous activity during the last 24 hours (if yes, please specify)		

How would you rate your quality of sleep?

1 2 3 4 5 6 7 8 9

Best sleep ever. Worst sleep ever

How difficult did you find to wake up/get up?

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
Very easy										Quite hard

Please indicate your level of sleepiness for the previous 5 minutes using the scale below.

Extremely alert	1
	2
Alert	3
	4
Neither sleepy nor alert	5
	6
Sleepy, but not fighting sleep	7
	8
Extremely sleepy; it is an effort to stay awake	9

1. Do you recall your dream/s from your last sleep episode/nap?

Yes ☐ No ☐

If yes, how intense were your dreams emotionally *(please tick the box that applies)?*

Not at all intense	Not that intense	Somewhat intense	Quite intense	Very intense
☐	☐	☐	☐	☐

5. What **was** the emotional tone of your dreams on average **(please tick the box that applies)?**

Very negative	Somewhat negative	Neutral	Somewhat positive	Very positive
☐	☐	☐	☐	☐

6. Did you experience a so-called lucid dream/s (see definition)? Definition: In a lucid dream, one is aware that one is dreaming during the dream. Thus it is possible to wake up deliberately, or to influence the action of the dream actively, or to observe the course of the dream passively.

☐ Yes ☐ No

If **yes** and you feel comfortable providing details please provide these below:

……
……
…….....
.....
.....

Participant ID:……

Form-2 Evening questionnaire

Date:……. Time:…….

You should complete the following questions at the end of each day. Please fill in the date and time above.

Over the last 24 hours, how often have you been bothered by the following problems? *Circle the most appropriate number below for the following statements.*

	Not at all	Several times	More than half the time	Nearly all the time
4. Feeling nervous, anxious or on edge	**0**	**1**	**2**	**3**
2. Not being able to stop or control worrying	**0**	**1**	**2**	**3**

Over the last 24 hours, how often have you been bothered by any of the following problems? *Circle the most appropriate number below for the following statements.*

	Not at all	Several times	More than half the time	Nearly all the time
2. Little interest or pleasure in doing things	**0**	**1**	**2**	**3**
2. Feeling down, depressed or hopeless	**0**	**1**	**2**	**3**

Please turn over

The following questions will ask you about the time you spent being physically active today.

Please answer each question even if you do not consider yourself to be an active person.

To describe the intensity of the physical activity, two terms (Moderate and Vigorous) are used:

Moderate activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal.

Vigorous physical activities refer to activities that take hard physical effort and make you breathe much harder than normal.

We understand that you cannot remember exactly all the activities and the actual time when those happened but please try to complete the questionnaire to the best of you knowledge by estimating the duration of those activities.

1. The first question is about the time you spent sitting during the day. Include time spent at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading, or sitting or lying down to watch television.

During the day, how much time did you spend sitting in total?

____ hours ___ minutes (total)

When*: morning □, early afternoon □, late afternoon □, evening □ (please tick at least one)*

---

2. Think about the time you spent walking today. This includes at work and at home, walking to travel from place to place, and any other walking that you might do solely for recreation, sport, exercise, or leisure.

During the day how many times did you walk for at least 10 minutes?

_____ times

How much time did you spend walking today in total?

_____hours ___ minutes

When*: morning □, early afternoon □, late afternoon □, evening □*

---

3. During the day how many times did you do moderate physical activities like gardening, cleaning, bicycling at a regular pace, swimming or other fitness activities.

Think only about those physical activities that you did for at least 10 minutes at a time. Do not include walking.

_____ times

How much time did you spend doing moderate physical activities today?

____hours ___ minutes (total)

When*: morning □, early afternoon □, late afternoon □, evening □*

4. During the day, how many times did you do vigorous physical activities like heavy lifting, heavier garden or construction work, chopping woods, aerobics, jogging/running or fast bicycling?

Think only about those physical activities that you did for at least 10 minutes at a time.

_____ times

How much time did you spend doing vigorous physical activities today?

____hours ___ minutes (total)

When*: morning □, early afternoon □, late afternoon □, evening □*

---

5. What is the average time you have spent outdoors exposed to direct sunlight?

____ hours ___ minutes (total)

When: *morning □, early afternoon □, late afternoon □, evening □*

---

6. **How many caffeinated beverages have you had today? (e.g. tea/ coffee/coke)**

____ cups

When: *morning □, early afternoon □, late afternoon □, evening □*

---

7. How many alcohol units have you had today? (One unit is half a pint of beer / one glass of wine/ one measure of spirits)

____ *units*

When: *morning □, early afternoon □, late afternoon □, evening □*

---

8. How many times did you have a meal or a snack today

a. Meal: _____
b. Snack: _____

---

9. When was the first and the last time you had a meal today and what did it include?

First: _____ Sweet □, Fatty □, Savoury □
Last:_____ Sweet □, Fatty □, Savoury □

---

10. Did you take a nap today?

If yes how long was the duration of your nap/s in total? ……..

11. Please indicate your level of sleepiness for the previous 5 minutes using the scale below. **Please complete this just before going to bed.**

Extremely alert	1
	2
Alert	3
	4
Neither sleepy nor alert	5
	6
Sleepy, but not fighting sleep	7
	8
Extremely sleepy; it is an effort to stay awake	9

Telephone interview

Date of call ...../ ...../ .....

Investigator conducting call ……

The following instructions should be used as a guide.

Instructions for investigator: *Introduce call to volunteer, explain purpose of call and ask if it's convenient for them to speak. If not proceed to re-arrange call with volunteer.*

If ok- *briefly explain research study and ask the following questions:*

1. *Does this study sound like something you would be interested in taking part in?*
2. *If you did take part in this study would you be happy for your GP to be notified of your participation in the study and relevant findings? (It should be explained that this is a requirement of the research.)*
   If no- *end call politely and thank participant for their time.*

If yes *and participant is happy to speak, investigator should advise the volunteer that the call should take around 10-15 minutes.* Answers should be recorded for the following questions:

3. ***Ask for following details or check details against existing JDR volunteer record (if applicable)**:*

Are you aged between: 40-90 years of age? YES/NO

Date of birth ……

4. ***If volunteer is female and potentially of childbearing age** (<60 years old)

Are you pregnant/ expecting? YES/ NO

5. Do you smoke or use an e-cigarette (vape)?
   YES / NO

If YES how many cigarettes (or equivalent) / how many times do you smoke per day?

.....

6. Do you currently work shifts or have you done any shift work in the past year (working by night)? YES / NO

If YES give details.....

……..…

7. Do you have any recent/ current acute infections or diseases? (e.g.. Influenza, Bronchitis etc?)

YES/NO

If YES give details

…….....

.....

8. What is your average weekly intake of alcohol?
(One unit is half a pint of beer / one glass of wine / one measure of spirits)

(beer).....pint x 2 + (wine/spirit).....glass/measure = ...units per week

9. Do you currently have any conditions relating to substance abuse/ alcohol dependency or are you currently taking any illicit substances? YES/NO

10. Do you currently have a diagnosis of a chronic psychiatric, mental health condition or neurological disease (for example: schizophrenia, dementia, multiple sclerosis, brain injury, motor neurone disease etc)?

YES / NO

If YES give details.....

……

11. Do you have dyslexia, other specific learning difficulty or learning disability?

YES / NO

If YES give details.....

.....

12. During the past month, how many hours of <u>actual sleep</u> did you get at night? (This may be different from the number of hours you spend in bed.)

Hours of sleep per night: .....

13. Are you pleased with your sleep quality? YES / NO

If NO give details.....

…..……..

14. Do you have any motor or sensory impairments? YES / NO

If YES give details.....

…..……..

15. Do you have a current diagnosis of cancer/ tumour or chronic pain condition? YES / NO

If YES give details.....

…..……..

16. Have you got any dependent or other responsibilities that could be affected by your participation in the study/screening? YES / NO

If YES give details.....

…..……..

17. Following my brief description of the study at the beginning of this call do you think you would be willing to take part in both the field session and lab session or just the field session?

Indicate volunteer preference below:

……

……

……

If volunteer indicates that they are open to take part in lab session please ask following question.

18. * If you wish to take part in the lab session of this study this will involve staying at the sleep lab at the University of East Anglia. You will be required to stay within the sleep lab for **2.5 consecutive days including 3 nights.** Will you be available for such a period of time in Autumn 2018- Spring 2019? YES / NO

19. Are there any days/ times that you would not be available for example: holidays/ weekly commitments etc.

a) Unavailable times

……

……

b) Are there any days/ times that are more convenient for you?

……

……

20. Consideration for COVID-19 risk

In the last 14 days have you had any of the following:

- High temperature (above 38C) or symptoms of a fever (feeling hot or shivery).
- A new continuous cough.
- A loss of, or change to, your sense of smell or taste.
- Had a COVID-19 test positive or waiting for results for a test?

If you have had COVID-19 suspected symptoms or have already had COVID-19:

- When was the last date of reported symptoms?
- Do you have a negative test result?

Have you had close contact with a person who had symptoms of COVID-19 or tested positive for the virus?

Have you recently travelled from abroad?

Investigator should thank volunteer for their time.

If volunteer appears eligible against the screening inclusion criteria their availability should be discussed, contact details taken/ checked against JDR record (as appropriate) and an appointment should be made for a face to face screening session. The volunteer should be advised that if any of their circumstances change after the telephone interview e.g) new diagnosis they should inform the study team as soon as possible. They should be sent the information sheet and consent form prior to the screening session (at least 48 hours before) and should be prompted to bring details of any medication they are taking/ GP details with them to the session. The investigator should advise that if the volunteer has any questions after receiving this information that they should call the study team for guidance.

If the investigator is unsure as to the volunteers' eligibility for the screening session they should advise the volunteer that they will discuss their case with the PI and will call the volunteer back to arrange a convenient time (as appropriate).

			initials
Contact information	**a**	**Name:**	
	b	**Email:**	
	c	**Phone:**	
	d	**City:**	
Scheduled date for screening	**Date Hour** **(confirmed on by email / post / phone)**		
Revised Date for screening *(just in case of reschedule)*	**Date Hour** **(confirmed on by email / post / phone)**		
Confirmation sent	**Yes No** *(Confirmation should be sent on the same day with the tel. contact details)*		
Remarks			